MODIFICATION OF MUFFLER FOR MINIDOR THREE-WHEELER

By: Ali Mohammed

A thesis submitted in partial fulfillment of the requirement for the award of the degree of Master of Science

in

Automotive Engineering

MECHANICAL SYSTEM AND VEHICLE ENGINEERING DEPARTMENT

School of Mechanical, Chemical and Materials Engineering

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

ADAMA (ETHIOPIA)

September, 27

MODIFICATION OF MUFFLER FOR MINIDOR THREE-WHEELER

By: Ali Mohammed

A thesis submitted in partial fulfillment of the requirement for the award of the degree of Master of Science

in

Automotive Engineering

MECHANICAL SYSTEM AND VEHICLE ENGINEERING DEPARTMENT

School of Mechanical, Chemical and Materials Engineering

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

Advisor: Dr. Ramesh Babu Nallamothu (Asst. Prof)

ADAMA (ETHIOPIA)

September, 27

Approval of Board of Examiners

We the undersigned, members of the Board of the Examiners of the final open defense by **Ali Mohammed** have read and evaluated his thesis entitled ‘‘Modification of Muffler for Minidor Three-wheeler’’ and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Masters of Science in Automotive Engineering.

Supervisor/Advisor	Signature	Date
Chairperson	Signature	Date
Internal Examiner	Signature	Date
External Examiner	Signature	Date

CANDIDATE'S DECLARATION

This is to certify that the thesis prepared by Ali Mohammed, entitled: **Modification of Muffler for Minidor Three-wheeler**; hereby declare this thesis is my original work and that it has not been submitted in full for a degree in any university/institution, which compiles with the regulation of the university and meets the accepted standards with respect to originality and quality.

Ali Mohammed Yimer (Candidate)

Signature ________________

Date ____________________

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

Advisor: : Dr. Ramesh Babu Nallamothu (Asst. Prof) Signature Date____________

ACKNOWLEDGEMENT

I would like to first express my deepest gratitude to Dr. Ramesh Babu Nallamothu for being my advisor for my MSc. study. His suggestions and guidance have made to finish the research effectively. I am thankful to the numerous ideas provided to me regarding to this thesis, which help me improve as a student.

I would also like to thank Dr. Amana for his guidance, comments, advice, criticism, encouragement and insight throughout for the completion of the thesis. I would also thank Mr. Idris Elmi for providing valuable suggestions and information.

I want to thank my classmate friends for their supporting ideas and always remember their discussions and friendship that help me confront the difficulties and frustrations.

TABLE OF CONTENT

Contents Page

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

CFR	- Cylinder Firing Rate
EFR	- Engine Firing Rate
FEA	- Finite Element Analysis
FFT	- Fast Fourier Transform
IC	- Internal Combustion
IL	- Insertion Loss
TL	- Transmission Loss
TMM	-Transfer Matrix Method
ω	-Angular frequency of the wave,
t	-Time,
ρ_o	-Density of fluid,
q	-Acoustic dipole source term,
Q	-Acoustic monopole source term.
σ	-Porosity,
$p_{i,}$ p_r	-Incoming wave and Reflected wave,
d_{mj} & d_{mi}	-Major and minor diameters,
f	-Design factor,
λ	-Wavelength of the acoustic wave,
μ	-Dynamic viscosity,
k	-Wave number,
ρ	-Density,

c	-Speed of sound,
t_p	-Plate thickness,
d_h	-Diameter of hole on perforated pipe,
δ_h	-End correction to the reactance,
θ_f	-Flow resistance,
p0	- static value of pressure,
P	- acoustic pressure,
P_{in}, p_{out}	- Inlet and outlet pressures,
Δp	- Pressure drop,
A, B	- Complex amplitude of incident and reflected wave,

ABSTRACT

*Internal combustion engines generate acoustic pulse due to combustion process. In order to minimize the acoustic pulse IC engine use muffler in the exhaust system. The higher sound pressure wave generated in the engine combustion chamber then passes through the exhaust manifold and attenuated inside the muffler to certain level. Thus the exhaust gas with reduced sound pressure gets released to the surrounding passing through the exhaust pipe. Some muffler designs are not much effective in their sound attenuation to desired sound pressure level due to less effective design nature of the muffler and contradicting behavior of sound reduction with back pressure. Inefficient muffler not only causes sound pollution but also vibration to vehicle components and increases toxic exhaust gas emission to the environment. In this research work specific vehicle was considered which releases higher sound pressure. Higher sound pressure generated during combustion propagates through the exhaust pipe, but with the help of effective muffler it is possible to reduce it to a desired level. For the effectiveness of the research work data was gathered from passengers and drivers to know what they feel and suggest about the sound emission of this vehicle. The goal of this research was to improve the acoustic performance of Minidor, Force three-wheeler vehicle by modifying the performance of existing muffler to minimize sound pollution. Muffler modification was done based on transmission loss prediction, prototype manufacturing and testing experimentally. A part modeling was done by using Auto CAD tool. Earlier method of muffler design was by trial and error method by manufacturing mufflers with various arrangement of internal pipes, perforations size, inlet and exit pipes and testing until desired output is gained. Here design was analyzed not by the earlier method, rather using COMSOL Multiphysics simulation prediction of muffler performance was done before manufacturing the component. From the result of the simulation, it was shown that the modified model has increased transmission loss by an average of 3.2 dB with little increase in backpressure. Finally, prototype of the modified Reactive muffler for Minidor, Force three-wheeler with reduced sound level and acceptable back pressure was manufactured***.** The sound pressure level at the exit of the existing and manufactured muffler was measured experimentally and the modified muffler gives about 2 dB sound reduction at idling and 3.7dB at full throttle position.*

Key words: *Muffler, Back pressure, Transmission loss*

CHAPTER ONE

INTRODUCTION

1.1 Background

Noise or higher sound can be generated in the exhaust pipe due to the pulses of alternating high and low pressure of the gases leaving the engine. Expansion chambers are effective components to attenuate high pressure sounds to a desired level in different application areas. The automotive exhaust system also uses muffler for optimizing the exhaust noise of automobile engine. Mufflers are typically arranged along the exhaust pipe as the part of the exhaust system of an internal combustion engine to reduce the release of exhaust noise to the environment. A muffler is designed to reduce higher sound to a desired level. Muffler is used to minimize sound pressure level at the tip of exhaust pipe or to increase sound transmission loss. Sound transmission loss is characteristics of a muffler which describes the amount of sound muffled or cancelled from transmission to the tip of exhaust pipe. The principle of sound attenuation is done either the sound pressure is absorbed by sound absorbing material or by destructive interference or sound cancellation principle by using resonating chamber, baffles and perforated pipe to scatter the pulse in numerous directions inside the chamber. Sound wave reflections occur whenever there is a change in geometry or discontinuity in the area of the exhaust pipe. The muffler composed of various components and internal geometry for its higher sound attenuation purpose. The performance of a muffler depends on parameters such as geometry and cross section, types and number of baffles, volume of muffler and the limit of back pressure. Using a number of chambers is one of the methods for better sound pressure reduction, but results in increase in back pressure due to obstruction of gas while passing through a complicated path. Backpressure is the pressure which is exerted by muffler on the engine through the restriction in the flow of exhaust gases.

Length of the resonating chamber affects the sound attenuation level. Increase in total axial length of the muffler results in more noise reduction but the size of muffler will increase [24]. While designing a muffler we should have to compromise and deal with these contradicting parameters to get an efficient design. Effective muffler design should give best noise reduction and reduced back pressure to the engine. Increase in back pressure reduces efficiency of the engine and increases fuel consumption [14].

Vibration of components due to high pulse of gas inside the muffler is also one of the problem which can cause less comfort. The higher pulse exhaust gas affects life of muffler components, mostly perforated pipes are subjected to this damage as observed from old mufflers.

1.1.1 Types of muffler

All muffling or silencing devices are used for the application area where sound attenuation is required, yet depending on the domains of application the right type is selected to fulfill need of specific requirement. There are several observable variations among these muffling devices.

There are two broad categories under which mufflers can be classified [41];

1. Passive Mufflers

2. Active Mufflers.

However, the most conventional and commonly available in motor vehicles is the Passive type. These mufflers are further sub categorized into three types [32].

1. Absorptive Mufflers
2. Reactive Mufflers
3. Hybrid (combination) Mufflers types.

The attenuation levels of these types of muffler are dependent on the frequency of the noise source. Depending on frequency of noise source the right type muffler is selected for the required application area. The first two of them have their own working principle but the third type is working with combination of reactive and absorptive principles. Each of these sub types are detailed as follows;

Absorptive muffler:

The Absorptive muffler can absorb high sound pressure with the help of sound absorbing material and convert into heat. The acoustic energy changed into heat through viscous losses in fibrous materials or flow-related which is resistive losses in perforated pipes. Absorptive mufflers are mostly constructed with straight and simple chamber which several layers of absorptive materials like fiberglass are provided to absorb the emitted sound power. The muffler utilizes materials which absorb sound pressure to avoid the energy of the acoustic pressure wave, as it emits through muffler. Some of the absorptive materials control noise generated due to exhaust gas flow and others control structure borne noise. The absorptive material has constant attenuation property as significant feature of this type of muffler [22]. This type of muffler produces less amount of back pressure to the engine but, it is only effective at higher sound frequency.

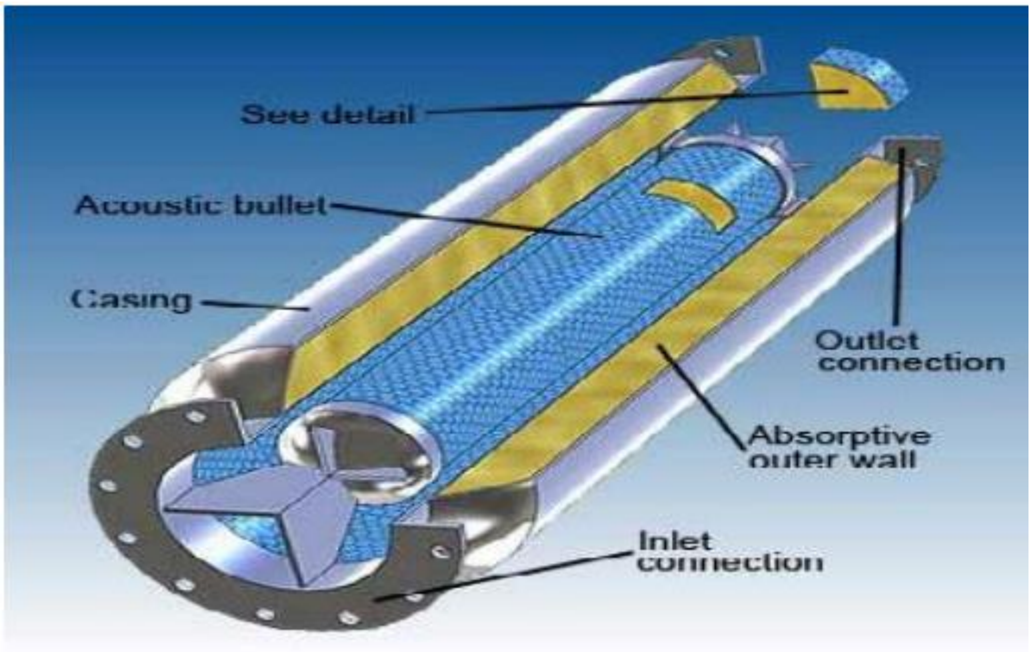


Figure 1.1 Absorptive muffler [31].

Reactive muffler:

The Reactive muffler gives best sound attenuation at lower sound frequency. Mostly it has chambers, baffles and perforations on the surface of internal pipes. Reactive mufflers utilize a series of complicated paths to maximize sound attenuation while keeping specifications like back pressure and others in a safe condition. Sound wave cancellation inside the chamber is done by the principle of destructive interference. The sound waves produced from engine noise are guided to produce another equal and opposite reflected sound wave inside expansion chambers.

Due to alteration in impedance the reflected waves generated and these waves collide with the incident sound wave to produce a destructive interference which causes sound cancellation. When the muffler has more chambers sound attenuation will be better but back pressure increases. Most of a time this type of muffler is used in automotive exhaust system due to its good performance at lower frequency and economical character. The existing and modified mufflers of considered vehicle for this thesis are reactive mufflers. The reactive muffler is designed for best performance by compromising the interacting parameters.

The existing muffler of Minidor, Force three-wheeler is a reactive type so, reactive type muffler is designed by fixing problems which are observed in the existing one.

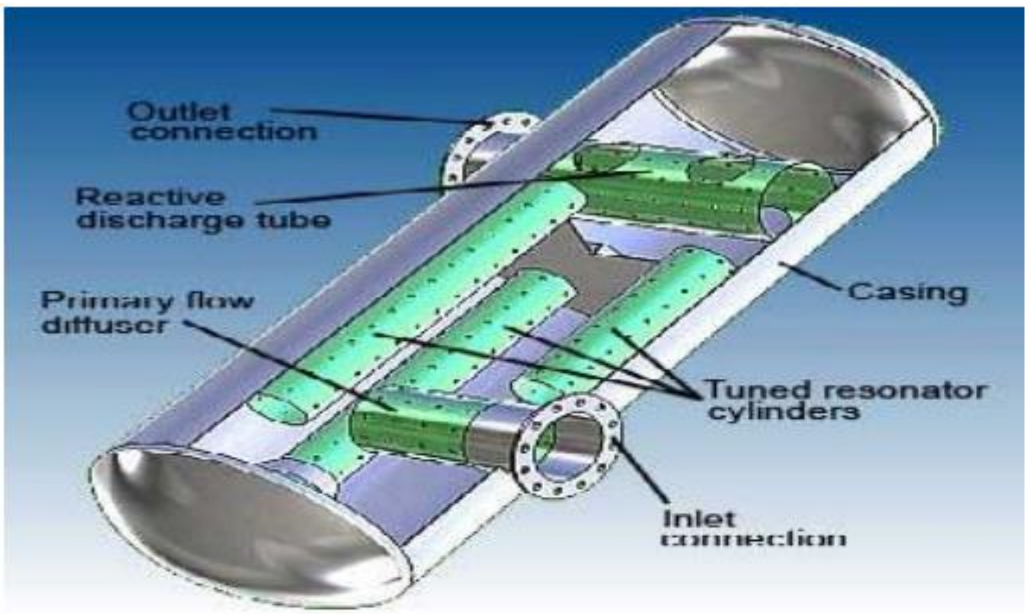


Figure 1.2 Reactive muffler [31].

Hybrid (combination) muffler:

The hybrid (combination) muffler is one includes both Reactive and Absorptive mufflers components. It includes working principle of both mufflers so that it is complex and not economical when compared with the Reactive and Absorptive mufflers. Thus, the design of hybrid silencer requires understanding of acoustic characteristics of each of dissipative and reactive elements, as well as the interactions among them. Hybrid silencer is an effective noise attenuator over a wide range of frequencies for its combined characteristics.

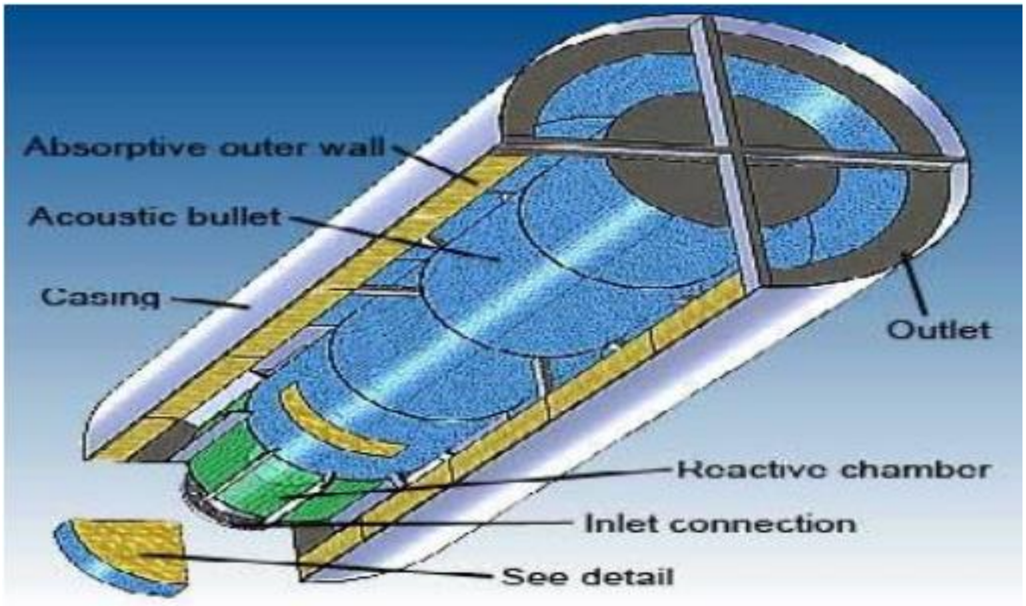


Figure 1.3 Hybrid muffler [31].

Active mufflers:

To fulfill specifications of regulations and customer, extensive researches were done on passive mufflers since earlier, although certain insufficiencies cause poor performances at particular frequency bands or too high prices. These drawbacks of passive mufflers have introduced the concept of active attenuation of sound.

The active sound attenuation technique done with the help of many electrical systems installed in the system. The unwanted noise component generated in the exhaust system is sensed and an adaptive inverted signal is fed back into the duct after being generated from the source. The original engine generated sound wave and the feedback source then act as an acoustic couple that subjected to destructive interference thus cancelling out each other's velocity output. An active noise control system produces an acoustical short-circuit and is most effective to damp low frequencies of 50 to 500 Hz [30].

Since the displacement of the electrical signal is faster than the acoustic signals, the active muffling techniques are gaining attention. These mufflers do not exert back pressure and unlike the passive mufflers are compact size however the concept is in the nascent stage of development.

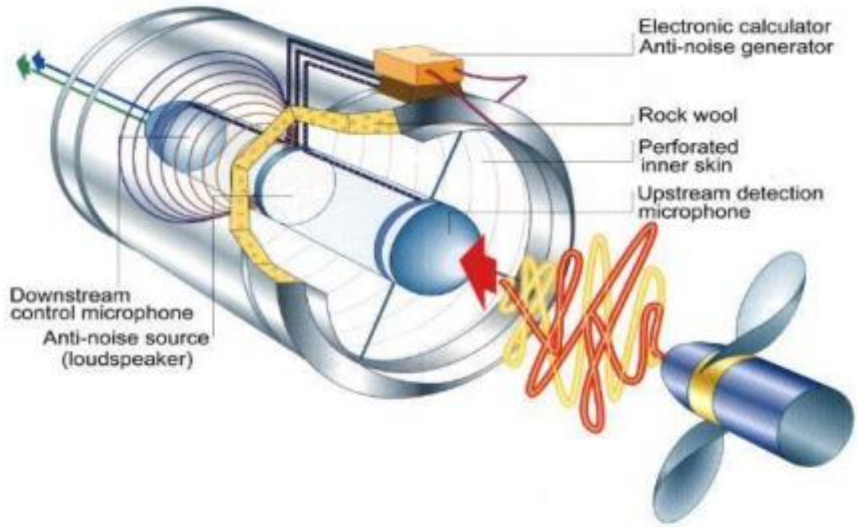


Figure 1.4 Active muffling system [30].

1.2 Statement of the problem

The development of automotive technology focused on emissions reduction for vehicle performance increment, sophistication and to keep environment safe. Emission includes toxic gases and higher sound emission. Here an effort is applied to minimize sound emission of Minidor, Force three wheeler vehicle. The muffler of this vehicle is not attenuating the emitted sound too much effectively. Face to face interviews were conducted to gather information from participants, what they feel when they listen sound emission from this vehicle.

The interview was provided with 5 drivers and 5 passengers. All of them respond that, the vehicle emits higher sound which causes mental stress and less comfort. Additionally, the drivers were asked for the source of this sound emission and they respond that, although exhaust system is the main source of noise but also along the intake manifold there is high sound emission which propagates passing through the air cleaner. Additionally, from observation it is clear that this vehicle has higher noise than other effectively silenced, sophisticated vehicles.

The sound emission from the existing muffler of Minidor, Force three-wheeler vehicle needs to be minimized with improved performance muffler since it causes mental stress to driver and passengers as well. Due to this reason the vehicle sound attenuation seeks a greater attention.

1.3 Objective

1.3.1 General objective

The general objective of this thesis is modification, performance evaluation and prototype preparation of better sound attenuating muffler with acceptable back pressure depending on the specified engine size of Minidor, Force three-wheeler.

1.3.2 Specific objectives

The specific objectives are as follows:

- Data collection,
- To study about the existing muffler, which is done experimentally and by using COMSOL simulation,
- To modify the geometry and model the muffler using CAD tool,
- To analyze the modified muffler using COMSOL Multiphysics for its transmission loss and backpressure performance,
- To prepare the prototype,
- To test the manufactured prototype experimentally to measure its performance in terms of sound pressure level,

1.4 Significance of the study

The importance of this thesis is;

- To reduce noise emission for vehicle sound attenuation performance improvement,
- To improve comfort for passengers by reducing sound emission and vibration of components and,
- The muffler modification, performance study and construction is not complex, so it is easy and essential for acoustical performance development and sophistication of the vehicle.

1.5 Beneficiaries

To provide comfortable environment which is free from sound pollution for the society is the main advantage of the research. Additionally, automotive industries, vehicle owners, researcher, and the country as a whole get benefitted with this work.

Moreover, in Ethiopia most muffler manufacturing companies are working based on old trends with traditional skill, they are not using software supported method for prediction of transmission loss and back pressure before manufacturing of the muffler for effective design.

1.6 Scope

Factors which have influences on the maximization of performance of mufflers are assessed and are applied. Size of muffler depends on swept volume and number of cylinders of engine; hence the design is limited to specific engine size of Minidor, Force three-wheeler. Modification of geometry, prototype construction and performance measurement using COMSOL Multiphysics and experimental set up for both existing and modified mufflers for the sake of result comparison was done.

1.7 Organization of the study

The thesis is organized with the following chapter:

Chapter one gives some introduction about muffler, the problem statement that initiates to work over this title.

Chapter two discusses about the literature reviews. Previous works on IC engine exhaust system sound attenuation are identified and considered. Descriptions about muffler performance parameters like transmission loss, backpressure and insertion loss are also discussed.

Chapter three describes about the equipment or tools and materials used for manufacturing of the muffler, the methods used for performance measurement and procedure followed in modifying the muffler are discussed.

Chapter four is talking about the result and discussion of existing and modified mufflers using software simulation and experimental results.

Chapter five contains conclusion and recommendation.

CHAPTER TWO

LITERATURE REVIEW

The new concept of wedge theory introduced by A. M., et al. (2018) to design a muffler based on reducing the back pressure and to attenuate the noise at the tail pipe of the exhaust system. They have showed as the noise has been controlled by means of this system. The sound reflection through wedge system introduced is redirected to the sound or noise reducing materials known as glass wool. The glass wool has a property of absorbing sound waves by converting the noise in to heat energy. Due to introduction of wedges not only possible to reflect sound but also can slide air from exhaust manifolds which passes through the chamber, which simultaneously control the back pressure inside the system. The introduction of the system enables the exhausts to pass through. The introduction of Pressure Maintainer Valve helps in maintaining the reduced back pressure to maintain a correct ratio. For different revolution per minute, backpressure must be kept constant to avoid fuel loss in the system and was controlled by pressure maintainer valve**.**

Basargi (2016), studied noise generated by four stroke petrol engine with or without mufflers to check the effectiveness of the muffler, and harmful effects of noise caused by it on engine. Haw vibration influence the design of the silencer is evaluated using software tools, the nature and characteristics of vibrations are studied. The validation is carried out on two-wheeler silencer of Hero Honda Splendor and compared experimental results of the prototype with software results. The silencer natural frequencies have been calculated by using the ANSYS package and by FFT analyzer. The natural frequencies by both methods are nearly same and that are useful in the design of silencer to fix the resonance.

Chaudhari et al. (2016), designed three various models of a muffler and the flow has been simulated using ANSYS. They have got 90.008% exhaust pressure reduction in base case model, elliptical shaped model gives 89.22% reduction, with inlet pipe length extension of 40 mm the base case model resulted in 90.615% sound pressure reduction. Length of extension of inlet pipe affects level of sound pressure reduction of a muffler.

Doijode & Gadre (2015), have discussed about the methods used to analyze transmission loss in reactive muffler. Analytical approach is one of the method, which is based on the one dimensional wave equation and empirical formula is generated for transmission loss. At the junction where area discontinuity occurs, the pressure and particle velocity continuity equations are applied. The assumptions required for this approach are; sound propagation is in the free field and in one direction only, the fluid is in stationary condition, mean density and mean pressure are uniform and steady throughout the fluid, the acoustic pressure is the excess pressure from the mean pressure, the method is limited to only small acoustic pressures, Muffler wall does not transfer sound also no viscos effect at the wall surface. The limitation to this method is that for complex geometry it is very difficult to evaluate. Transfer matrix method is the second one which calculates the transmission loss of acoustical silencer by determining the four poles parameters of a transfer matrix. The most important quality of this method is its ability to break the system into discrete elements, which can be modeled by using basic acoustic principles. The last approach is numerical approach which is done with the help of variety of commercially available codes such as ANSIS, COMSOL, etc.

According to Guhan et al. (2017), reduced muffler size without changed the baffle position and number of holes in inlet pipes resulted in increased back pressure. Increased number of holes in the inlet pipe and changed baffle position resulted in reduced back pressure. They have constructed a muffler with reduced size than the previous one. For existing as well as new down sized mufflers CFD analysis has been carried out, the CFD result has been verified with experimental test. From the analysis the overall volume of muffler has been reduced up to 15 %. This leads to weight reduction of 2 % and gives cost benefits as well as fuel economy benefits.

Habib et al. (2016), applied an effort to stabilize the back pressure to a suitable value by using an automated mechanical IRIS at the muffler exit tip. This mechanical IRIS is used to provide a variable exit diameter to the exhaust muffler. Depending on the engine speed an automated mechanical IRIS will vary the exit diameter automatically. Using CFD simulation it is found that the back pressure remains constant for a variable speed of the engine. This makes the vehicle fuel efficient but, does not reduce the exhaust sound of the muffler.

Jha, & Sharma (2013), dealt with determination of frequencies at which higher noise effects are observed during vehicle operation. They have conducted an impact test by applying a force using a hard head hammer and graph of transfer function has been plotted using MATLAB using the data generated. Six points were selected on the muffler for impact test and data from these points have been analyzed for addition of damping. From the result, increase in mass increases the damping and lowers the modes of transfer function. As a design principle of muffler they have suggested the frequency at which generated pulse recurs at firing frequency of engine. The exhaust noise frequency is controlled over by a pulse at the firing frequency and also having a broad band module which widens to higher frequencies. Mufflers are designed to attenuate sound in the frequency range of 0-600 Hz because of majority of pulse energy lies in this range. Engine at full load creates noise of 10dB more than un loaded condition.

Kakadiya et al. (2017), compared noise level for six different arrangements of mufflers with; 3-chamber single exhaust, 3-chamber single exhaust at side inlet and side outlet, 3-chamber dual exhaust, 4-chamber single exhaust, 4-chamber single exhaust at side inlet and side outlet, 4-chamber dual exhaust. From comparison it is found that the dual exhaust type mufflers get better reduction in noise compared to the single center exhaust type and single side exhaust type mufflers. This dual exhaust type muffler provides reduction in noise by 29.56 dB in case study of 5 HP diesel engine.

kamarkhani et al. (2017), have evaluated automotive muffler with and without baffle and perforations, using COMSOL 5.2. They have studied the effect of baffle and perforations. The acoustic silencer pressure was compared with the experimental results and showed that the effect of the baffle and perforations resulted in increasing the transmission loss. The muffler with perforation gives increase in transmission loss. To solve with COMSOL three boundary conditions are applied. The hard wall boundary at the wall surfaces, the combination of incoming and outgoing plane waves at inlet and the outgoing plane wave at outlet are basically applied boundaries.

Mane et al. (2016), studied on analysis of back pressure of the muffler by using CFD simulation to avoid the tedious experimentation. More over the effect of baffle spacing and perforation size on value back pressure are studied. Due to its suitable behavior for turbulent flows with less converging time, k-ε turbulent model is used for flow simulation. The condition for CFD analysis of k-ε turbulent model with standard wall functions, the inlet is velocity and outlet condition is pressure Three modifications are made from the base model, from those models the one with reduced baffle spacing produced least back pressure with reduction in back pressure by 9.60%. They have discussed effect of back pressure, it decreases engine efficiency or increase in fuel consumption, and overheating, complete shutdown of engine may also happen if it is much higher. From the simulation result it is clear that for mufflers with similar perforation diameter and equal d/p ratio, the one with lower baffle spacing (reduced central chamber length) gives list back pressure.

Munjal et al. (1998), studied for a reverse-flow open-end perforated element by deriving transfer matrix where waves in the inlet pipe, outlet pipe and the chamber cancel with each other. They have showed the noise reduction in side the elements of muffler which is determined by means of transfer matrices has greater approach with experimentally observed values at different sound frequencies. The drawback is at each frequency calculation is required, thus the transfer matrix method consumes much time.

Nazirkar et al. (2014), have carried out modal analysis by ANSYS to study the vibration and natural frequency of muffler in order to differentiate between the working frequency from natural frequency and to avoid resonation. Analyzing for single and double expansion chambers, double expansion chamber muffler gives better result of sound attenuation and natural frequency lies within range that does not has resonance. Adding protrusion pipe at inlet and outlet will result in increase of transmission loss of expansion chamber. Using double expansion chamber enables increasing the frequency and avoiding the resonance. The drawback here is the weight and size of muffler becomes large and big space is required for installing it.

Pal (2015), compared transmission loss for dissipative muffler models with experimentally measured values and using FEA method with ANSYS. It was found that Measured TL & predicted TL are matching well within +/-3dB, this validated that the FEA method holds good for this analysis. The hybrid muffler having three different iterations solely based on different air gap between absorptive layer (fibrous material) and perforated pipe was analyzed. Transmission loss analysis was compared with the TL of existing models which showed an increase of TL at higher frequency ranges.

Pal et al. (2014), designed an adjustable a hybrid type muffler for stationary petrol engine so that its length can be varied by using a piston that can be set at different positions. The noise level is also measured at different positions of resonator to know the effect of variation of length of silencer that shows the smaller the resonator size better is insertion loss. Sound intensity is measured before and after muffler installation at different position of resonator piston to study the effect of resonator length. At different engine speed sound level is measured before and after the muffler installed. When the resonator is extreme inside position insertion loss is calculated since minimum sound level is recorded at almost all engine speed. This type of resonator is not economical since it includes piston and cylinder arrangement, so it is not used for all purpose due to its higher cost.

Pangavhane et al. (2013), studied the effect of change in perforation diameter and change in porosity of internal tube using CFD analysis and the simulated result is compared with experimentally tested results. It is found that the change in diameter of holes and porosity of the pipe has greater effect on the backpressure across the muffler. When the porosity is doubled, the Backpressure shows reduction by 75%. When the diameter of the hole increases the backpressure decreases sharply by 40%. Even if the porosity is doubled, it has been seen that the small diameter holes has higher backpressure as compare to bigger diameter holes. But for higher diameters the backpressure value remains the same even when the porosity is doubled. The CFD and experimental values are in good approach with each other. Pressure drop in exhaust system happen due to factors including losses due to piping, silencer, and termination. Effects of higher backpressure are discussed as it can cause an increase in fuel consumption, emissions, overheating, additionally may result in a complete shutdown of the engine which may cause significant damage. Specially, two stroke engines can only withstand small amounts of exhaust back pressure. The life of exhaust valve and turbocharger decrease as backpressure increase. Also exhaust backpressure should be kept within specified limits for those engines with higher level of emissions.

Parlar et al. (2013), focused on acoustical and flow field analysis of perforated muffler design. The muffler flow field is analyzed with ANSIS and transmission loss was measured experimentally and using COMSOL. From flow field analysis back pressure is calculated and compared with experimental value and the numerical result gives 20% approximate error. The examined muffler is consisted of three expansion chambers separated by two perforated baffle plates and perforated inlet, outlet and interior pipes. perforated sections create a cross flow inside the muffler. For flow field analysis the flow is assumed as turbulent and k-ε turbulence model was used due to the change in density with change in temperature. As inlet boundary condition velocity and temperature were used and pressure and temperature were defined as outlet boundary condition. Physical properties of air were defined for flow analysis. The numerical and experimental results for transmission loss are in good agreement only back pressure showed 20% error. As they have described the back pressure of gasoline engine is expected to be between 200 and 300 mbar, the designed muffler developed approximately 150 mbar which is in between the acceptable range for better engine performance.

Patil et al. (2018), focused on CFD analysis of exhaust system for four-stroke compression ignition engine and determined the backpressure developed. They have find out pattern between the exhaust backpressure levels and component placement occurred in exhaust flow design. Performance of existing as well as the modified muffler is done with the help of CFD analysis since it is used to find out pressure variation pattern while the exhaust gas passes through various exhaust system components in complete system. Factors limit engine back pressure are discussed, exhaust emission, exhaust temperature, turbo charger performance, and fuel consumption. The larger the engine has lower back pressure limit because of its valves overlap timing and high turbo boost pressure. The smaller the engine having the higher backpressure due to very fewer valves overlaps timing and if it is non-turbo charge. Engine size of less than 50KW has back pressure limit of 40KW as Swiss VERT program determined. Higher exhaust system back pressure results reduced intake manifold boost pressure, increased pumping work, turbocharger problems**,** cylinder scavenging and combustion effects. The work of engine became so hard to pump out exhaust gases from combustion chamber due to increased back pressure also, for turbo charged vehicle the pressure required to drive turbo charger component became not sufficient. To maintain engine output power increasing fuel flow and reduced air flow to combustion chamber which increases exhaust gas temperature. This leads to increase in wear and shorter components life. The exhaust back pressure increase by muffler placement toward engine and by reducing exhaust pipe diameter. From these the exhaust back pressure can be managed by placement of muffler as well as by changing its exhaust pipe diameter.

Prasad and Thiagarajan (2016), dealt with a muffler performance at the design stage numerically. Numerically predicted performance of reactive muffler and compared with traditional built and test process. The muffler model consists of five separate resonating chambers divided by thin walls. The resonating chambers are connected by tubular pipes for easy passage of exhaust gases and better sound reflection. Delta type thin baffles are provided step by step at three different positions to separate the sound wave and flow at nose mix them at tail for extra sound reduction. Since the flow directions are opposite to each other, they tend to cancel the sound effectively. A minimum exhaust sound pressure at respective higher transmission loss is achieved with this muffler. For effective sound cancellation and high automobile engine performance numerical model has been applied to optimize muffler design.

Pratap et al. (2015), have reviewed the effect of perforated tube on transmission loss of muffler. As they mentioned, ability of attenuation of a muffler depends on internal geometry and material used. Perforated pipes affect transmission loss and back pressure of a muffler. They have discussed about the relationship between transmission loss and back pressure as, one is inversely proportional to the other. Performance of mufflers has been studied by varying number of perforated holes, hole diameter and different loading conditions. From the results, they have concluded that the number of holes and the size of the hole in the perforated tube affect the amount of back pressure and transmission loss in the mufflers. For large hole diameter, the lower will be the backpressure. Perforated muffler together with the porous material gives increased transmission loss. When length of perforated tube increased, better sound attenuation is observed by increasing the transmission loss. Increase in porosity of perforated tube results the transmission loss to grow at lower frequencies and vice versa.

Priyadarsini et al. (2016), have studied four different geometries of chambered exhaust muffler to select the best possible design for least pressure drop. Their main concern is to insure minimum back pressure to have reduced fuel consumption. Flow simulation is conducted using solid work 2014 pressure distribution across the muffler exhaust and mass flow rate of exhaust gas is calculated and used as input parameter for flow simulation. Geometries of those four exhaust mufflers is generated by changing position of inlet pipe with respect to width of muffler, V shaped plates were provided with different arrangements. The muffler with plates placed perpendicular to inlet of muffler and the inlet pipe placed at middle of width of muffler gives minimum back pressure. The back pressure is compared by calculating pressure drop across a muffler for each design. Their work focuses only on back pressure reduction, sound transmission loss of muffler is not considered. If transmission loss is not considered the muffler may be less effective in sound attenuation because of contradicting property of TL and backpressure. When exhaust gas flow path in the muffler is not complicated the back pressure is minimum but transmission of sound is higher so it seeks focus on these parameters.

Ramu et al. (2017), modified the existing muffler section to improve the thermal efficiency and the combustion efficiency by exhaust silencer. In terms of brake thermal efficiency and brake specific fuel consumption comparison of existing muffler with developed one is done and the brake thermal efficiency of engine is higher for developed as compared to existing muffler also the brake specific fuel consumption is low compared to existing muffler. The maximum transmission loss of approximately 20 dB is obtained for the new muffler.

Ranjbar & Kemani (2015), focused on maximization of noise transmission loss in mufflers using shape modification concept. They have been followed three approaches for the noise transmission loss maximization in mufflers by using of shape modification. Three-point and transfer-matrix methods are used to calculate the transmission loss for a muffler also self-written program has been used to calculate the TL for different modified shapes of muffler. The diameters and lengths of inlet pipe, outlet pipe and silencer chamber are considered as design variables. Finally, based on the considered design variables genetic algorithm method is used to find optimum shape of a muffler which results in maximum transmission loss. The considered model is inline three-chamber muffler without perforation, baffle and extended internal pipes. MAP software is used for the calculation of TL of a muffler, the three-point method is considered for the analysis of noise TL in their study. It was observed that increasing of inlet diameter had the most significant influence on maximization of TL and it can be a key factor for designing the shape of mufflers. From transfer matrix analysis, increasing the length of all inlet, outlet and expansion chamber with increased outlet diameter resulted in increase the TL amount.

Rao et al. (2016), have designed reactive muffler, validated and tried to get improved performance. They have used conventional numerical method with shorten product development cycle time and validation. Modern CAE tools has been leveraged for optimizing the overall system design balancing conflicting requirements like Noise & Back pressure.

Reddy and Prakash (2016), constructed a reactive muffler to meet their main target of reduced noise and back pressure level. By redesigning the internal arrangement of pipes and perforations best sound attenuation and acceptable back pressure is achieved when compared with the previously existing one. Using specific engine data design analysis of new muffler is done. A model which contains a simple set of perforated tubes and baffle plates is fabricated and tested. The muffler satisfied good insertion loss, reduced sound and minimal backpressure.

Roy et al. (2010), studied the effect of backpressure on the emissions and performance of a CI engine under various speed and loading conditions. Engine performance described by parameters such as brake thermal efficiency and brake specific fuel consumption, and exhaust emissions like NOx, CO and odor were measured by flue gas analyzer. The engine backpressure produced by the flow regulating valve in the exhaust line was measured by Hg (mercury) manometer. A four-stroke single cylinder naturally aspirated DI diesel engine was used in this experiment. After the engine reached in its normal working condition, load, fuel consumption, and exhaust emissions were measured for each test. From this result brake specific fuel consumption and efficiency were computed and the variations of these parameters with backpressure are discussed. From the result increasing backpressure up to 40 mm of Hg pressure for all engine speed and load conditions, the brake specific fuel consumption and brake thermal efficiency are almost unchanged rather the NOx emission showed a little decrease with increasing backpressure. At low engine speed condition, the generation of CO was slightly higher with increase in load and back pressure, however under high speed conditions CO shows reduction with increasing backpressure for all load conditions. The odor level changed little more from the normal with increasing backpressure for all engine speed and load conditions. Hence, backpressure up to a certain level is not detrimental for a CI engine.

Saripalli & Sankaranarayana (2015), simulated the pressure distribution in the muffler and pressure loss is analyzed for the structure modification also experimentally verified as performance of the modified muffler is better than the earlier one. Two different mufflers are designed with similar design parameters and their performance is compared, the second model was more effective in reducing the exhaust pressure than the first one because of its internal baffle arrangement. The baffle arrangement can vary muffler sound reduction level.

As suggested by Sherekar & Dhamangaonkar (2014), the basic and suitable guidelines for selection of muffler grade are, muffler length and diameter, determination of tail-pipe length according to engine cubic capacity and calculation of pressure drop in muffler on the basis of exhaust gas flow rate. They also explained the checking criteria for suitability of muffler for particular application.

Shinde et al. (2017), have designed U shaped muffler with converging and diverging sections, which are used to change gas flow velocity without changing the direction of flow of gases. Perforated baffles are used instead of solid baffles to reduce the exhaust gas backpressure. Usually, the normal absorptive type muffler consists of a perforated cylinder which is surrounded by an absorptive material. The modified type of this type of muffler is made by adding converging-diverging perforated cones inside a perforated cylinder with perforated baffle at the intersection of the cones. Noise transmission loss, engine output power and weight, of the designed muffler gives better result than the conventional muffler. Absorptive mufflers can give best result at higher sound pressure only and are less effective at lower sound pressure.

The effect of a muffler on the performance of an engine has been studied by Singh & Shrivastava (2015). The muffler selected for their work is reactive type and the exhaust gas is introduced at the inlet and flowing into the space between inner and outer cylinder of a muffler then distributed and coming into the center chamber space through the radial openings using a U-type shaped pipe. In each assembly, the coming exhaust gases are divided into two parts which has the same magnitude and 180º angle difference, when gases from these two directions meet together at center-line of the chamber, they are cancelled to each other and leads to relatively low gas flow rate. The expansion chamber in the middle of the muffler helps to reduce the noise and enables to keep the backpressure of the muffler is lower.

Thorat et al. (2016), dealt with modifications of silencer of upcoming Eicher tractor to fulfill the current sound standards. The current noise level at operator ear level is 97dB an attempt has done to reduce it to 94 dB and below. The modified design is analyzed with respect to both acoustics and back pressure since the maximum allowable backpressure to be maintained up on the engine is 50 mm of Hg. The modifications are verified for their acoustic performance by COMSOL Multi-physics software. For modification purpose important design considerations have been taken such as the mufflers with extended tube in the chamber have better attenuation than that of simple chamber, muffler with reversal flow and muffler with extended tube have almost similar insertion loss, more the number of chambers better is the attenuation, larger the area of expansion chamber results in higher insertion loss. Finally, the modified muffler is made of three chambers and perforated pipe inside the chamber. The muffler composed of a resonator chamber to attenuate most dominant frequency. The reduction in total length of muffler plays a role for its cost effectiveness.

From the review of Vegad and Naik (2017), performance of different types of mufflers has been studied to come up with the one which reduces a large amount of noise level with reduced back pressure of engine. In their outstanding discussion, the hybrid automotive muffler gives best performance than reactive and absorptive. Moreover, they have recommended active silencer for new and future research work.

Wankhade & Bhattu et al. (2015), designed elliptical muffler which is simple in construction and effective in emitted noise reduction. Acoustic analysis is done with the help of finite element analysis method with COMSOL Multiphysics. Sound pressure level on the wall of the muffler and material of muffler constructed is not considered. Extension of inlet and outlet pipe inside the chamber and extra inlet pipe is provided to the chamber to maximize the transmission loss. Finally, validation of the muffler is done experimentally. Comparison of TL of model using FEM analysis and experimental setup gives approaching result. They have concluded that the extended inlet and outlet pipes improve the transmission loss of a muffler. The elliptical muffler with extra divided inlet pipe and extended inlet and outlet pipe increases TL compared to muffler without extra inlet pipe.

Here a number of papers were reviewed but there are some ideas which affect performance of a muffler. The effect of flow direction and at which chamber the exhaust gas should expand to improve transmission loss of a muffler needed to be considered. The internal perforated pipes arrangement together with flow direction affects the transmission loss of a muffler. When the exhaust gas flows in the perforated pipes which are placed in parallel with each other and reversed flow direction (i.e. the flow in the two pipes is opposite with each other), then sound attenuation is better. The arrangement of internal pipes which enables the exhaust gas for reverse flow in the chamber and the size of the chamber at which the exhaust gas expands has an effect on transmission loss and back pressure. Additionally, when the inlet pipe extends up to the final chamber like the existing muffler of Minidor three-wheeler, the flow of exhaust gas became direct without obstruction and the gas expands only in third chamber, thus sound wave transmits easily. When the exhaust gas expansion was in two chambers rather than in single chamber was focused and studied in this research to improved transmission loss.

2.1 Muffler performance Parameters

Earlier mufflers are manufactured by try and error method which is not effective to have muffler of best performance. If the constructed muffler is not that much efficient then reconstruction is done by changing internal geometry. The way of studying the performance of the muffler is also challenging with earlier time. Different methods were there for calculating muffler performance such as, transfer matrices method, three-point method, but the methods are time consuming, lengthy and tough. Now there are a number of software to determine performance parameters easily such as COMSOL, ANSIS, etc. Performance parameters are those describe or tell us acoustic effectiveness and flow characteristics of exhaust gas across a given muffler. The acoustics performance of a muffler is described using transmission loss, insertion loss or noise reduction [12]. For the case of this thesis acoustic performance of the existing as well as the modified muffler is discussed using the transmission loss. The flow characteristics is defined using the backpressure developed across the muffler due to flow restriction of exhaust gas while passing through different sections. These parameters are discussed below.

2.1.1 Insertion loss

The insertion loss indicates sound pressure level difference at a point usually outside system without and with the muffler installed [41]. A mufflers acoustic performance can be defined in terms of insertion loss or transmission loss.

2.1.2 Back pressure

It is the pressure exerted on the exhaust valve and exhaust manifold of the engine due to pressure developed in the muffler because of restriction of exhaust gas flow while passing through obstructions provided in muffler. The back pressure needed to be minimum as much as possible, the more the back pressure will reduce the engine efficiency. For the case of Reactive muffler to get best sound attenuation it is better to have a greater number of chambers but it increases the back pressure which reduces the power output of the engine [3].

2.1.3 Transmission Loss

Transmission loss (TL) is a measurement that can be used for evaluating muffler performance prior to installing the muffler into the system. It is the difference in the sound pressure level between the incident wave entering and the transmitted wave exiting the muffler. If it is required to measure experimentally, the muffler is installed on the actual source for actual measurement.

Transmission loss is independent on source and an anechoic termination at tail pipe. It is one of the most frequently used criteria of muffler performance because it can be predicted very easily from the known physical parameters of the muffler [41].

The total acoustic power at the inlet and the outlet, respectively.

$$p_{in} = 2\int_{S_3} \frac{{p_o}^2}{2\rho c} \qquad (2.1)$$

$$p_{out} = 2\int_{S_1} \frac{|p|^2}{2\rho c} \qquad (2.2)$$

The transmission loss in the muffler is defined as;

$$\mathrm{TL} = 10\log_{10}\left(\frac{\mathrm{p_{in}}}{\mathrm{p_{out}}}\right) \qquad (2.3)$$

2.2 Methods for measuring transmission loss of muffler

Several methods have been studied to choose the methodology that was to be followed and to understand the best and suitable techniques with best practices for modelling and analyses of the research work.

The basic understanding was established in terms of the theoretical basis on the working principle of muffler and the related acoustics parameter determination. Here different methods such as; wave decomposition, three point, transfer matrix and numerical methods were discussed in order to compare basic principle, effectiveness and ease of each method.

Wave decomposition method:

The acoustic wave in the duct is the superposition of the forward and backward moving waves [11]. Acoustic problems often involve simple harmonic waves such as sinusoidal waves. From plane-wave theory, the sound pressure at the at the location *x* of the inlet duct for which the pressure varies with position is expressed as,

$$p(x) = Ae^{-jkx} + Be^{jkx} \qquad (2.4)$$

Where A is the complex amplitude of incident wave, B is the complex amplitude of reflected wave, and k is the wavenumber.

Because of the anechoic termination assumption at the outlet for the TL calculation, only the outgoing wave exists, and the sound pressure at the location x of the outlet duct is,

$$p(x) = Ce^{-jkx} \quad \text{......(2.5)}$$

Therefore, the TL of the silencer can be calculated in terms of A and C, as shown below.

$$\mathrm{TL} = 20 \log_{10} \frac{|\mathrm{A}|}{|C|} + 10 \log_{10} \left(\frac{\mathrm{S_i}}{\mathrm{S_o}}\right) \quad \text{......(2.6)}$$

Three-point method:

The three-point method is used to compute TL of a muffler at each frequency. At the inlet uniform velocity or pressure is taken and anechoic termination or impedance is applied at the outlet end (Fig. 2.1). The sound wave at the inlet contains an incoming wave and a reflected wave, where as in the outlet pipe only an outgoing wave is available. To extract the incoming wave in the inlet tube two points are selected. The longitudinal coordinates of the two selected points along the muffler axis be x_1 and x_2. The corresponding sound pressures at these points p_1 and p_2 can be written as,

$$p_1 = p_i e^{-ikx_1} + p_r e^{-ikx_1} \quad \text{...... (2.7)}$$

$$p_2 = p_i e^{-ikx_2} + p_r e^{-ikx_2} \quad \text{...... (2.8)}$$

Where p_i represents incoming wave and p_r is a reflected wave. Solving the above equations

$$p_i = \frac{1}{2i\, sin[k(x_2 - x_1)]} (p_1 e^{ikx_2} - p_2 e^{ikx_1}) \quad \text{...... (2.9)}$$

$\sin [k(x_2 - x_1)] \neq 0$,

The third point can be at anywhere in the outlet pipe with pressure p_3 at this point. The TL of a muffler can be evaluated as;

$$\mathrm{TL} = 20 \log_{10} \frac{|p_i|}{|p_3|} + 10 \log_{10} \left(\frac{\mathrm{S_i}}{\mathrm{S_o}}\right) \quad \text{...... (2.10)}$$

Where s_i and s_o are inlet and outlet tube areas.

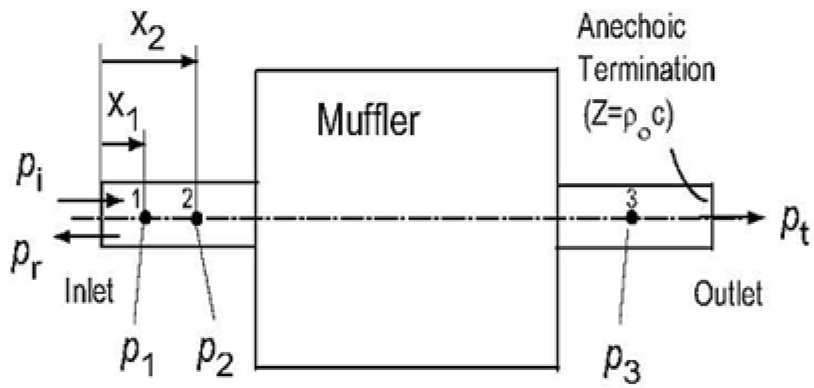


Figure 2.1 The three-point method [34].

When compared with transfer matrix method, the three-point method is faster to compute the TL. The three-point method does not produce the four pole transfer matrix. The four pole transfer matrix method contains important parameters when the muffler is made of a number of chambers or if it is connected with other component in the exhaust system [37].

Transfer matrix method:

The transfer matrix method is useful, easy and quick approach for the case of one dimensional acoustic elements to model and analyze acoustic system. It allows formulating the transfer matrices for different sections individually and combining them by successive multiplication for the whole system analysis [37].

For the case of one dimensional analysis of exhaust muffler systems the transfer matrix is solved based on plane wave theory. The important characteristics of the muffler can be represented by four pole parameters and combined with other four pole matrices when the muffler is connected to other elements in the exhaust system. The transfer matrix method gives an accurate result at low to medium frequency range with minimal data input and therefore can be used repeatedly in an iterative design method [37]. In this method, an overall muffler is considered as a combination of individual acoustic elements which are characterized by a known transfer matrix which means the system is broken down into subsystems that interact with the adjacent systems and thus through such transfer matrix the information about the field applied at the beginning of the system helps in deriving the information at its end.

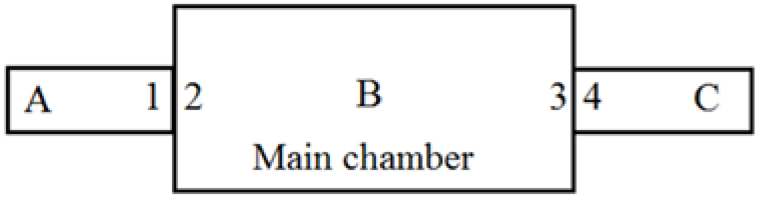


Figure 2.2 Simple expansion chamber [42].

Four pole parameters of the muffler (Fig. 2.2) can be obtained as;

$$\begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix} = \begin{pmatrix} T_{A11} & T_{A12} \\ T_{A21} & T_{A22} \end{pmatrix} \times \begin{pmatrix} T_{B11} & T_{B12} \\ T_{B21} & T_{B22} \end{pmatrix} \times \begin{pmatrix} T_{C11} & T_{C12} \\ T_{C21} & T_{C22} \end{pmatrix} \text{.......... (1.11)}$$

Where subscript A refers to inlet chamber (A), B refers to main chamber (B) and C refers to outlet chamber (C) and after substituting the values in terms of dimensions of muffler the transfer matrix can be obtained.

The analytical methods discussed above in the analysis of acoustical performance of exhaust mufflers is very extensive and less accurate. There were a number of methods for muffler acoustic performance analysis but, for much effective muffler design multi-dimensional analysis method is required. For multi-dimensional problem analysis analytical methods become very complicated, time consuming and greater disagreement appears between the analytical and experimentally measured TL result. Numerical methods in contrast to this provide a technique to measure or analyze the acoustical characteristics of muffler [4].

The numerical method:

The incident sound pressure and transmitted sound pressure are required to find the transmission loss of an acoustical silencer. When the considered muffler geometry is complex not only difficult to calculate the transmitted sound pressure also accuracy of solution drops. For simplifying lengthy and time consuming analytical approach, in recent days many software packages such as COMSOL, ANSYS and SYSNOISE etc. are available which calculate the transmission loss by different numerical algorithms. These softwares have the ability to analyze various muffler types made of complex internal arrangements with reduced time and cost compared to experimental and analytical methods.

This research was done to improve the muffling characteristics of the exhaust system by FEM. Performance of a muffler is measured by performance prediction software (COMSOL Multiphysics).

2.3 Propagation of sound and governing equation of transmission loss for simulation

If we measure sound pressure the signal can be written as a function of time p(t) and it changes with time. When sound is measured at two different positions, sound is expressed as a function of position and written as p(x). Since sound depends on both time and position, it can be expressed as a function of both parameters and can be written as p (x, t). Sound cannot vary independently in time and in space [35]. Same sound is heard at two different positions, but they might not be heard at the same time.

If we take two points $x_1$and x_2 and look at the sound at those two points p(t) and q(t), we know that the two sounds are the same with the possible exception of some time difference,

$$p(t) = q(t + \Delta t)$$

Where Δt is a time difference.

If we assume that sound 'travels' at some speed c, we could say that Δt=R/c where R is some distance. The time difference between the two signals is related to some distance over which sound has to travel. Then we can write:

$$p(t) = q(t \pm R/c)$$

The linear wave equation governing the propagation of small (linear) disturbances in a compressible medium is derived below. The wave equation is applied to fluids governed by the Navier–Stokes equations.

The equations of continuity and momentum for an inviscid fluid are given by:

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho v) = 0 \quad \text{......} \quad (2.4)$$

$$\rho \frac{\partial v}{\partial t} + \nabla \mathrm{p} + \rho v \nabla v = 0 \quad \text{......} \quad (2.5)$$

Mass is conserved and that Newton's laws apply to a fluid as well as to solid particles. The basic assumption in deriving a wave equation is that the fluctuations in the fluid dynamical quantities are small. These dynamical quantities are the sum of a mean part and a small fluctuation. These fluctuating parts are so small that their products can be neglected. Decomposing the quantities:

$$\rho = \rho o + \rho'(t)$$

$$v = v'(t)$$

$$p = po + p'(t)$$

Where 0 indicates a mean value and a prime symbol a fluctuation.

Applying this assumption to the equations of continuity and momentum and neglecting second order terms (products of small quantities), we find the linearized Euler equations:

$$\frac{\partial \rho\prime}{\partial t} + \rho o \nabla . \mathrm{v}' = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad (2.6)$$

$$\rho o \frac{\partial v\prime}{\partial t} + \nabla \mathrm{p}' = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots... \quad (2.7)$$

Eliminating the velocity v′ to give us a single equation:

$$\frac{\partial}{\partial t}\left(\frac{\partial \rho'}{\partial t} + \rho o \nabla . \mathrm{v}'\right) - \nabla\left(\rho o \frac{\partial v'}{\partial t} + \nabla \mathrm{p}'\right)$$

$$\frac{\partial^2 \rho\prime}{\partial t^2} - \nabla^2 \mathrm{p}' = 0 \ldots\ldots...\ldots\ldots\ldots\ldots\ldots\ldots\ldots.... \quad (2.8)$$

To deal with only one quantity at a time we need to eliminate the density. A relationship is required between density and pressure depending on the thermodynamical properties of the fluid. Linearizing the pressure-density relationship;

$$p = po + \left.\frac{\partial p}{\partial \rho}\right|_{\rho=\rho o} (\rho - \rho o) + \frac{1}{2}\left.\frac{\partial^2 p}{\partial \rho^2}\right|_{\rho=\rho o} (\rho - \rho o)^2 + \cdots$$

$$p' = p - po \approx \left.\frac{\partial p}{\partial \rho}\right|_{\rho=\rho o} (\rho - \rho o) = c^2 \rho'$$

$$c^2 = \left.\frac{\partial p}{\partial \rho}\right|_{\rho=\rho o}$$

Substituting this relationship into equation 2.8, we find a wave equation for the acoustic pressure:

$$\frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} - \nabla^2 p = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.9)$$

This is the most fundamental equation in acoustics. It describes the properties of a sound field in space and time and how those properties evolve. The most fundamental obvious property of the wave equation is that it is linear. When we come to solve the wave equation, we will find that c is the speed of sound, the speed at which a small disturbance propagates through a fluid. It depends on the thermodynamical properties of the fluid and is calculated on the assumption that sound propagation is adiabatic [35].

The generated sound is detected with our ear whenever there is rapid change in acoustic pressure P with respect to the static atmospheric pressure value p0. The acoustic pressure variation at some arbitrary point on the path which is described by pressure wave propagating in space and time as discussed earlier. The change in pressure above and below static pressure can cause pressure maxima and pressure minima. Sound wave of alternating high and low pressure propagates with speed of sound. The number of pressure peaks perceived per second is frequency which describes the temporal variation of a pure tone and the distance between two peaks is wavelength. The speed of sound is product of frequency and wavelength. The wave number (k) is defined as $k=2\pi/\lambda$, it is number of waves over a specific distance and gives information about the direction of propagation of the wave.

The muffler design is based on a Helmholtz resonator or expansion chamber, so it needs theory of acoustic transmission. The equation that describes about propagation of sound in fluids are obtained from equation of fluid flow. Fluid flow equations like conservation of mass, conservation of momentum, conservation of energy, model constitutive equations, and equation of state for developing relation between thermodynamic variables.

For this analysis the basic assumptions are; the flow is lossless and adiabatic, viscous effects are neglected and linearized isentropic equation of state is used.

The acoustic field is described by one variable, the pressure p (Pa) and governed by the wave equation.

$$\frac{1}{\rho_{oc^2}}\frac{\partial^2 p}{\partial t^2} + \nabla.\left(-\frac{1}{\rho_o}(\nabla p - q)\right) = Q \text{ ………………………….. (2.10)}$$

Where t is time (s), ρo is density of fluid(kg/m^3), q is acoustic dipole source term, Q acoustic monopole source term.

2.3 Muffling mechanisms

There are various passive muffling mechanisms such as impedance matching, resonant absorption, porous absorption. These muffling techniques are applied and used depending on the type of muffler provided for a given application.

2.3.1 Impedance matching

Acoustic impedance is the impedance which a propagating medium offers to the flow of acoustic energy. It is defined as the ratio of acoustic pressure p to the velocity of propagation u.

When sound wave is transferred from one medium to another, an impedance matching occurs at the interface. If the acoustic impedance of the adjacent media is different, most of the sound energy is majorly reflected, and in some cases absorbed, rather than being transmitted across the interface [41].

The incident sound wave inters through the inlet of the muffler and strikes a reflecting surface inside the muffler then the wave is reflected backwards towards the source. In the area around the reflecting surface the incident and reflected waves interact each other to cancel each other.

Impedance of perforated plate:

The perforated pipes offer resistance to the transfer of acoustic energy when the wave propagate through the pipe. The transfer impedance of perforated plate is calculated using the equation below and it is used to specify the properties of the perforated plate.

$$\frac{Z}{\rho_c C_c} = \left(\frac{1}{\sigma}\sqrt{\frac{8\mu k_{eq}}{\rho_c C_c}}\left(1 + \frac{t_p}{d_h}\right) + \theta_f\right) + i\,\frac{k_{eq}}{\sigma}\left(t_p + \delta_h\right) \text{………………….. (2.11)}$$

Where μ is dynamic viscosity, k is the wave number, ρ is the density, c the speed of sound, σ is area porosity, that is a dimensionless number is 0.145. which means 14.5% of the plate's area consists of holes, t_p is plate thickness and is 1.5mm, d_h is diameter of hole on perforated pipe, End correction δ_h to the reactance in meter. Flow resistance θ_f gives additional contribution to the resistive part of the impedance like mean flow or nonlinear effect at large sound pressure levels. The value of θ_f is 0 for this analysis neglecting such effects.

2.3.2 Resonant absorption

The Helmholtz resonator and the membrane absorber can be represented as spring-mass-damper systems, are the main types of resonant absorptive muffling mechanisms. In case of the Helmholtz resonator, absorbers are based on the principle that the air in the slots of the plate represents a mass and that the air volume of the cavity behind the plate represents the spring stiffness in an equivalent oscillator while for a panel or membrane based absorber, the membrane material itself serves as the vibrating mass. The damping is provided by the inclusion of a small amount of absorbing material such as mineral wool which is necessary to take away the noise off the system. The membrane absorber has thin metal sheet. The requirements for obtaining a reasonably high absorption are low surface weight and high internal losses in the membrane plate material. Aluminum or steel panels having a thickness of 0.5–1.0 mm mounted at a certain distance from a hard wall normally absorbs in a limited frequency range only. By using thin sheets of plastic materials instead of metal much better performance may be achieved [42].

2.3.3 Porous absorption materials

Porous materials are used for sound absorption purpose, which are often placed directly on to a hard surface or with a cavity behind to increase the absorption at low frequencies. They gate this sound absorbing property by nature and composition of various materials. These materials can be classified as fibrous, cellular, and granular. These materials can be considered as dissipative fluids because of the acoustic wave motion through these materials are limited to the fluid within the pores. The acoustic pressure amplitude and phase get altered under the influence of the visco-thermal exchanges within the pores of the material. Well-known porous materials are products of mineral fibers and plastic foams. Commonly used are blankets of mineral “wool”, either glass or stone wool. These have fibers with a diameter in the range 2–20 μ [42].

2.3.4 Acoustic metamaterials

Arrangement or periodic configurations of repeating structures consisting of solids and fluids embedded within a base medium are known as metamaterials. Sound absorption using these systems are sometimes based on the acoustic black hole effect.

The working mechanism is the sound wave interacts with these metamaterials and scatter within the structure in which local resonance is provided by the individual cells. Due to the effect of the metamaterial, band gap is formed on a propagating acoustic wave. These prevent the transmission of the sound energy through the material at a target frequency range. The form and physical structure of the inclusions has a greater influence on the frequency range within which the transmission can be blocked [41].

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

Even though the material of the muffler is not considered for improvement of sound transmission loss across the muffler, the required properties of materials for effective design and factors affecting muffler material selection are discussed under this section.

The proper material should be selected for construction of effective muffler. The type of material can affect durability, weight and ease of manufacturability of a given muffler. As discussed earlier this reactive muffler is made of pipes, perforated pipe and simple plates. The hot gas passes against and through these components so that parts subjected thermal stress additional to the mechanical stress which is caused due to pressure of exhaust gas flow. The material must have to withstand these thermal as well as the mechanical stresses. Most of a time sections provided with perforation are damaged earlier than other sections due to the pressurized hot gas flow through the holes. Here for the modified muffler perforated section on outlet pipe is avoided to overcome this problem.

Corrosion is one of the main problem that leads components to shorter life. When exhaust system component is working at higher temperature it became sensitive for reaction with corrosive elements due to high temperature oxidation, salt-induced external corrosion, condensate induced internal corrosion. The ability of materials to resist corrosion differ from material to material so the less reactive one should be selected for better age of performance. Now a day, stainless steels are used for exhaust muffler construction for their good performance of high temperature characteristics, formability, reduced weight for better fuel economy and high corrosion resistance to meet longer life and clean exhaust gases. Moreover, condensate corrosion resistance characteristics of stainless steel makes it appropriate and effective for parts like muffler which works in humid environment. Also, due to high wear resistance, lightweight, high fatigue strength and high heat resistance it is expected that more automobile parts will be made of titanium and its alloys in the very near future [39].

For the modified muffler outer shell galvanized iron is selected for its less sensitivity to oxidation and its reduced weight. Under the galvanized iron, steel alloy sheet metal is used for its high thermal stress resistivity and les reactivity to condensate induced corrosion. The inlet and exhaust pipe of the muffler are made of steel alloy which has excellent strength characteristics, corrosion resistance and formability. The modified muffler gives better sound attenuation and reduced weight when compared with the existing. Reducing the weight of vehicle is one of the concern in modern technology for the sake of having reduced fuel consumption. Thus the modified model is more effective since it fulfills this requirement.

Materials and Equipment's those required to construct the muffler are listed in the table below.

Table 3.1 The materials required for prototype manufacturing.

No	**Item**	**Unit**	**Specification**	**Quantity**
1	Sheet metal	Millimeter	1.5 ×500×500	2
2	Pipe	Millimeter	Ø32, Ø 37	4
3	Bolt &nut	Millimeter	M10	4
4	Flange	Millimeter	5×80×100	1
5	Electrode	Pack	Ø2.5	3
6	Plate	Millimeter	1.5×100×200	4

Table 3.2 Required equipment

No	**Equipment**	**No**	**Equipment**
1	Arc welding machine	4	Grinder
2	Oxyacetylene welding machine	5	Hacksaw
3	Vernier caliper	6	drilling machine

3.2 Design methodology

The methodology followed by this work was started by observing the problem and selecting this idea for research. Then reviewing different papers was done to study working principle, effect of change in geometry and also the way haw to improve transmission loss of muffler. Different methods used to measure transmission loss of a muffler are also reviewed. With the help of studied techniques to improve the transmission loss, geometry of muffler is designed and modeling is done with CAD. Importing the model in COMSOL and simulation is done for both existing and modified model to compare the result. After good result is obtained from simulation, manufacturing of the muffler was done for experimental measurement.

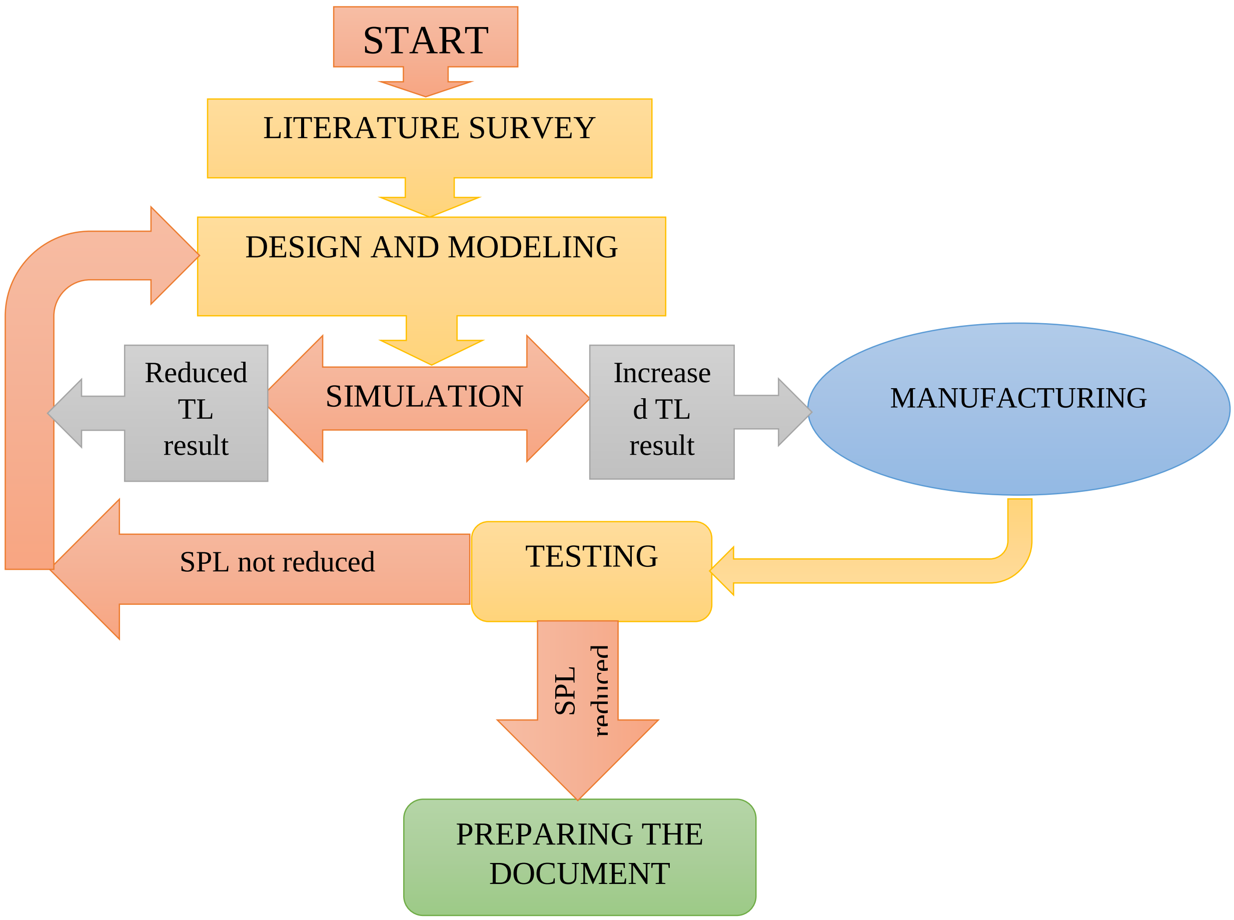


Figure 3.1 Flow chart of the methodology of thesis.

3.2.1 Work flow

For effective progress and completion of the thesis, method is used with clear procedure and work flow order. To avoid confusion and fix problems those happen during work technically it is essential to have a guiding procedure and method to be followed.

I. Literature Reviews: To have enough understanding about different types of mufflers, their working principle and the way haw to fix less effective muffler designs literatures are essential source of knowledge.

II. Data collection: The necessary data for muffler of Minidor, Force will be collected by the following method.

- Basic engine data (specification): By visiting websites which are help full for this design important information's are gathered. Based on the provided engine input data target frequency is calculated. Engine specification of Minidor, Force is given in the table below.

Table 3.3 Engine data for Minidor, Force three-wheeler

Engine data	**Specification**
Model	TD 499 LC 15° - DI
Type	Single Cylinder,4 Stroke
Bore / Stroke	85.0 x 87.8 mm
Displacement	499 cc
Max. Output power	7.2 kW (ISO)@ 2800-3000rpm
Max. Torque	28 Nm @ 1800-2000rpm

- Data collection about the geometry of existing muffler of Minidor, Force three wheeler by visiting concerned Automobile industries was done. For the purpose of comparison of performance of existing muffler with the modified one, data about internal and external dimension of the existing muffler was collected. Using the collected data, the three dimensional model is constructed with Auto CAD and imported in COMSOL for the analysis of transmission loss and back pressure of a muffler. Measurements like volume of shell, diameter of pipes, perforations, dimension of each chamber, and proper position of internal pipes are studied from used existing muffler.

III. Muffler Volume Calculation: The volume of existing muffler was calculated using the data or measurements gathered about its dimension from garage. Using measured value and equating with the volume calculated from engine basic data the design factor was determined. The need for knowing the design factor is to study the model for comparison and to give some more factor for improvement of gas expansion in the newer model.

Swept volume (Vs) of an engine is calculated by;

$$V_s = n \times \pi \frac{{d_b}^2}{4} L \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.1)}$$

Where n is number of cylinder, d_b is bore diameter, L is length of stroke of cylinder.

Volume of muffler to be considered for calculation is;

$$V_c = n \frac{V_s}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.2)}$$

Where, n = number of cylinders.

Finally, the volume of a muffler to be modeled is calculated by multiplying considered volume with design factor.

Muffler Volume = Factor * Consider Volume

$$V = f \times V_c \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.3)}$$

Volume of muffler must be factor of at least 12 to 25 times the volume considered [12]. Volume can be adjusted depending on the space provided for the muffler installation.

IV. Internal Configuration and Concept Design: Using basic engine data and Target frequencies each concept and internal configuration are then adjusted to the best possible configuration so as to achieve best acoustic performance and least backpressure.

Diameter of perforation:

Perforated pipe is one of an important acoustic element of muffler. The diameter of holes to be punctured needed to be calculated during muffler design. Here the modification does not include change in diameter of holes, which is 5 mm for the existing model. The diameter of the hole to be drilled on the pipe can be calculated by:

$$d_1 = \frac{1.29}{\sqrt{N}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.4)}$$

Where d_1 is hole diameter, N is maximum revolution of engine per minute.

Open area ratio (Aop):

Aop = (Area of perforation / Area of the plain sheet)

Area of perforation was calculated using diameter and number of holes drilled on pipe surface and area of the plain sheet can be calculated from perimeter and length of perforated pipe. Lesser the Aop results improved acoustic performance [23].

Porosity (σ): The total area of the holes in each perforate divided by the area of the corresponding region from the geometry and the porosity values were obtained. The lesser the porosity more is the restriction and hence more will be the backpressure [23].

For this work the porosity of the modified model is equal with that of the existing one, no change in dimension is applied. Porosity is given by;

$$\sigma = \frac{\left(\frac{\pi}{4} \times {d_1}^2\right)}{c_1 \times c_2} \quad \text{...} (3.5)$$

Where d_1 is perforation hole diameter, $c_1$and c_2 are the distance from center of considered hole to center of another hole in the vertical and horizontal direction respectively.

V. Virtual simulation: Referring concept design, after accomplishing the design of parts simulation of the system was continued. COMSOL Multiphysics is used for analysis of back pressure and for transmission loss measurement.

VI. Target Frequencies: At fundamental frequency the tone generated is higher because for 4-stroke engine every two rotation of crank shaft leads to one full cycle of engine is completed at starting of power stroke during which higher pressure is generated inside the cylinder so that higher tone is generated at this fundamental frequency. A high pressure acoustic pulse is generated due to combustion inside engine cylinder and propagates along the exhaust pipe. The pulse repeats at the firing frequency of the engine and higher tone is generated at this fundamental frequency which dominates frequency content of exhaust noise, but it also has broadband component that extends to higher frequency. During muffler design all frequencies where pulse energy lies are considered. The majority of pulse energy lies in the frequency range of 0-600Hz [7]. The muffler is designed for the range of these frequencies for best performance.

Calculation of cylinder firing rate (CFR) based on basic engine data, calculation of engine firing rate (EFR) based on cylinder firing rate (CFR). The need to calculate the target frequencies is to give more concentration of higher transmission loss. For calculating the target frequencies engine max power rpm is required.

Formula to find fundamental frequency of exhaust sound:

Cylinder Firing Rate (CFR) = Engine speed in RPM/120 (four-stroke engine)

$$CFR = \frac{N}{120} \quad \text{...} (3.6)$$

=3000/120

=25

Engine firing rate (EFR) = Number of cylinder * (CFR),

$$EFR = n \times CFR \qquad (3.7)$$

Where n is number of cylinders,

$$= 1 \times 25 = 25\text{Hz}$$

VII. Prototype manufacturing and testing: After good results were obtained from simulation, prototype manufacturing was performed by following basic manufacturing procedures. Parts are manufactured individually and then are assembled together to construct functional muffler. Finally, the muffler was tested for its acoustic performance.

3.2.2 The approaches used and concept applied for modification

Sound propagation and attenuation studied and done by following the most effective approaches based on the complexity of the problem and ease of extraction of the desired outcome.

Theoretical Approach:

Depending on acoustics of muffler, the methods such as geometric analysis and drawing of component are prominently considered by avoiding as much of approximations as possible. Conservation of mass and momentum equations together with state equation are majorly considered under the theoretical basis. The requirement of this technique is to know haw a wave propagate through the fluid domain to study the overall impact and superimposition of all such waves. This approach gives high level of clarity and understanding while attempting to derive the effects during analyzing a given design. The effects of change in geometry as a factor on various performance parameters of a muffler are discussed taking different reviews as a base point. Not all of actual problems can be represented mathematically as a single model owing to the coupling effect of several events occurring simultaneously. This limits the type and complexity of tasks because of all real life engineering problems may not be solved by pure analytical approach.

The basic construction of reactive automotive muffler usually consists of the expansion chamber, baffle plate and perforated tubes. The arrangement of these components will guide the exhaust gas to flow from the inlet pipe of the muffler to the outlet with required effect on the sound pressure level. The noise from the exhaust gas will be cancelled inside the muffler by the basic design principle of noise cancellation before the gas flows out to the atmosphere.

In the case of reactive muffler sound is cancelled with the principle of distractive interference or reflecting the propagated sound pressure back to the source. The sound pressure is cancelled by changing flow direction of exhaust gas to avoid direct flow of gas through pipe. Expansion of gas in the chamber is also one of the method. The other one is perforated pipes are used to cancel sound pressure, but if it is not properly designed it cause greater effect in increasing back pressure. For smaller diameter perforation better is the transmission loss but, increases the back pressure. A smaller hole diameter but higher porosity creates high peak power with acceptable back pressure value.

For the case of this design the porosity is not changed, it is similar to existing one. Attenuation is done by changing flow direction of exhaust gas for reflection of sound pressure back to the source. The change in flow path is used to overcome direct transmission of sound pressure through the muffler. The gas flow in the existing muffler is not that much complex rather there is direct gas flow, the inlet pipe of muffler extends up to third chamber. The exhaust pipe is arranged in offset position and perpendicular to inlet pipe position in third chamber. This shows the exhaust gas flows with simple path without much obstruction which leads to transmission of more sound pressure.

In the new design the inlet pipe is extended up to second chamber. Gas expanded in the second chamber flows back to the first chamber through perforated pipe which is installed at the mid position of the first baffle plate. Reverse-flow configuration is best technique to minimize sound pressure transmission. The gas from the first chamber then passes to third chamber through the pipe which is extended up to third chamber. This pipe is provided with perforations on its surface on some places. Finally, the gas through offset and perpendicular exhaust pipe escapes to the surrounding. Through this flow path the exhaust gas gets more obstructions that reduces transmission of sound pressure from muffler inlet to exhaust pipe tip.

The size of expansion chamber is also changed in the case of the new design. It is increased in small amount for better expansion of exhaust gas in the chamber which results in increase in transmission loss. The change in flow direction is the main factor in the modified design to have better sound reduction when compared with the existing model. Additionally, arrangement of extension of inlet pipe and reversing perforated pipe fitted on first baffle plays great role in sound attenuation. When incoming gas flows through the perforated section of inlet pipe, the sound waves pass through the perforations and the waves collide to cancel with each other. Similarly, reversing direction of flow with the help of reversing perforated pipe enables incoming and reversed sound waves cancel with each other.

With the help of concepts studied for improved performance muffler design, volume calculations, internal pipes arrangement, perforation on pipe surface, baffle plates number and arrangement were discussed. The volume of the muffler is calculated from basic engine data using swept volume of the engine. Then the design factor is considered which is 12-25 as used by different researchers. The factor is selected based on the space provided for muffler installation and effective chamber size for exhaust gas expansion.

The general guiding criteria followed and considered during muffler modification for best functional requirements are discussed below [32].

1. The acoustic criterion: Better sound transmission loss as a function of frequency should be achieved compared to the existing muffler.
2. The aerodynamic criterion: Since the efficiency of the engine is affected by the extra static pressure developed in the muffler the muffler must operate for an acceptable range of pressure drop (below maximum acceptable average pressure drop for a given engine size). This additional pressure drop in the muffler must be in the allowable range to satisfy good fuel consumption and engine power.
3. The geometrical criterion: Which specifies the maximum allowable volume and restrictions on shape of muffler. Various factors may affect size selection of a muffler such as, pressure drop, acoustical performance, weight, the provided space where the muffler should be located, the level of sound needed to be reduced. The muffler is designed by compromising these factors.
4. The mechanical criterion: Describes the materials from which the muffler constructed is durable and requires less maintenance. The muffler should give proper function including muffler mounts and all other functional parts must perform their body operation for a

given period of time without failure. Silencer construction weather it is easy or tough to fabricate and materials availability must be also determined.

5. The economical criterion: To provide the product with preferable cost to the customer and to be competitive in market place this criterion is considered. The larger the muffler the more will be its weights and costs.

To reduce noise emission of Minidor, Force three-wheeler and improve its comfortability, in this work the muffler is modified by considering and ensuring the above basic criteria.

The numerical approach:

Numerical methods consider the overall behavior of waves within a fluid volume. Essentially the numerical approach includes the discretization of the problem and the solution is obtained when subjected to a pre-developed program running in the background of the numerical solver. Governing equations developed based on various concepts and laws, thus results to higher accuracy and simplifications of the problem which are beyond the scope of manual calculations. This method tends to solve a problem which is in a complicated manner that is not only hard to compute but also larger the problem, larger is the modelling complexity.

3.2.3 Geometry of the existing and modified muffler

Muffler interior:

Muffler interior contains interior hard walls and pipe perforates. Interior hard walls are those pipes and baffles or chamber separating plates used as obstructions placed one after another inside the muffler. When exhaust gases pass from inlet to outlet of muffler baffles obstruct the flow, so at outlet sound will completely minimized. The exhaust gas flows through the pipe and expand in the free space in the muffler. Thickness of pipes and baffle plates is equal which is 1.5 mm. Pipe perforates with a given porosity value is one of internal part of a muffler that has effect on transmission loss and back pressure of a muffler. Internal pipes with diameter of 32mm were used for both existing and modified models. Pipe perforates is a pipe with perforation or holes on its surface. when porosity value is smaller more is the restriction and hence more is the back pressure. Smaller hole diameter with higher porosity gives acceptable back pressure. The porosity for the modified design is similar with that of the existing one.

Muffler exterior:

The exterior of muffler includes extended inlet pipe, outlet pipe, flange and shale of muffler which is made of sheet metal of multi layers for the sake of good sound attenuation and strength. The inlet pipe is made of 37mm diameter pipe, which is used to transport the exhaust gas from exhaust manifold extension to the muffler chamber. Depending on the diameter of a pipe coming from exhaust manifold, the inlet pipe diameter of the modified muffler is not changed from existing muffler dimension. The tip of the inlet pipe is provided with flange which is used to mount on an identical flange available on tip of exhaust manifold pipe extension. The outlet pipe is 37 mm in diameter for both mufflers and it is used to transfer the exhaust gas from the muffler to the environment.

Existing muffler volume calculation:

Data is gathered about the existing muffler of Minidor, Force three-wheeler. It is elliptical shaped muffler with main diameter of 180mm and miner diameter 80mm, overall length of muffler is 390mm. Using the above data volume of muffler can be calculated by multiplying area of elliptical section with length of muffler.

$$\mathrm{V} = \pi \times \frac{d_{\mathrm{mj}}}{2} \times \frac{d_{\mathrm{mi}}}{2} \times \mathrm{L} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.8)$$

Where d_{mj} & d_{mi} are major and minor diameter respectively.

$$\mathrm{V} = \pi(9 \times 4 \times 39)cm^3$$

$$\mathrm{V} = 4410.796cm^3$$

Muffler Volume = Factor * Considered Volume (i.e. factor 12-25)

$$V_c = n\frac{V_s}{2}$$

$$V_s = n \times \pi \frac{{d_b}^2}{4} L$$

Where, n is number of cylinders.

$$V_s = 1 \times \pi \frac{(8.5)^2}{4} 8.78$$

$$V_s = 497.9 \approx 499cm^3$$

$$V_c = n\frac{V_s}{2}$$

$$V_c = 1 \times \frac{499cm^3}{2}$$

$$V_c = 249.5cm^3$$

$$V = f \times V_c$$

$$4410.796cm^3 = f \times 249.5cm^3$$

$$f = 17.7$$

From this we can understand that the factor used for existing muffler design is 17.7, for better expansion of exhaust gas the modified model is designed with factor greater than the existing one.

Modified muffler volume calculation:

For the sake of having effective expansion of exhaust gas the size of expansion chamber is enlarged little more from that of the existing model.

The volume of the modified model is calculated by using a factor greater than the existing one, but there is a limitation that affects the design to select factor of large number. If the factor selected is so large the size of the muffler also become larger, thus it may not be suited for the space provided on the vehicle. Additionally, the larger the muffler cause increase in weight of the vehicle which results in an increase in fuel consumption. During design, factors needed to be considered are good expansion of exhaust gas, the space provided for the muffler installation and proper weight for effective fuel consumption.

Muffler Volume = Factor * Consider Volume (take f=22)

$$V = f \times V_c$$

$$V = 22 \times 249.5cm^3$$

$$V = 5489cm^3$$

Since the shape is similar to the existing one, the elliptical portion has major diameter of 180mm and using the free space available on the vehicle in the minor diameter direction the minor diameter is taken as 90mm. Using these dimensions, the length of the muffler can be calculated with the help of above formula.

Muffler Volume = Area of elliptical cross-section*Length of muffler

$$\mathrm{V} = \pi \times \frac{d_{\mathrm{mj}}}{2} \times \frac{d_{\mathrm{mi}}}{2} \times \mathrm{L}$$

$$V_c = 249.5cm^3$$

$$5489cm^3 = \pi(9 \times 4.5 \times L)cm^3$$

$$L = 43cm$$

Porosity Calculation:

$$\sigma = \frac{\left(\frac{\pi}{4} \times {d_1}^2\right)}{c_1 \times c_2}$$

Where d_1 is diameter of holes on a pipe and is 5mm, c_1 & c_2 are indicating the distance from center of one hole to center of another neighbor hole along the axial and radial direction of a pipe and are 9mm and 15mm respectively. Since there is no change in porosity, the values are measured from the existing muffler component.

$$\sigma = \frac{\left(\frac{\pi}{4} \times (5mm)^2\right)}{9mm \times 15mm}$$

$$\sigma = 0.145$$

3.3 Simulation using COMSOL Multiphysics

Three dimensional CAD model of the muffler is constructed with Auto CAD. The model is composed of interior space enclosed by the muffler, internal pipes, chamber separating baffles, and external parts of muffler in contact with the external air. Once 3D modeling is finished, simulation is done with COMSOL Multiphysics using pressure acoustic frequency domain.

Parameters those affect the performance of muffler are listed and are taken from data collected except the inlet pressure of 1 pa which is taken as an assumption.

Boundary condition is applied for different components of muffler like, inlet, outlet, interior hard walls, pipe perforates. Tasks to be done while analyzing are discussed below under the listed process stages.

Preprocessing:

The fluid domain is modelled and meshed under physics of pressure acoustics in the frequency domain for the case of transmission loss analysis. Under pre-processing stage as a first step, the problem definition and the declaration of the associated parameters and variables is done. This is followed by the geometrical formation where the muffling section a pre designed model is imported in compatible formats from Auto CAD software as well. The working medium(air) is defined in this stage as well. The variables consist of the characterizing entities that help in defining the nature of the medium, as also the expressions for the post processing such as transmission loss, inlet and outlet acoustic power. The inlet and outlet boundaries are considered as an explicit selection and then integrated over for applying the boundary conditions later.

Processing:

The necessary guiding conditions like the boundary conditions need to be preset and the process is done by the software. Under the Pressure acoustics module, the defining of the following is crucial;

- Sound hard boundary, which comprises of the outer walls and internal structures that do not allow the fluid to travel through.
- The initialization of the pressure and velocity at the start has to be set to zero.
- The incoming wave at the inlet and outgoing wave at the outlet has been set into the plane wave radiation and applied to the geometry.

Now the model is meshed considering surfaces and dimensions of the smallest and the largest structures of the model. The global maximum element size is set equal to the minimal wavelength of the acoustic wave divided by 8, that is, $\lambda/8 = c/fmax/8$. This model solved for a range of frequencies from 20 Hz to 500 Hz and free tetrahedral mesh is applied.

Post processing:

Once the internal calculations have completed with COMSOL, using the processed information is available for the user the plots for the acoustic pressure including the total acoustic pressure, the sound pressure levels, graph of frequency v_s transmission loss are plotted.

For the case of back pressure analysis since the pressure distribution is processed, selecting the inlet and outlet surfaces and calculating the average pressure distribution for each of these sections and by subtracting one from the other the pressure drop is determined across the muffler. The plots and graphs as obtained have been discussed in the following sections.

3.3.1 Transmission loss analysis of existing and modified muffler using COMSOL Multiphysics

Acoustic performance of the muffler is determined under pressure acoustics branch in COMSOL Multiphysics with pressure acoustics, frequency domain (acpr) interface which is used to study propagation of acoustic waves in a fluid medium. The domain features contain background incident acoustic fields, as well as domain monopole and dipole sources. This interface describes the interactions between acoustic waves and model geometry. It is used for modeling of acoustics problems that do not involve fluid flow. The sound pressure *p*, which is analyzed in pressure acoustics represents the acoustic variation to the ambient pressure (static absolute pressure).

Boundary conditions for transmission loss analysis

Boundary conditions are used to define the nature of boundaries of conceptual domain in the muffler. The boundaries applied include physical surfaces like hard walls, artificial boundary conditions like an open boundary where no sound is reflected. Reacting boundary condition is also applied for perforated plates.

Sound Hard Boundary (Wall):

The sound hard boundary is used for hard walls at which the normal component of the acceleration is zero. It applied for the outer walls of the muffler chamber and the pipes.

Incident Pressure Field:

The incident pressure field node is a sub node applied to all non-reflecting boundary conditions. Plane wave is selected to define an incident pressure field of plane wave type. Then Pressure amplitude of p_0 =0 Pa is used.

Interior sound hard boundary (wall):

The interior sound hard boundary added as a boundary condition for a sound hard boundary or wall on interior boundaries inside the muffler. A sound-hard boundary is a boundary at which the normal component of the acceleration is zero:

3.3.2 Backpressure analysis of existing and modified muffler using COMSOL Multiphysics

K-epsilon (k-ε) turbulence model is the most common model used in Computational Fluid Dynamics (CFD) to simulate mean flow characteristics for turbulent flow conditions. It is used for simulating single-phase flows at high Reynolds numbers. The k-ε model is the simplest turbulence model for which only initial values and boundary conditions needs to be supplied. The physics interface is suitable for incompressible flows, and compressible flows at low Mach numbers (typically less than 0.3). k-ε model focuses on the mechanisms that affect the turbulent kinetic energy. The underlying assumption of this model is that the turbulent viscosity is isotropic.

The equations solved by the turbulent flow, k-ε interface are the Navier-Stokes equations for conservation of momentum and the continuity equation for conservation of mass. Flow close to walls is modeled using wall functions.

The Turbulent Flow, k-ε interface can be used for stationary and time-dependent analyses. The main feature is fluid properties, which provides an interface for defining the fluid material and its properties. When k-ε physics interface is added, the default nodes added in the model builder are; fluid properties, wall, and initial values.

For this thesis backpressure simulation some assumptions were taken. The velocity of exhaust gas at the inlet is assumed as 10m/s, also the pressure at the exhaust pipe tip is assumed as it is equal with atmospheric pressure 101320Pa.

Boundary conditions for backpressure analysis

Fluid properties, Wall, Initial values:

Under fluid properties density (ρ)and dynamic viscosity(μ) values are filled from the selected working fluid. From materials list air is selected and properties of air are used for the space provided under fluid properties. The default dynamic viscosity describes the relationship between the shear rate and the shear stresses in a fluid.

The wall node includes a set of boundary conditions describing the fluid flow condition at a wall. The wall condition of no slip is selected for a stationary solid wall, the condition prescribes $u = 0$, that is, the fluid at the wall is not moving.

The initial values node adds initial values for the velocity field and the pressure that can serve as initial conditions for a transient simulation or as an initial guess for a nonlinear solver.

Inlet, Outlet, Interior Wall, Screen:

The inlet node includes boundary conditions describing the fluid flow conditions at an inlet. The velocity boundary condition of 10m/s is used here.

The Outlet node includes boundary conditions describing fluid flow conditions at an outlet. Pressure of 101320pa is used assuming the pressure at the outlet pipe tip is equal with atmospheric pressure.

Under interior wall boundary condition the fluid-flow conditions at an interior wall is described. The interior wall condition can only be applied on interior boundaries. It is similar to the wall boundary condition available on exterior boundaries except that it applies on both sides of an internal boundary. It allows velocity, pressure, or turbulence discontinuities across the boundary.

Screen node is used to model interior wire-gauzes, grilles, or perforated plates and it can only be applied on interior boundaries. Here this node is applied for perforated plates. Values of solidity, resistance and refraction coefficients for the surface selected under screen boundary condition are calculated and filled in the space provided.

CHAPTER FOUR

RESULT AND DISCUSSION

Under this section performance characteristics of the modified and existing mufflers was discussed observing simulation and experimental results. The software simulation part is implemented here to study the performance of both mufflers in terms of transmission loss and backpressure measurements. Since the main concern is to get higher acoustic performance, simulation results of modified model became acceptable when its sound transmission loss is greater than existing muffler transmission loss. Increasing the transmission loss cause the back pressure to increase but the generated back pressure must be in acceptable range of which provided by the engine manufacturer and is must be below 40kpa for engines size less than 50KW [17]. Experimental measurement in terms of sound pressure level is performed at a distance of 1 m from tip of the exhaust pipe for both mufflers performance comparison.

4.1 Transmission loss and backpressure analysis of existing and modified mufflers

4.1.1 Transmission loss simulation result and discussion of existing muffler

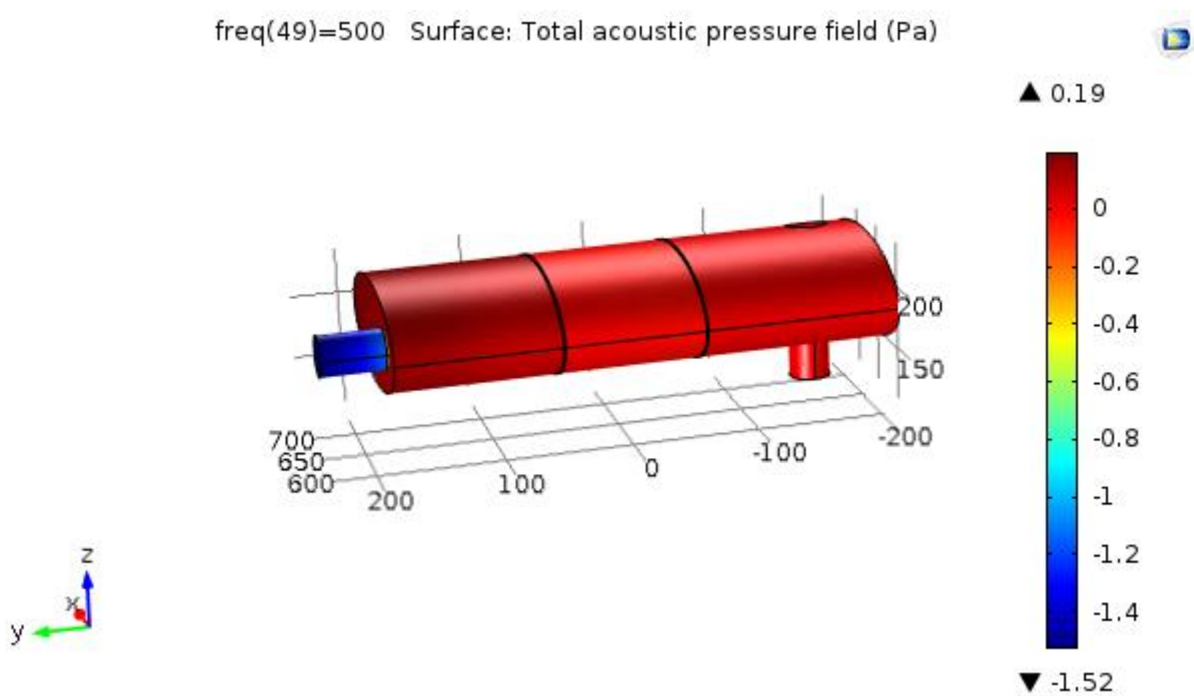


Figure 4.1 Total acoustic pressure distribution on the walls of the muffler.

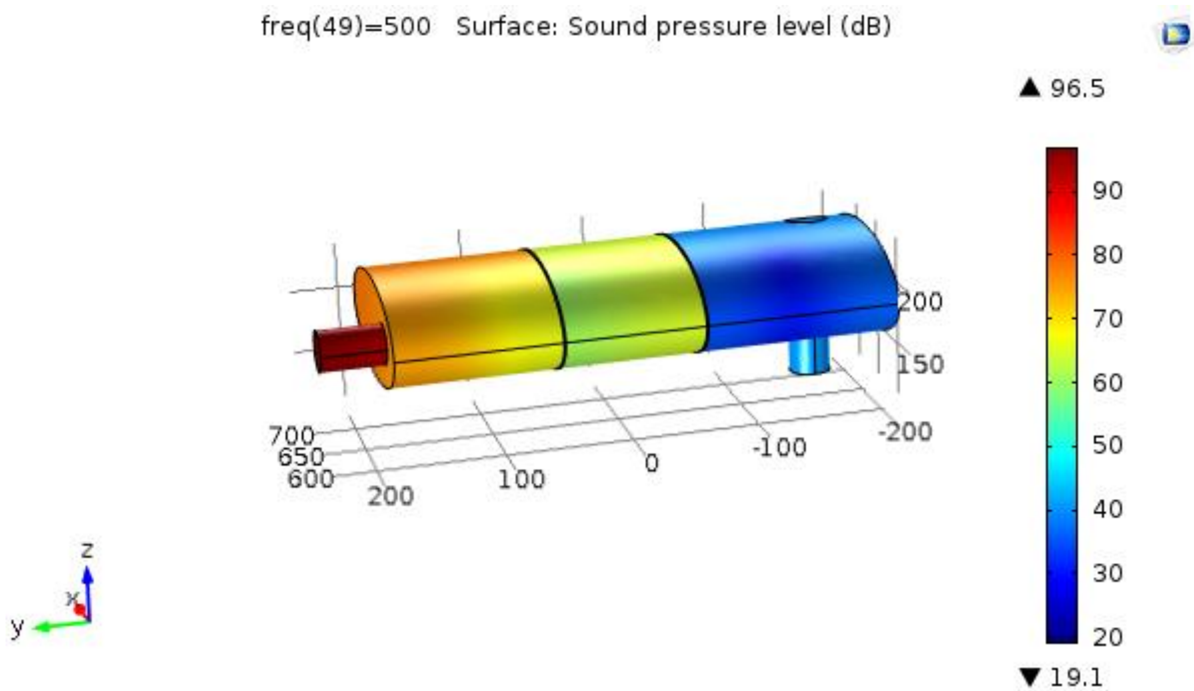


Figure 4.2 Sound pressure level distribution across the muffler.

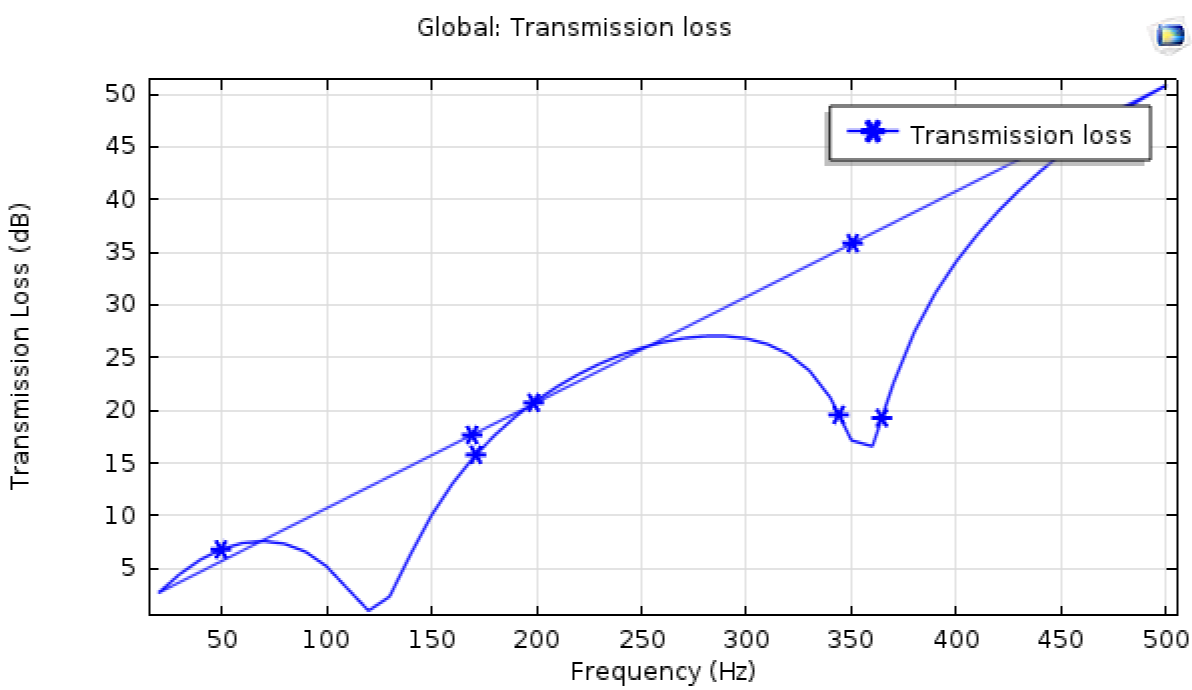


Figure 4.3 Sound transmission loss vs frequency of existing model.

The total acoustic pressure distribution (Fig. 4.1), shows the acoustic pressure field(Pa) across the muffler at a frequency of 500 Hz. The acoustic pressure at the inlet side is about -1.52 Pa and the higher acoustic pressure value recorded across the muffler was about 0.19 Pa. when the difference of acoustic pressure field values between inlet and out let is small better is the attenuation. The variation describes the attenuation performance of the muffler.

Sound pressure level (dB) distribution across the muffler (Fig. 4.2) was plotted for frequency of 500 Hz. At the inlet sound pressure level is higher and is 96.5 dB while at the outlet is about 19.1dB. This variation shows sound pressure level reduction across the muffler when passing from inlet of muffler up to outlet tip. From the figure it is clear that sound wave shows reduction when we compare first and second chamber, second and third chamber.

The transmission loss of a muffler for a frequency range of 20-500 Hz was plotted (Fig. 4.3), the transmission loss gates reduced value of 0.99 and 16.579 at frequencies 120 Hz and 360 Hz.

4.1.2 Transmission loss simulation result and discussion of modified muffler

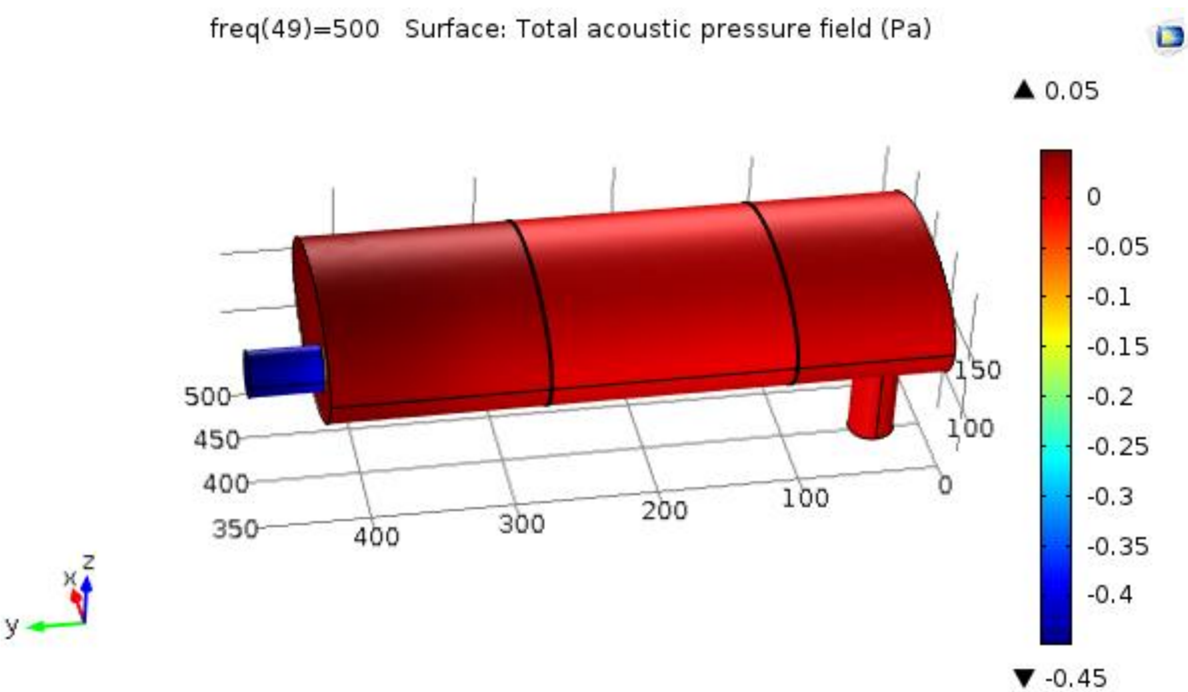


Figure 4.4 Total acoustic pressure distribution on the walls of the muffler.

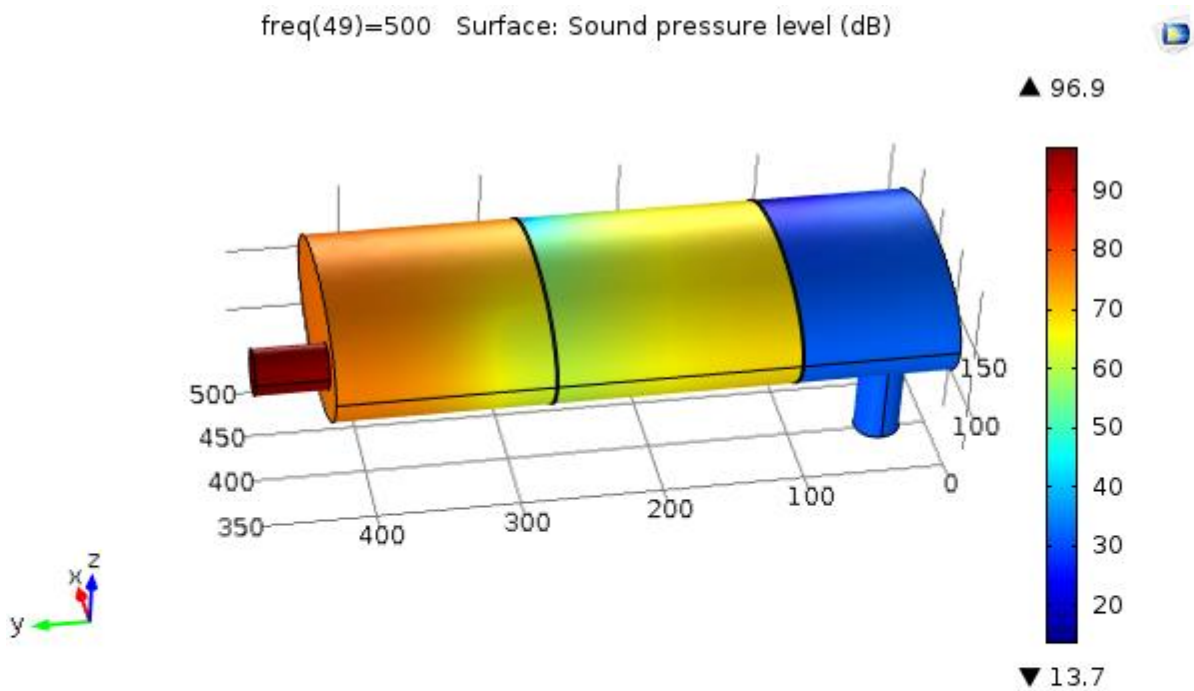


Figure 4.5 sound pressure level distribution across the muffler.

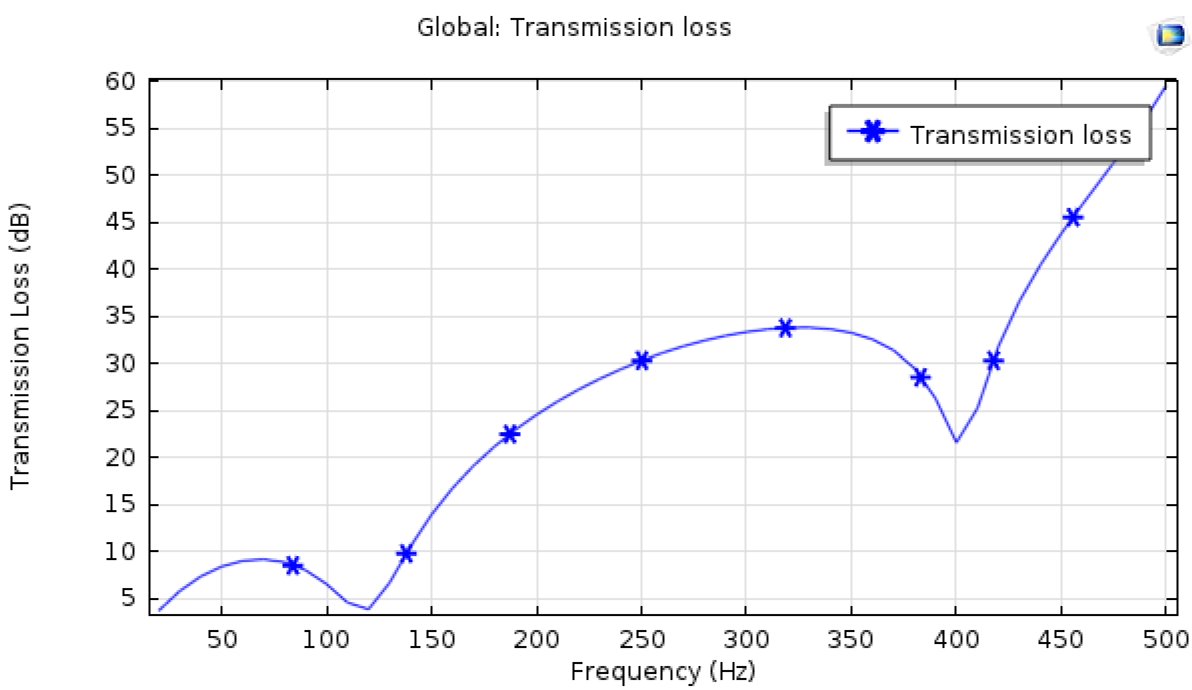


Figure 4.6 Sound transmission loss vs frequency for modified model.

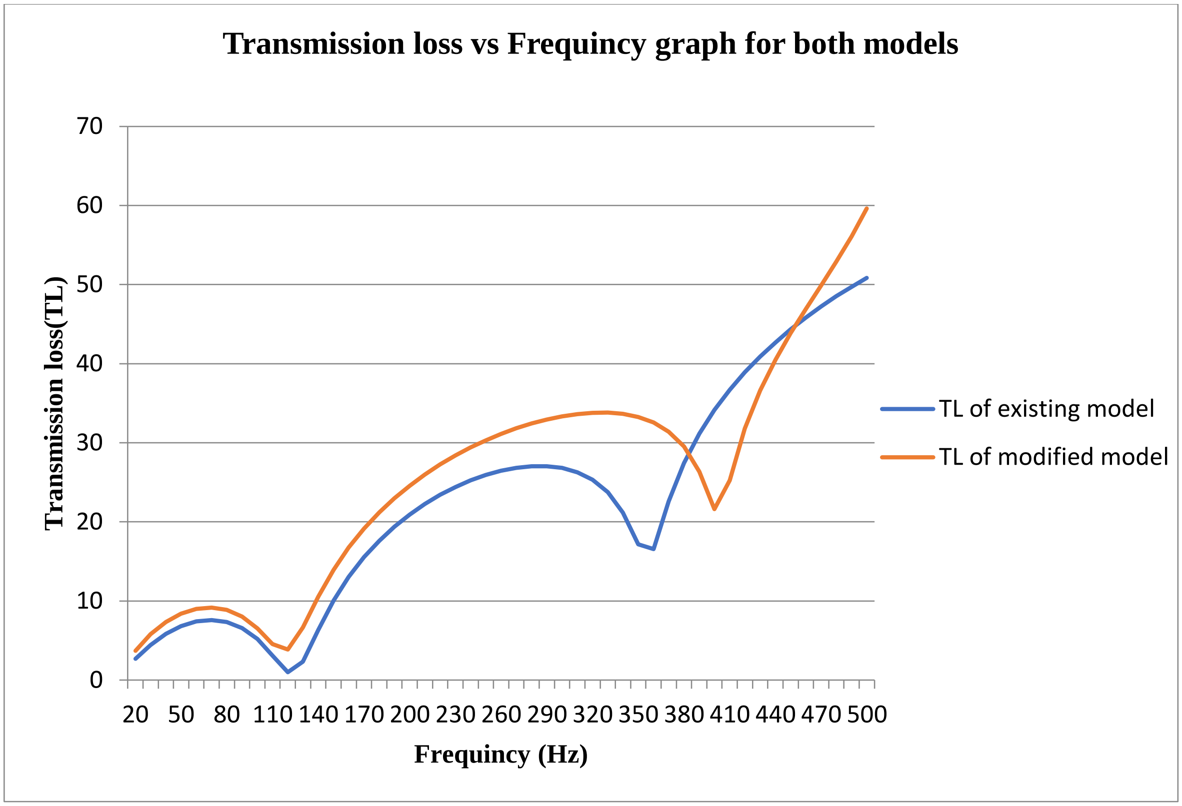


Figure 4.7 Transmission loss comparison between the existing and modified model.

The total acoustic pressure distribution (Fig. 4.4), shows the acoustic pressure field(Pa) across the muffler at a frequency of 500 Hz. The acoustic pressure at the inlet side is about -0.45 Pa and the higher acoustic pressure value recorded across the muffler was about 0.05 Pa. The difference in acoustic pressure field values at the inlet and exit of this modified muffler is smaller than the existing model (Fig. 4.1), thus the attenuation performance of the modified muffler is better.

Sound pressure level (dB) distribution across the muffler (Fig. 4.5) was plotted for frequency of 500 Hz. At the inlet sound pressure level is higher and is 96.9 dB while at the outlet is about 13.7dB. This variation shows sound pressure level reduction across the muffler when passing from inlet of muffler up to outlet tip. From the figure it is clear that sound wave shows reduction across successive chambers. Sound pressure level of modified model (Fig. 4.5) gives good result of attenuation when compared with the existing model (Fig. 4.2).

The transmission loss of a muffler for a frequency range of 20-500 Hz was plotted (Fig. 4.6). From the graph, the transmission loss gates reduced value of 3.86 and 21.62 at frequencies of 120 Hz and 400 Hz respectively. When compared with existing model, transmission loss is improved in the modified one. Only in the range of 390-450 Hz the existing model shows good result.

The graph (Fig. 4.7) shows the comparison of transmission loss of existing and modified models. Taking the derived values of transmission losses results with their respective frequencies from COMSOL simulation and importing in Microsoft office excel gives the above graph. From the graph it is clear that the modified model gives higher transmission loss for wider range of frequencies.

4.1.3 Backpressure simulation result and discussion of existing model

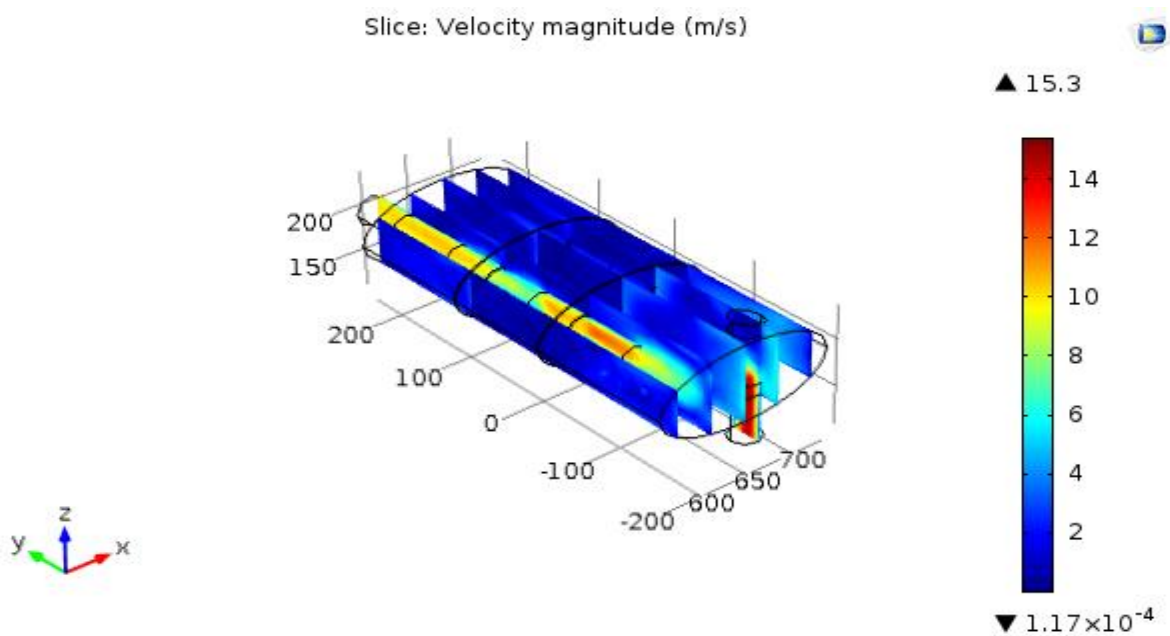


Figure 4.8 Velocity profile of existing model.

The above figure (Fig. 4.8) shows the velocity profile in the existing muffler. In the inlet pipe and outlet pipe the velocity is high but lower in other sections.

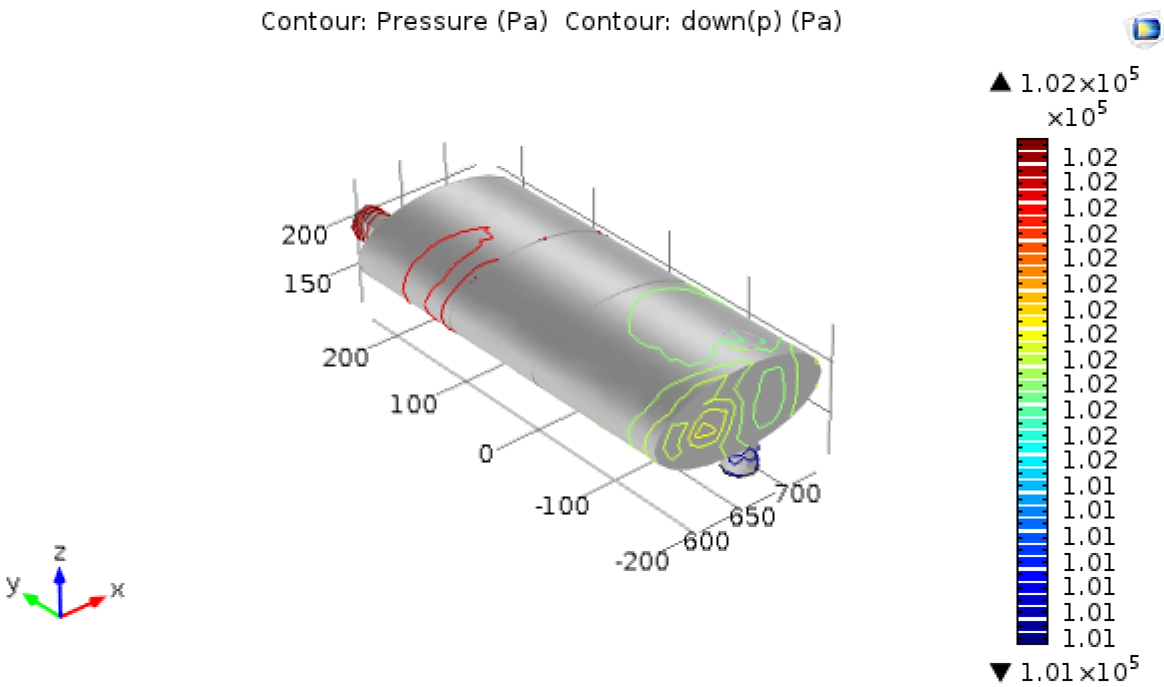


Figure 4.9 Pressure distribution of existing model.

The above figure shows pressure distribution in the existing muffler. The pressure at the inlet is greater than pressure at the outlet, this pressure difference enables the flow of fluid from inlet to the outlet. As described previously simulation is done with assumptions of inlet exhaust gas velocity of 10m/s and outlet pressure of 101320 Pa (atmospheric pressure). Selecting the inlet surface (Fig. 4.9) and the average pressure distribution is 1.0187E5 Pa similarly the average pressure distribution at the outlet became 1.0133E5 Pa.

The pressure drop can be calculated by subtracting the average outlet pressure from the average inlet pressure [8].

$$\Delta p = p_{in} - p_{out}$$

$$\Delta p = 1.0187\text{E5 Pa} - 1.0133\text{E5 Pa}$$

$$\Delta p = 0.0054\text{E5 Pa}$$

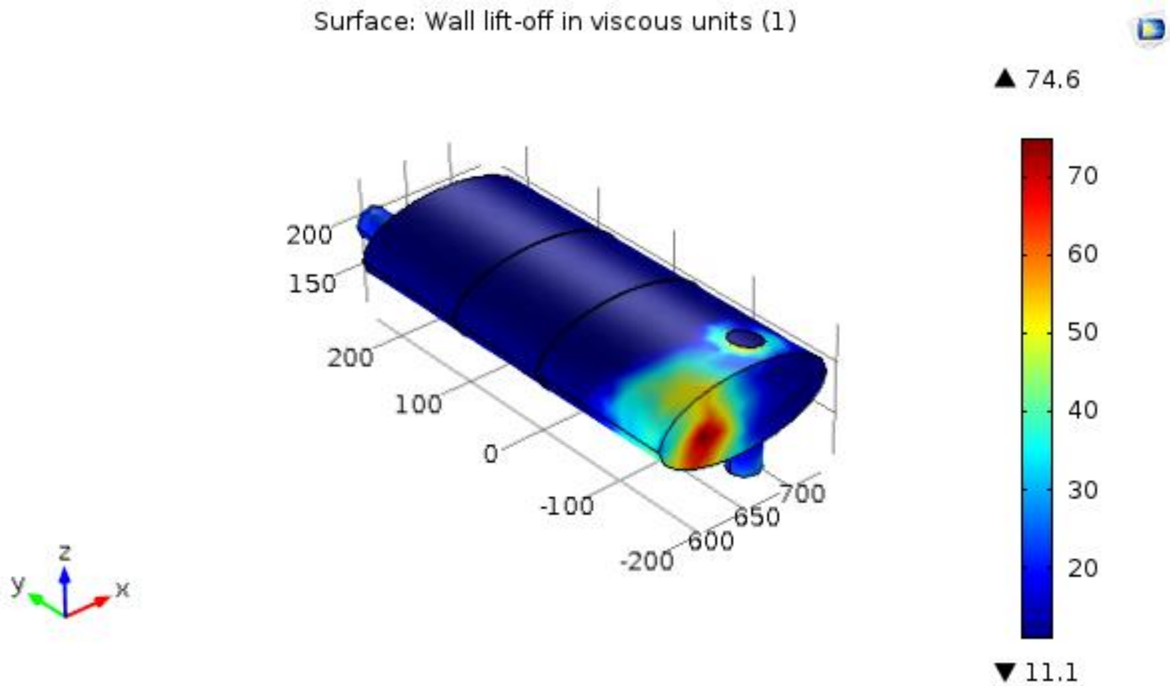


Figure 4.10 Existing muffler wall Resolution in viscous units.

4.1.4 Backpressure simulation result and discussion of modified model

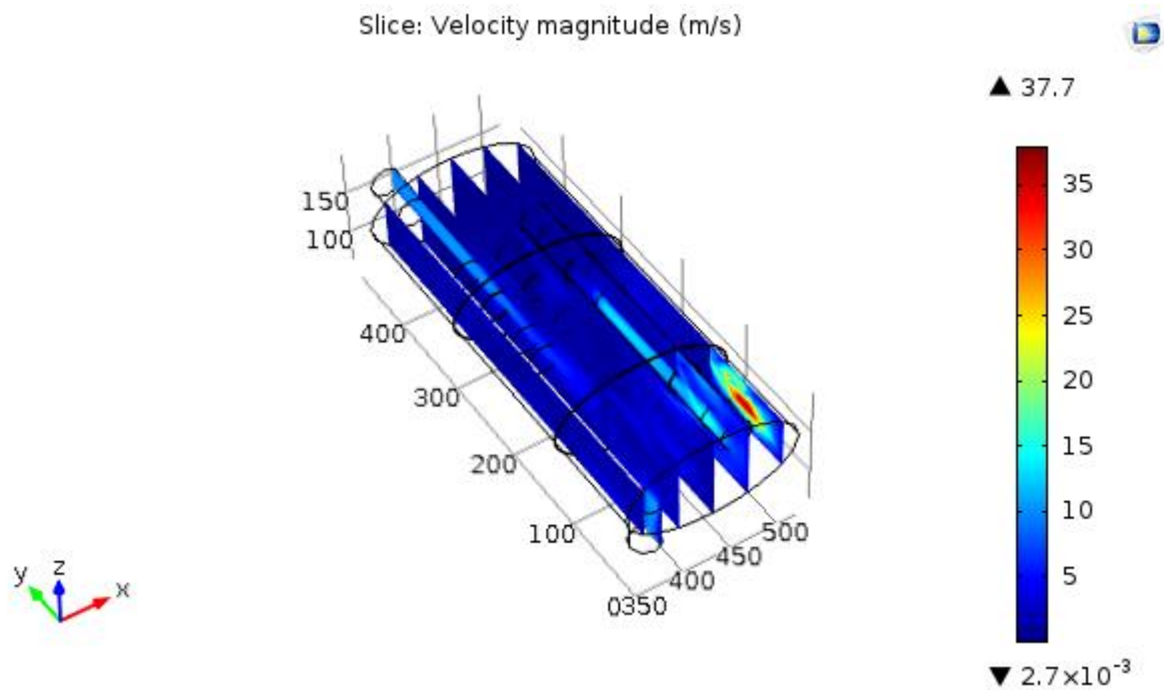


Figure 4.11 Velocity profile of modified model.

From the above figure it is shown that, the velocity profile in the inlet pipe extension is slower. The higher velocity is observed in third chamber at the tip of a pipe which extends from first chamber to third chamber. A gas flowing through perforated pipe in the third chamber has got higher velocity as well.

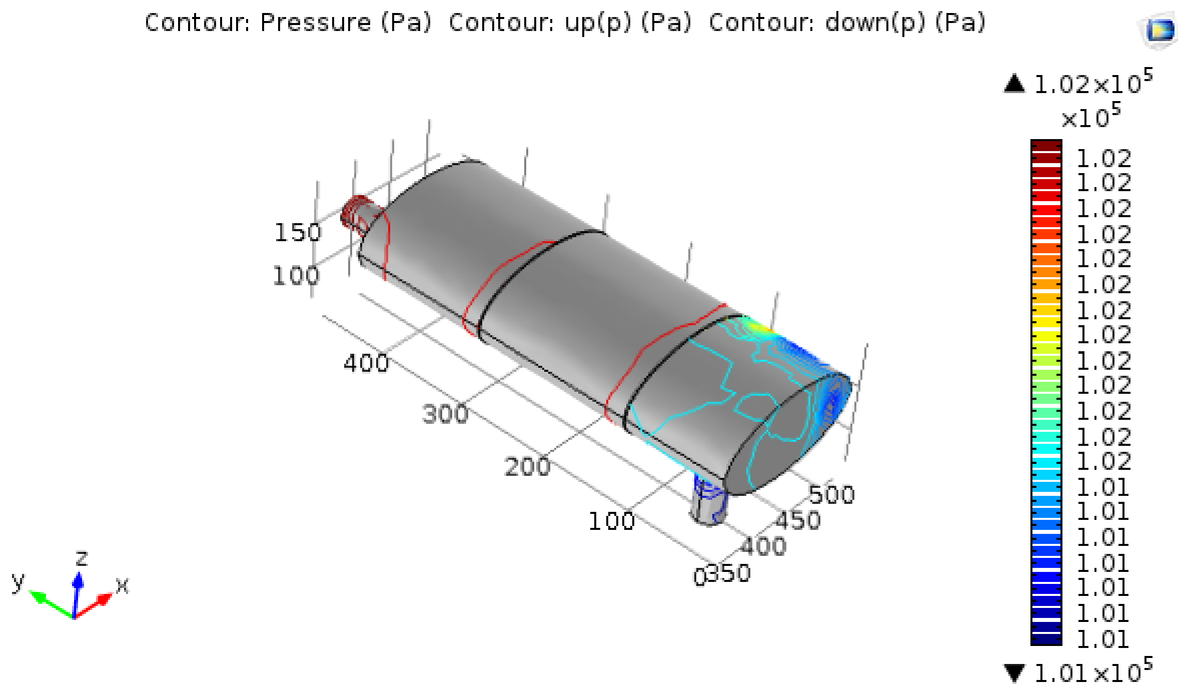


Figure 4.12 Pressure distribution of modified model.

In the modified model (Fig.4.12) also the pressure at the inlet is greater than at the outlet this shows the possibility of gas flow. Similar to the existing model here for modified model the pressure drop is calculated for average inlet pressure of 1.0191E5 Pa and average outlet pressure of 1.0133E5 Pa.

$$\Delta p = p_{in} - p_{out}$$

$$\Delta p = 1.0191\text{E5 Pa} - 1.0133\text{E5 Pa}$$

$$\Delta p = 0.0058\text{E5 Pa}$$

From the result it is observed that the pressure drop for the modified muffler shows increase when compared with the existing model.

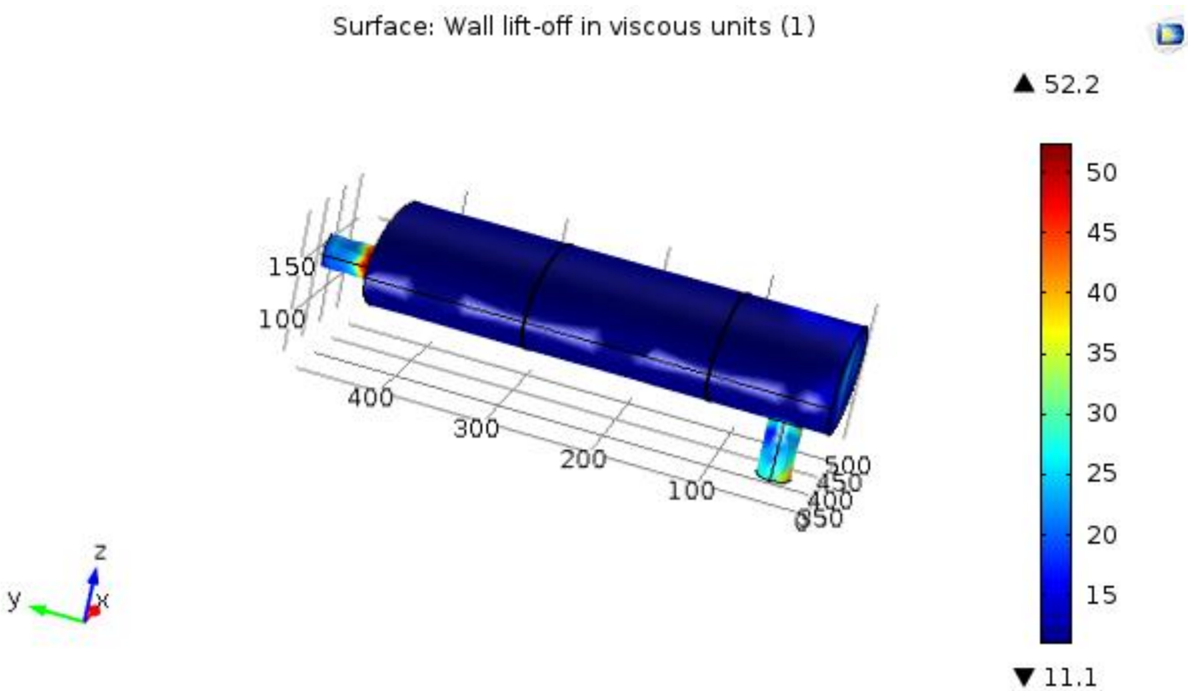


Figure 4.13 Modified muffler wall Resolution in viscous units.

4.2 Experimental results and discussion of existing and modified mufflers

Due to absence of engine provided for experimental purpose, measurement is done by installing the muffler on the actual Minidor, Force three-wheeler. Measurement is carried out with the help of iNVH application which is a mobile based measurement tool of Robert Bosch Engineering and Business Solutions Pvt Ltd. The measurement is made at a distance of 1m away from muffler exhaust pipe tip. This distance was indicated as standard position for measurement on the software introductory part. The iNVH application can be installed in our mobile and used for such measurement purpose. The result may vary from one mobile phone to another due to the variation of sensitivity of the phone sensor as described on the application. The measured result is used only to compare sound pressure level performance of existing and modified mufflers. All the measurements were done with single mobile phone for good result and reduced error.

First sound pressure level of existing muffler is measured at a position 1 m away from the tip of the exhaust pipe using sound pressure meter. The modified muffler prototype is manufactured and installed on the vehicle. At similar position to the existing muffler sound pressure level is measured. The measurement is done at two conditions, when the vehicle is at idling condition and at full throttle position. The results of measurement are shown below.

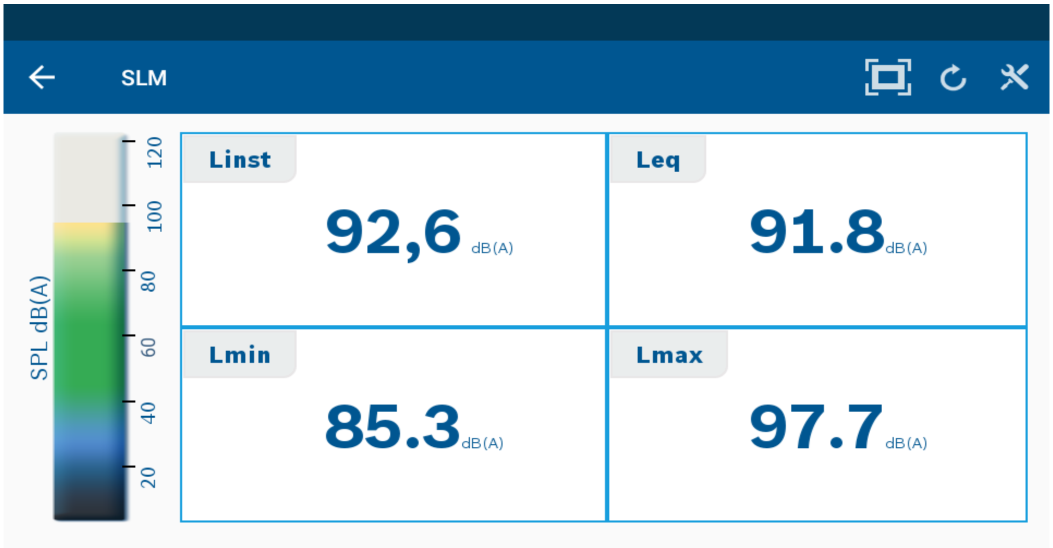


Figure 4.14 Sound pressure level of existing muffler at idling condition.

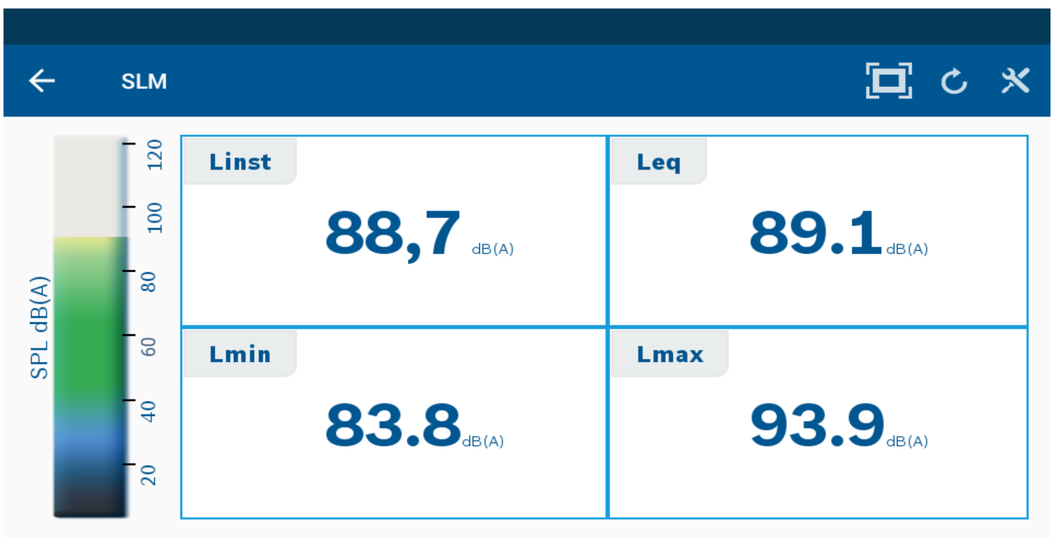


Figure 4.15 Sound pressure level of modified muffler at idling condition.

From the above experimental results comparison is performed between the mufflers. The existing model has equivalent sound pressure level of 91.8 dB at an idling condition (Fig.4.14), the modified model has scored 89.1dB (Fig.4.15). From this we can see that the modified muffler has 2 dB of sound pressure level reduction when compared with the existing model at idling condition. Also comparing the maximum sound pressure level of these mufflers, the modified model shows reduction of sound by about 3.8dB.

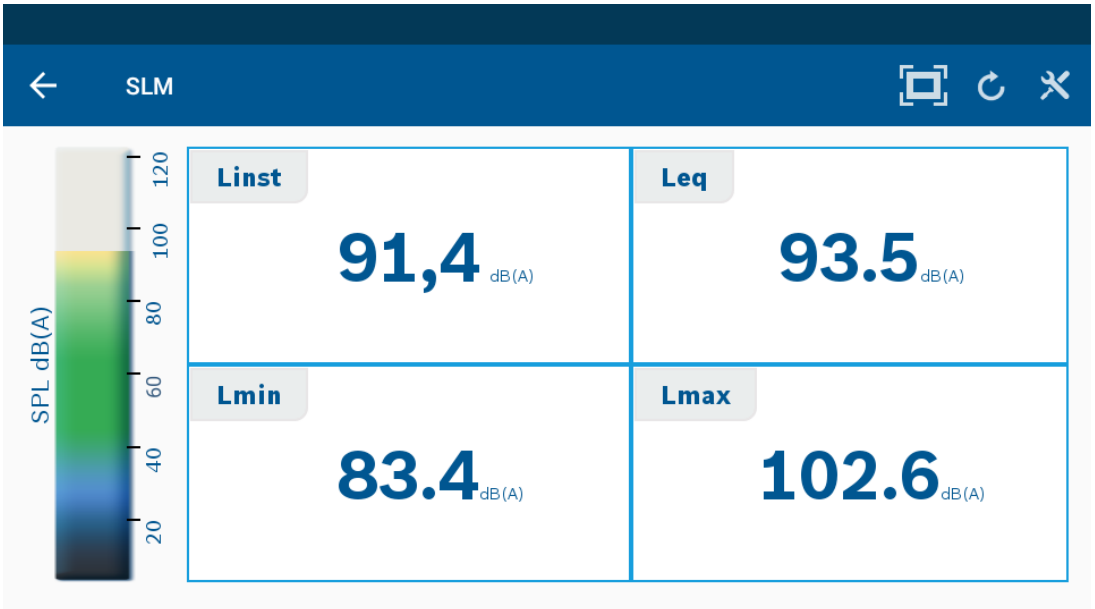


Figure 4.16 Sound pressure level of existing muffler at full throttle position.

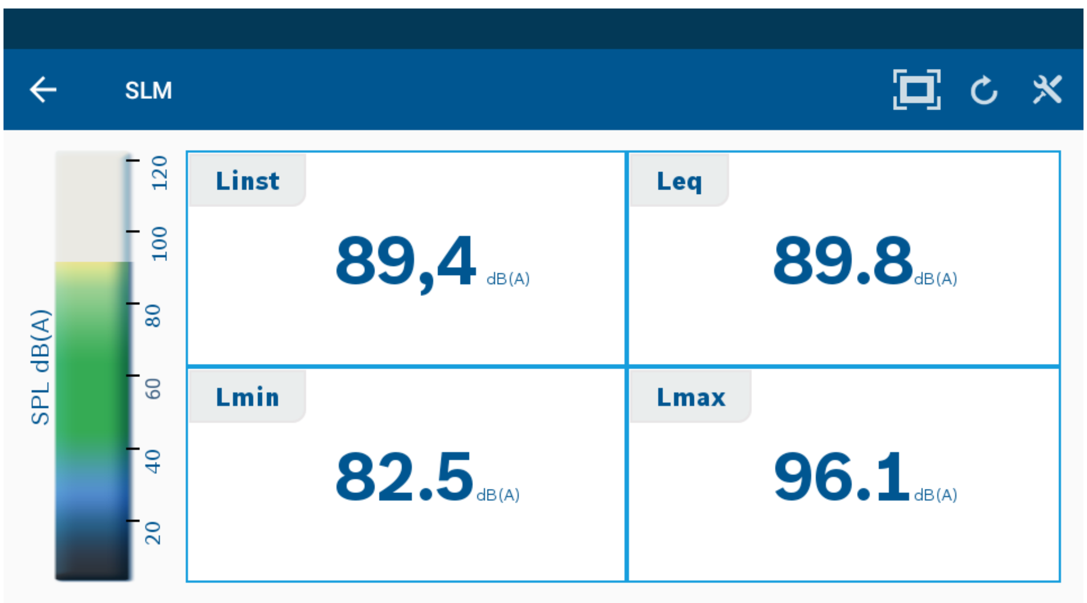


Figure 4.17 Sound pressure levels of modified muffler at full throttle position.

At full throttle position the existing muffler has equivalent sound pressure level of 93.5 dB (Fig.4.16), while the modified model has 89.8 dB (Fig.4.17). Here the modified model shows reduction in sound pressure level by almost 3.7 dB than the existing model. Similarly comparing the maximum sound pressure level, of modified model shows reduction of 6.5dB. Thus good performance is observed for modified model in terms of sound attenuation.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Summary

Muffler modification of Minidor, Force three-wheeler for improvement of sound attenuation has been done in this research. The influence of geometry on sound attenuation technique for designing the low frequency reactive muffler has been discussed in depth. A review of the various available muffling technologies and a theoretical understanding of the concepts associated with the modelling and design of the reactive muffler have been carried out to analyze and validate the designs and their performance. The solid modeling of exhaust muffler is created by Auto CAD 2007 and simulation of sound transmission loss and backpressure is done with the help of COMSOL Multiphysics 5.0. From various methods available to calculate transmission loss of a muffler, the numerical method is most effective and the modern technique.

5.2 Conclusion

Both existing and modified mufflers are three chambered and elliptical in shape. Performance characteristics for these system was obtained in terms of total acoustic pressure, sound pressure level, back pressure and the sound transmission loss and comparative analyses have been carried out for both existing and modified one.

- The modification is based on optimization of product development time & cost by balancing conflicting requirements like noise & back pressure.
- Techniques has been studied for evaluation of acoustic as well as flow performance of a muffler.
- The modification focused on modern CAE tools for optimization of overall system design to choose the best concept.
- Experimental test is applied to estimate the quality of muffler and to compare performance of existing and modified model.

These characteristic plots have been generated against the TL values and trough frequencies in the range of 20-500Hz. To further this understanding, a study has been carried out to realize the impact of change on internal rigid structures such as the pipe arrangement and chamber size. Longer the chamber length, incorporating better in sound transmission loss, also the reflection of exhaust gas back to the source is reduced so that the back pressure against the engine is reduced. From the comparison of transmission loss of existing and modified model, it was observed that the modified model has increased the TL by 3.21dB. From the experimental result it is observed that the old model gives 3.7 dB of more sound pressure level than the modified model at full throttle position and 2 dB of more sound pressure level at idling.

Little increase in backpressure was occurred but it is in acceptable range. The back pressure of the modified muffler increased by 0.0003E5 Pa when compared with backpressure of existing model. This happens due to change in flow path of the modified model. This model has characteristics of flow reversal type of muffler when first and second chamber are considered. The exhaust gas from second chamber returns back in the first chamber then from this chamber transported to the third chamber through the pipe that connects the first and third chamber. Finally, from third chamber the gas exhausted to the environment through exhaust pipe which is welded in the direction of minor diameter elliptical section. It has been concluded that the change in internal pipe arrangement together with little increase in size of muffling body with acceptable back pressure demonstrates better noise attenuation which results increase in sound transmission loss.

5.3 Recommendation

The transmission loss of mufflers is determined using COMSOL Multiphysics. Sound pressure level for each of the mufflers is calculated with COMSOL and also experimentally, the result variation is due to the assumed initial sound pressure, used experimental set up, problem of accuracy during prototype production and materials from which mufflers are constructed. The fluctuating sound pressure component ($p0=1Pa$) is an assumed value, if it is changed the sound pressure level also will change. The software results are analyzed at frequency range of 20-500 Hz. The experimental results are measured by installing the mufflers on actual Minidor three-wheeler vehicle when the engine is in idling and at full throttle position due to absence of provided experimental set up and lab working at required sound frequency. Thus it makes difficult to get similar result with frequency dependent simulated results. Due to absence of some machines, some parts of the muffler were produced by manual techniques that reduced the performance of the muffler because of changes in dimension of geometry.

The type of materials used for muffler production also plays great role in sound attenuation. Even though here the materials are not considered, the experimental result can be affected when muffler of various materials are tested. It is better if the experimental measurement is carried out for mufflers made of similar material since software result does not depend on various material properties. Here different materials are used, the experimental results are used only for comparison of the existing and modified models.

5.4 Future scope of the research

Noise attenuation is one of the interesting research area for the sake of having silenced environment and to solve human beings mental stress due to sound pollution. This research work focusses on reactive type of muffler to improve its performance by changing chambers volume and direction of exhaust gas flow. Only modification of existing reactive muffler geometry will not give desired result (greater attenuation). Using sound absorbing materials such as fibers together with the reactive component will give better attenuation and is effective for wider range of frequencies than simple reactive component, thus in the future the modification will be widen to combination type of muffler. Also studying sound propagation along the intake manifold and evaluating air cleaner sound damping performance will be the future work. Sound attenuation is implemented in wider application areas such as for generators, automobiles, in different industrial areas etc. In this work sound propagating in fluid medium is focused, but also it is possible to attenuate the noise generated due to impact of mechanical parts in the industries and it became interesting research area for the future.

REFERENCES

[1]. A., M. F. Sankar, S., Mathew, C., V, S. K. (2018) ‘‘Design and Development for Exhaust Back Pressure Reduction with Noise Control for Motorcycles’’, International Journal of Innovative Research in Science, Engineering and Technology.

[2]. Basargi¹, S. A., & Joshi, G. (2016). Design and Development of Automobile Silencer for Effective Vibration and Noise Control. Order, 1(2), 3.

[3]. Chaudhari, K. C., Patil, R. Y., Suryawanshi,N. R., Chaudhari, S.J. (2016). Investigation of Geometrical Parameter on Performance of Muffler Using CFD Analysis. International Research Journal of Engineering and Technology.

[4]. Doijode, A. G., & Gadre, O. S. (2015). Transmission losses in reactive muffler analysis by boundary element method, numerical method & experimental method.

[5]. Guhan, C. O. A., Arthanareeswaran, G., K. N., & Krishnan, S. (2018). Exhaust System Muffler Volume Optimization of Light Commercial. Materials Today: Proceedings,5(2), 8471-8479.

[6]. Habib, M. A., Anwar, A. S., & Patwari, M. A. U. (2016). An innovative concept to improve the muffler performance using automated mechanical IRIS. Journal of Engineering and Applied Sciences, 11(2), 1035-1039.

[7]. Jha, S. K., & Sharma, A. (2013). Optimal automobile muffler vibration and noise analysis. International Journal of Automotive and Mechanical Engineering, 7, 864.

[8]. Kakadiya, Y. K., Patel, B. S., & Hadiya, J. P. (2017). Design and Comparison of Mufflers Having Different Arrangements for Diesel Engine.

[9]. Kamarkhani, S., Karimyan, A., Kheybari, M., & Khanali, J. (2017). Muffler Design with Baffle Effect and Perforations on Transmission Loss. The Journal of Engine Research, 47(47), 47-52.

[10]. Mane, S. S., Bhosale, S.Y., Deshpande, H.N. (2016). CFD analysis of back pressure of reactive muffler. International Journal of Innovations in Engineering Research and Technology.

[11]. Munjal, M. L., Behera, B. K., and Thawani, P. T. (1998). Transfer Matrix Model for the Reverse-flow, Three-duct, Open End Perforated Element Muffler. Applied Acoustics.

[12]. Nazirkar, R. D., Meshram, S.R., Namdas, A. D., Navagire, S. U., Devarshi, S. S. (2014) Design & optimization of exhaust muffler & Design validation. International Journal of Mechanical and Production Engineering.

[13]. Pal, S. (2015). Design and acoustic analysis of hybrid muffler. International Journal for Ignited Minds.

[14]. Pal, S., Golan, T. S., Kumar, V., Jain, V., Ramdas, N., & Sharma, O. P. (2014). Design of a muffler & effect of resonator length for 3-cylinder SI engine. IOSR J. Mech. Civil Eng, 11(3), 85-91.

[15]. Pangavhane, S. D., Ubale, A. B., Tandon, V. A., & Pangavhane, D. R. (2013). Experimental and CFD analysis of a perforated inner pipe muffler for the prediction of backpressure. International Journal of Engineering & Technology, 5(5), 115-119.

[16]. Parlar, Z., Ari, Ş., Yilmaz, R., Özdemir, E., & Kahraman, A. (2013). Acoustic and flow field analysis of a perforated muffler design. International Journal of Mechanical and Mechatronics Engineering, 7(3), 447-451.

[17]. Patil, N., Chaudhary, S. (2018). CFD analysis of exhaust backpressure for four-stroke ci engine.

[18]. Prasad, A., and Thiagarajan, R. C., (2016). Acoustic performance of automotive muffler.

[19]. Pratap, A., Kalita, U., & Kumar, S. (2015). Effect of perforated tube on transmission loss of muffler-a review. International Journal of Engineering Research and General Science, 3(3).

[20]. Priyadarsini, C.I., Modali, M., Krishna, S. V., Reddy, N. D. (2016). Design and analysis of muffler to reduce the back pressure. International Journal of Scientific Research Engineering & Technology.

[21]. Ramu, S., Srinivasan, R., Somasundaram, S., & Achamyeleh, T. (2017). Design of exhaust silencer muffler for transmission losses with the performance of a four stroke diesel engine with and without muffler section. Technology, 8(1), 139-145.

[22]. Ranjbar, M., & Kemani, M. (2016). A comparative study on design optimization of mufflers by genetic algorithm and random search method. Journal of Robotic and Mechatronic Systems, 1(2), 7-12.

[23]. Rao, P. C., Varma, B. M., Rao, L.V.V.G. (2016). Muffler Design, Development and Validation Methods. International Journal of Innovative Research in Science, Engineering and Technology.

[24]. Reddy, G.G., and Prakash, N. (2016). Design and fabrication of reactive muffler.

[25]. Roy, M. M., Joardder, M. U. H., and Uddin, S. (2010). Effect of Engine Backpressure on the Performance and Emissions of a CI Engine, The 7th Jordanian International Mechanical Engineering Conference (JIMEC'7) 27 - 29.

[26]. Saripalli, P., & Sankaranarayana, K. (2015). CFD Analysis on Flow Through a Resistance Muffler of LCV Diesel Engine. International Journal of Science, Technology and Society, 3(4), 132-145.

[27]. Sherekar, V., & Dhamangaonkar, P. R. (2014). Design principles for an automotive muffler. International Journal of Applied Engineering Research, 9(4), 483-489.

[28]. Shinde, A. R., Patil, J. B., Chougule, N. K., & Gawande, S. H. (2017). Design and Analysis of Performance Oriented Road Legal Muffler.

[29]. Singh, A., Shrivastava, N., (2015). Study of noise behavior on mufflers for IC engine: a review.

[30]. Thorat, S. G., Kothavale, B. S., Hatwalane, S. S., & Bhaskar, D. (2016). Review paper on Design and Development of Muffler to Optimize Transmission Losses. International Journal of Current Engineering and Technology, Special Issue-4.

[31]. Vegad, H. V., Naik, B. R. (2017). Noise Attenuation for Muffler Design in Automobile Engineering-A Review. International Journal of Engineering Technology Science and Research.

[32]. Wankhade, A. W., & Bhattu, A. P. (2015). Optimization and experimental validation of elliptical reactive muffler with central inlet central outlet. International journal of engineering research and technology, 4(5), 1321-1328.

[33]. Bhadke, P. B., & Mahajan, K. A. (2017). Effect of Change in Diameter on Muffler Transmission loss using COMSOL. IOSR J. Mech. Civ. Eng., no. March, 2278-1684.

[34]. Bhattacharya, P., Ghosh, B., & Bose, P. K. (2010). Transmission Loss and performance test of a two cylinder four stroke diesel engine. Journal of Engineering Science and Technology, 5(3), 284-292.

[35]. Carley, M. (2001). Some notes on acoustics. University of Bath, UK.

[36]. Chiu, M. C., & Chang, Y. C. (2011). Numerical assessment of two-chamber mufflers with perforated plug/non-plug tubes under space and back pressure constraints using simulated annealing. Journal of Marine Science and Technology, 19(2), 176-188.

[37]. Cui, Z., & Huang, Y. (2012). Boundary element analysis of muffler transmission loss with LS-DYNA'', In 12th international LS-DYNA users Conference.

[38]. Mohiuddin, A., Ideres, M., & Hashim, S. (2005). Experimental study of noise and back pressure for silencer design characteristics. Journal of Applied Sciences(Pakistan), 5(7), 1292-1298.

[39]. Reddy, K. A. (2017). A critical review on acoustic methods & materials of a muffler. Materials Today: Proceedings, 4(8), 7313-7334.

[40]. Rienstra, S. W., & Hirschberg, A. (2004). An introduction to acoustics. Eindhoven University of Technology, 18, 19.

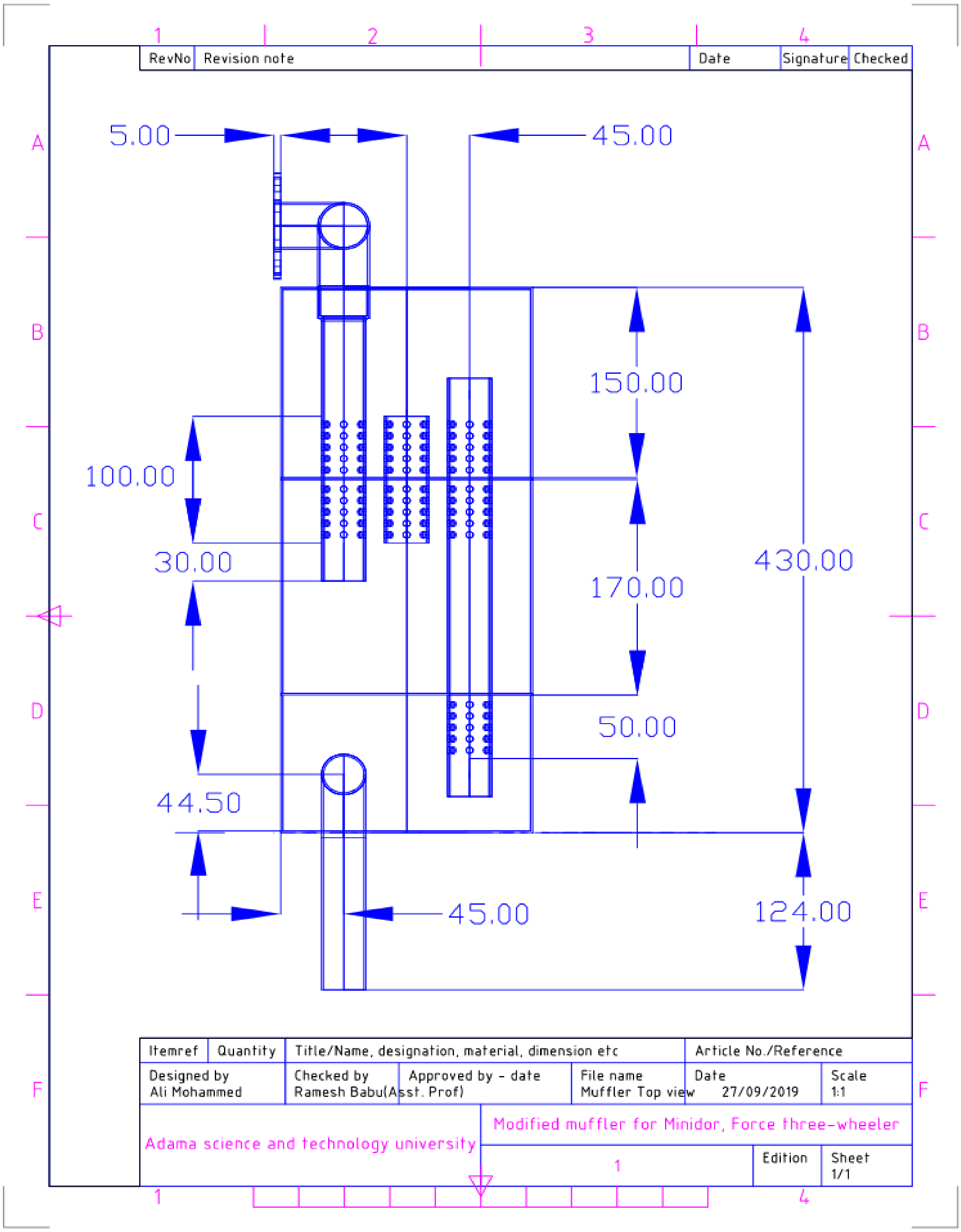
[41]. Sharma, N. L. K. (2017). Modelling of Low Frequency Muffler based on Acoustic Black Hole Effect, Unpublished" MSc. Thesis Submitted to University of Salford.

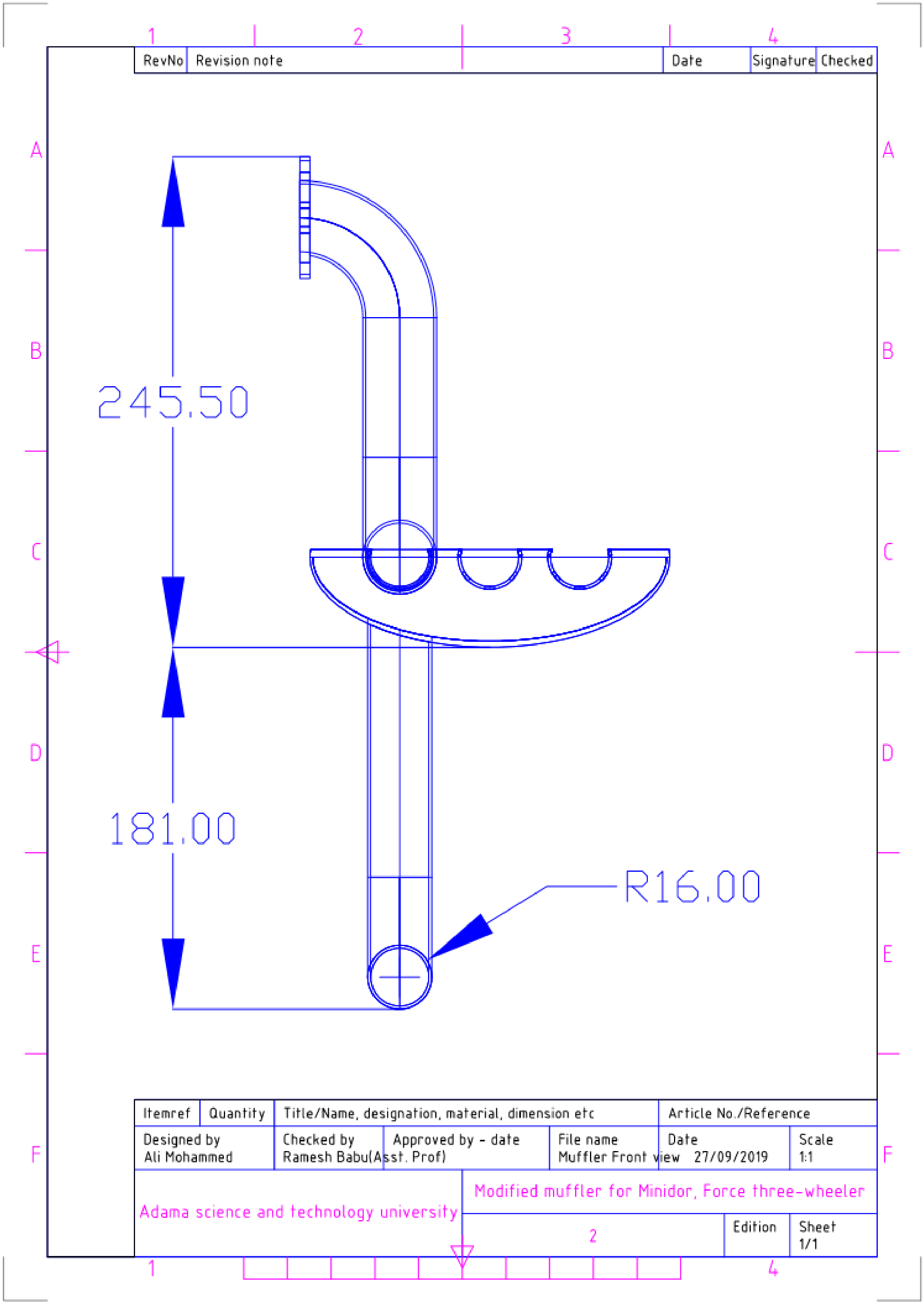
[42]. Vigran, T. E. (2014). Building acoustics. CRC Press.

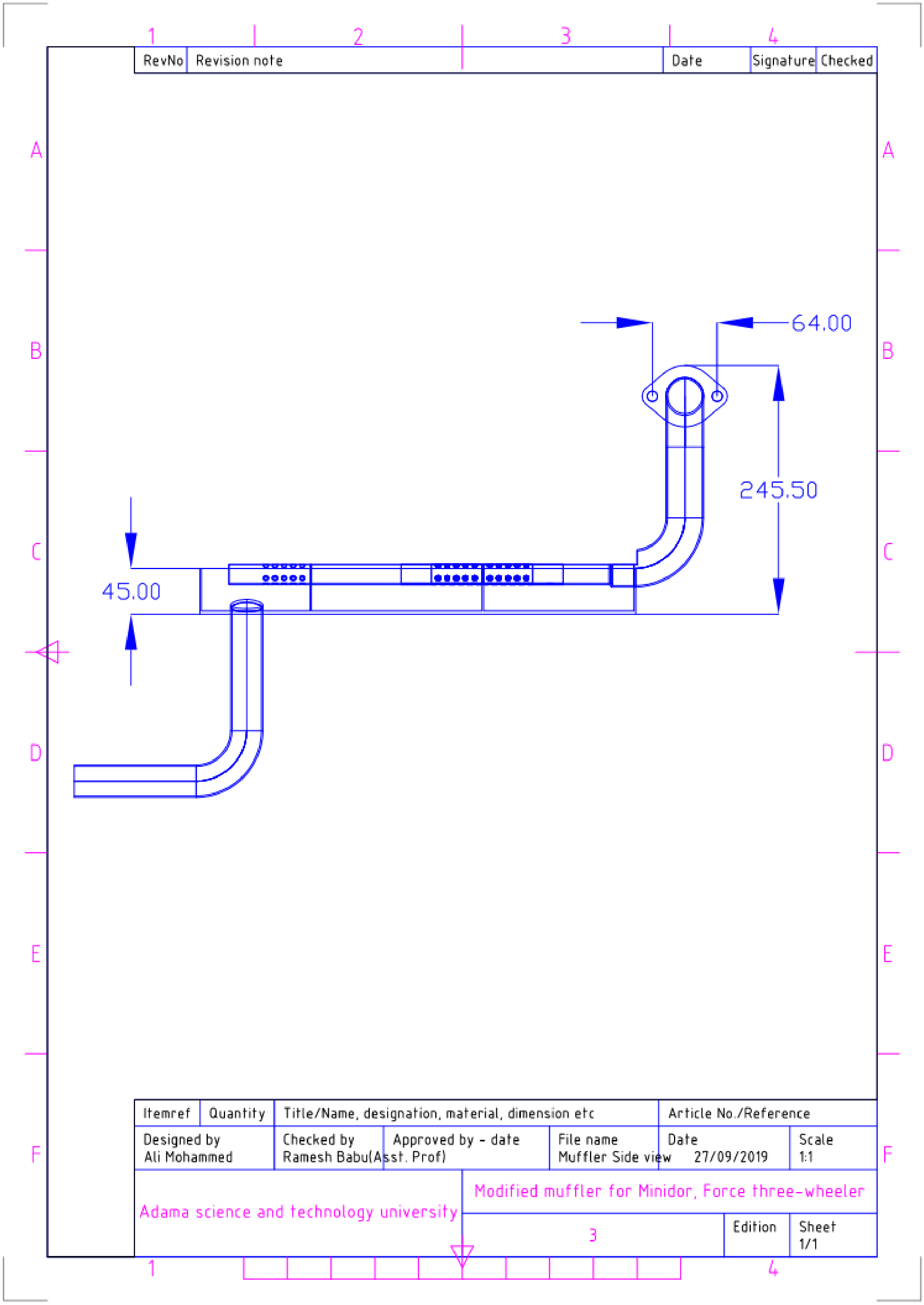
[43]. Zhang, Y., (2016). Acoustic Performance by Determination and Assessment of the Source Characteristics and Impedance Optimization, Unpublished" Submitted to University of Kentucky.

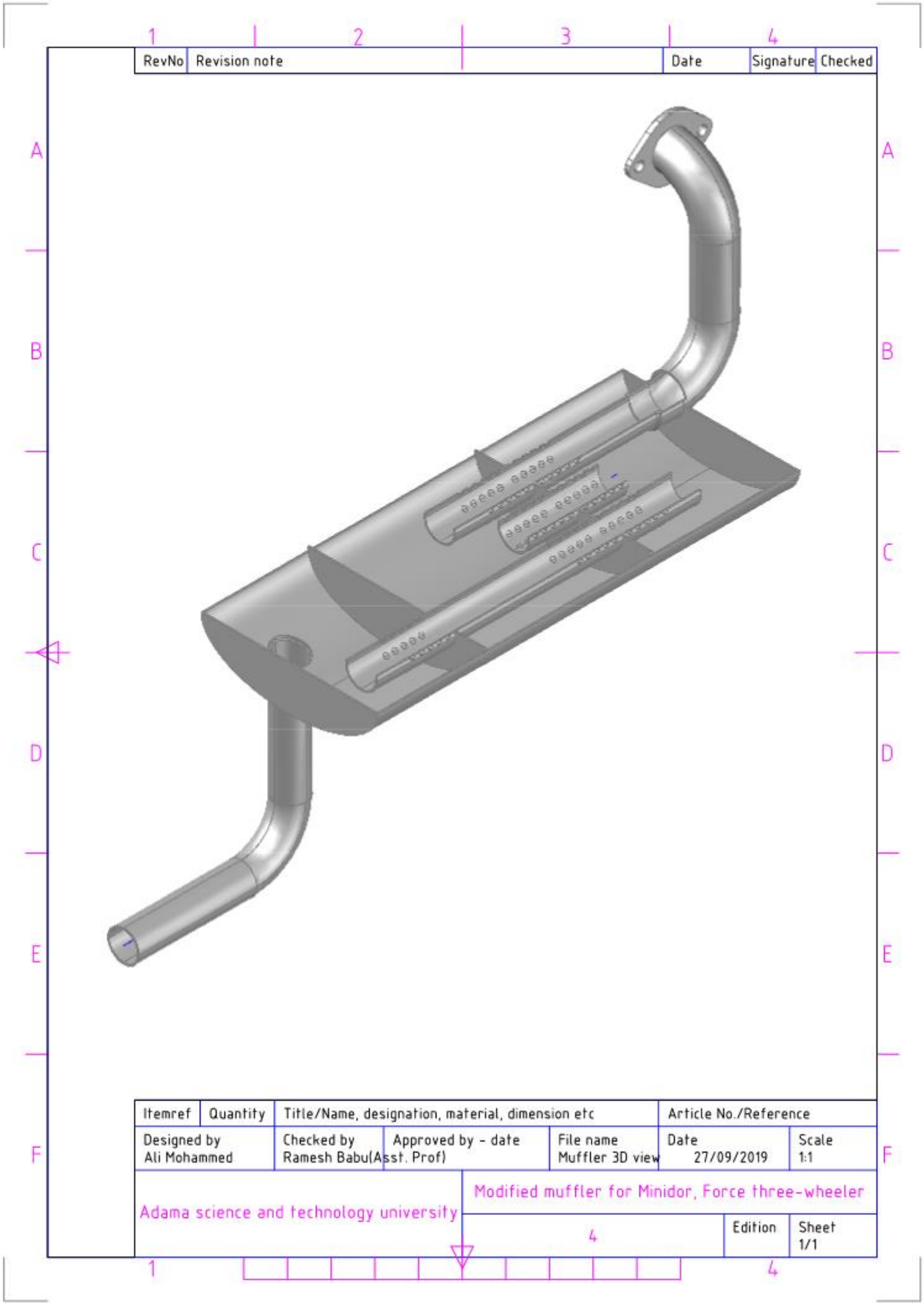
APPENDIX

Sectioned two and three dimensional view of the modified muffler:




RevNo
Revision note
Date
Signature
Checked
245.50
181.00
R16.00
Itemref
Quantity
Title/Name, designation, material, dimension etc
Article No./Reference
Designed by
Ali Mohammed
Checked by
Ramesh Babu(Asst. Prof)
Approved by - date
File name
Muffler Front view
Date
27/09/2019
Scale
1:1
Adama science and technology university
Modified muffler for Minidor, Force three-wheeler
2
Edition
Sheet
1/1


RevNo
Revision note
Date
Signature
Checked
64.00
245.50
45.00
Itemref
Quantity
Title/Name, designation, material, dimension etc
Article No./Reference
Designed by
Ali Mohammed
Checked by
Ramesh Babu(Asst. Prof)
Approved by - date
File name
Muffler Side view
Date
27/09/2019
Scale
1:1
Adama science and technology university
Modified muffler for Minidor, Force three-wheeler
3
Edition
Sheet
1/1



RevNo
Revision note
Date
Signature
Checked
Itemref
Quantity
Title/Name, designation, material, dimension etc
Article No./Reference
Designed by
Ali Mohammed
Checked by
Ramesh Babu(Asst. Prof)
Approved by - date
File name
Muffler 3D view
Date
27/09/2019
Scale
1:1
Adama science and technology university
Modified muffler for Minidor, Force three-wheeler
4
Edition
Sheet
1/1

Sectioned three dimensional view of existing muffler: