INVESTIGATION ON NOISE ATTENUATION PERFORMANCE OF EXHAUST MUFFLERS OF FARM TRACTORS WITH APPROPRIATE DESIGN ALTERATIONS

BY

M. D. VORA

M.Tech. (Agril. Engg.)

(Registration No. 04-2075-2012)

COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

ANAND AGRICULTURAL UNIVERSITY

GODHRA 389001 (GUJARAT) INDIA

2017

INVESTIGATION ON NOISE ATTENUATION PERFORMANCE OF EXHAUST MUFFLERS OF FARM TRACTORS WITH APPROPRIATE DESIGN ALTERATIONS

A THESIS SUBMITTED TO THE
ANAND AGRICULTURAL UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE
OF

DOCTOR OF PHILOSOPHY

(AGRICULTURAL ENGINEERING)
IN
FARM MACHINERY AND POWER ENGINEERING

BY

M. D. VORA
M.Tech. (Agril. Engg.)
(Registration No. 04-2075-2012)

कृण्वन्तो राष्ट्रं कृषि संपन्नम्

COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
ANAND AGRICULTURAL UNIVERSITY
GODHRA 389001 (GUJARAT) INDIA
2017

INVESTIGATION ON NOISE ATTENUATION PERFORMANCE OF EXHAUST MUFFLERS OF FARM TRACTORS WITH APPROPRIATE DESIGN ALTERATIONS

Name of Student
M. D. Vora
Regi. No. 04-2075-2012

Major Advisor
Dr. R. Swarnkar

COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
ANAND AGRICULTURAL UNIVERSITY
GODHRA 389001 (GUJARAT) INDIA

ABSTRACT

Mechanical equipment is the most popular kind of farm power sources being used in current times in the field of agriculture. Majority of the farm operations connected with crop production processes are successfully adapted to mechanization. Tractor has remained at centre as a source of farm power and has played a vital role in agricultural mechanization. All mechanical equipments produce noise and vibrations of different intensities. Excessive vibrations and noises have been considered as damaging factors to both men and machines. Noisy environment has been one of those threats which have emerged out of modern life styles in urban and rural areas both. Tractors dominate rural areas most. While cultivating a field, tractors operate for long hours and generate high level of noises that make an imact on the operators and the neighbourhood. It has now been established that exceeded noise levels cause negative impacts resulting into the mental tiredness and lesser working efficiency. Noise exceeding the certain limits can even cause permanent damage to hearing ability of human beings.

Tractor noise is composed of mainly two kinds of noises (i) noise due to motions of machinery parts & vibrations involved, and (ii) noise that is generated during the repeated explosions taking place into the cylinders during combustion which is delivered out through exhaust that is termed as exhaust noise. Exhaust mufflers play an important role in the mitigation of noise levels arising out of engine operation. Reactive muffler is most commonly used on tractors. Investigating the

effect of altered design of mufflers on the noise levels can be helpful as a strategic attempt to mitigate the ill effects taking place on human health and comfort due to noise generated out of tractor and farm machinery operations. The primary function of a reactive silencer is to reflect sound waves back to the source. Energy is dissipated in the extended flow path resulting from internal reflections. Reactive silencers generally consist of several pipe segments that interconnect with a number of larger chambers. The reflective effect of the silencer chambers and piping (typically referred to as resonators) essentially prevents some sound wave elements from being transmitted past the silencer. The reactive silencers are more effective at lower frequencies than at high frequencies, and are most widely used to attenuate the exhaust noise of internal combustion engines.

The examination of existing noise and vibration levels on farm tractors provided useful data on the intensities of noise and vibrations associated with farm tractor. Vibration levels were observed in velocity (mm/s) and acceleration (m/s^2). Regression analysis of data revealed the extent of the effect of vibration levels in longitudinal (X), lateral (Y) and vertical (Z) directions (as observed upon different tractor surfaces) on the noise levels generated. The linear regression equation and graphs were obtained with vibration component as an explanatory variable on x-axis and respective noise level as dependent variable on y-axis along with corresponding value of coefficient of determination (R^2). The values of R^2 for the linear equation expressing noise level as a function of vibration velocity in X, Y & Z direction were respectively found 0.9333, 0.731 & 0.8597 and 0.9854, 0.9992 & 0.9853 for Tractor-1 (mini tractor) and Tractor-2 respectively. The values of R^2 for the linear equation expressing noise level as a function of vibration acceleration in X, Y & Z direction were respectively found 0.9783, 0.9102 & 0.9999 and 0.8936, 0.7796 & 0.9705 for Tractor-1 (mini tractor) and Tractor-2 respectively.

The detailed noise level measurement was conducted under three selected muffler mountings namely muffler-A, B & C along with standard muffler (muffler-S) on Tractor-1 i.e. mini tractor (muffler-B excluded) & Tractor-2 (muffler-A excluded). The noise levels (SPL in dBA) recorded at operator’s ear level revealed that the mean noise level observed under muffler-C (82.95 dBA) on Tractor-1 (mini tractor) was significantly lower than that recorded under muffler-S (83.09 dBA) but was not significantly different when compared with noise level obtained under muffler-A (83.04). While, on Tractor-2, the noise levels observed under muffler-B (84.52 dBA)

& muffler-C (84.46 dBA) both were significantly lower than that recorded under muffler-S (84.90 dBA). The difference in noise levels generated under muffler-A & C on Tractor-1 (mini tractor) was found significant. But, difference in noise levels among altered design mufflers on Tractor-2 i.e. muffler-B & C was found insignificant. The noise level (SPL) test conducted at 10 m distance from the tractor revealed that on Tractor-1 (15 hp mini tractor), the noise levels observed under muffler-A (67.44 dBA) & muffler-C (67.43 dBA) both were significantly lower than that recorded under muffler-S (68.09 dBA). Similarly, on Tractor-2 (60 hp), the noise levels observed under muffler-B (71.53 dBA) & muffler-C (71.90 dBA) both were significantly lower than that recorded under muffler-S (72.61 dBA). Though, difference in noise levels of altered design mufflers namely muffler-A & muffler-C on Tractor-1 (mini tractor) was not found significant. But, the noise level observed under muffler-B on Tractor-2 was found significantly lower than that observed under muffler-C. At 30 m distance away from Tractor-1 (15 hp mini tractor), mean noise levels measured under muffler-A (60.27 dBA) & muffler-C (59.92 dBA) both were significantly lower than that recorded under muffler-S (60.51 dBA). Similarly on Tractor-2 (60 hp), mean noise levels measured under muffler-B (62.72 dBA) & muffler-C (62.70 dBA) both were significantly lower than that recorded under muffler-S (62.89 dBA). Noise level observed under muffler-C was also significantly lower than that observed under muffler-A on Tractor-1 at 30 m distance away from the tractor. But, the difference between noise levels under muffler-B & muffler-C on Tractor-2 was however insignificant.

On Tractor-1 (mini tractor), the noise attenuation observed under muffler-S, muffler-A & muffler-C in comparison to no muffler mounting were respectively found 3.0, 3.2 & 3.3 % at ear level, 1.9, 2.9 & 2.9 % at 10 m distance and 2.4, 2.7 & 3.4 % at 30 m distance when noise levels were counted in decibels. When noise levels were counted in μPa, the amount of noise attenuation observed under muffler-S, muffler-A & muffler-C in comparison to no muffler mounting were respectively found 25.9, 26.7 & 27.6 % at ear level, 13.9, 20.6 & 20.6 % at 10 m distance and 15.9, 17.8 & 21.5 % at 30 m distance on Tractor-1 (mini tractor). Thus, muffler-C performed well followed by muffler-A & muffler-S in the next positions with average attenuability of 23.2, 21.7 & 18.6 percent (averaged over three distances of observation) respectively.

On Tractor-2, the noise attenuation observed under muffler-S, muffler-A &

muffler-C in comparison to no muffler mounting were respectively found 5.7, 6.1 & 6.1 % at ear level, 3.8, 5.3 & 4.8 % at 10 m distance and 4.6, 4.9 & 4.9 % at 30 m distance when noise levels were counted in decibels. When noise levels were calculated in µPa unit, the amount of noise attenuation observed under muffler-S, muffler-A & muffler-C in comparison to no muffler mounting were respectively found 44.4, 46.9 & 46.9 % at ear level, 28.4, 36.9 & 33.9 % at 10 m distance and 29.2, 30.8 & 30.8 % at 30 m distance on Tractor-1 (mini tractor). Thus, muffler-B performed well followed by muffler-C & muffler-S in the next positions with average attenuability of 38.2, 37.2 & 34 percent (averaged over three distances of observation) respectively.

Peak frequency observations obtained under muffler-C on Tractor-1 were found quite lower than that observed under standard muffler (muffler-S) at two places of measurement viz. at ear level and at 10 m distance. But this was not in similar fashion on Tractor-2 where lower peak frequency occurrences were greater under muffler-S than C. Analysis of amplitude levels of tractor noise frequencies conducted with the help of spectrograms revealed greater presence of lower frequencies in the range 0-2.5 kHz at 1500, 1750 & 2000 RPM at ear level under modified muffler than that observed under standard muffler.

(Keywords: Tractor, Mini Tractor, Noise, Vibration, Noise Attenuation, Exhaust Muffler, Decibel, Micro Pascal)

Department of Farm Machinery and Power Engineering
College of Agricultural Engineering and Technology
Anand Agricultural University
Godhra – 389 001

~~~~~~

Dr. R. Swarnkar — Mobile No.: +91-9825053349
Professor & Head — Email: rswarnkar@aau.in, swarnkarraghunandan@gmail.com

~~~~~~

CERTIFICATE

This is to certify that thesis entitled **"INVESTIGATION ON NOISE ATTENUATION PERFORMANCE OF EXHAUST MUFFLERS OF FARM TRACTORS WITH APPROPRIATE DESIGN ALTERATIONS"** submitted by **Er. MOHAMMADHANIF DAVALBHAI VORA** (Registration No. 04-2075-2012) in partial fulfillment of the requirements of the degree of **DOCTOR OF PHILOSOPHY** (Agricultural Engineering) in the subject of **FARM MACHINERY AND POWER ENGINEERING** of Anand Agricultural University is a record of bonafide research carried out by him under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma or other similar title.

Place : Godhra — **(R. Swarnkar)**
Date : 24.04.2017 — **Major Advisor**

DECLARATION

This is to declare that the whole of research work reported herein is submitted for partial fulfillment of the requirements of the degree of **Doctor of Philosophy (Agricultural Engineering)** in the subject of **Farm Machinery and Power Engineering** by the undersigned is a result of investigation done by me under direct guidance and supervision of **Dr. R. Swarnkar**, Major Advisor, Professor and Head, Department of FMPE, College of Agricultural Engineering & Technology, Anand Agricultural University, Godhra and no part of this work has been submitted for any other degree so far.

Place : Godhra **(M. D. Vora)**
Date : 24.04.2017

Countersigned by

Place : Godhra **(R. Swarnkar)**
Date : 24.04.2017 **Major Advisor**

ACKNOWLEDGEMENT

In the order of acquiring various academic qualifications ranging from undergraduate to postgraduate, doctorate level has been placed at a bit higher level and signifies a considerable value and weightage among the academia and also in the professional world. Therefore, author, being a believer in the رَبِّ ٱلْعَٰلَمِينَ (RABBIL AALAMEEN – LORD OF ALL WORLDS), does not want to miss this opportunity to express his gratitude and indebtedness towards the one and only, almighty God – Allah (in Arabic), who has created everything. Out of all creations, numerous entities are disclosed to humankind till now but still remain innumerable things hidden from us viz. soul of a living being, existence of jinn and angels, life after death etc. However these all are highly significant, scientific investigations has still so far not attended them objectively or meaningfully. In his recent address through video conferencing, **the prime minister of India** mentioned that God is one only. The God of Hindu, Muslim and other believers is not different. Truth is one. Different people present it in different ways **(Source: Gujarat Samachar, Daily News Paper, Vadodara edition, Dated 27th March, 2017, page 11).**

Allah in Arabic implies Al-lah i.e. one and only divine being **(Source: The Quran and Modern Science by Maurice Bucaille, 2012)** who has laid out the earth for his creatures, produced fruits, palm trees, sheathed clusters, grains with husks and aromatic herbs to name a few. The almighty God says, see the seed that you sow in the ground, is it you that cause it to grow or am I the cause? Don't you see the water which you drink? Do you bring it down the rain from the cloud or do I? Were it my will, I could make it (raining water) unpalatable; then why do you not give thanks? (Why not become humble?) See the fire which you kindle? Is it you who grow the tree which feeds the fire, or do I grow it? Almighty God asks the deluded people: if you are able then call back the soul of a dead, if you are true in your claim of independence?

Almighty Allah (God) is entirely merciful and especially merciful to all creations with particular blessings to human kind that have been provided with ability of speech and expression, ability to learn and train into various languages, God has made us able to understand & interpret the natural laws, guided us to the morals and spirits, inspired us to discover, invent & excel. As stated in the Quran, the sun and the moon run with precision by his power only, the stars and trees keep on prostrating before him, the sky is created high that is well beyond our reach and imagination, and the balance is set in the nature which is so precise that we are

not able to find any flaw into it. As further stated in the Quran, human beings are directed not to transgress in behavior and balance, we have to observe the equity and justice to all living beings and should not fall short in rights of others.

Author prays the almighty God to bless the mankind of goodness with peace, prosperity and security for this life and hereafter. Author is especially grateful to Prophet Mohammad (Peace be upon him) whose advent has lead the people from a time of ignorance to the time of knowledge and awareness all around this earthen globe and has provided us the unaltered message of almighty God in form of the Quran. Further author expresses a sense of gratitude on behalf of mankind to all messengers of Allah who were born in every nation and tribes (before advent of final prophet in Arabia) to deliver the message of creator in their own languages and traditions, thus developing historic civilizations in various parts of the world including the Indian subcontinent. Messages in this Asiatic region have been found scattered in different scriptures. In India, messages are mostly scribed in Sanskrit language while Quran has been revealed in Arabic which is spoken by around more than 160 million people around the world. Those who do not know Arabic can easily understand Quran through its translations in English and other languages as author has himself learnt.

Author also expresses his humble respects towards the scientists and philosophers of the recent past (past several centuries) who have contributed in the development of modern science and have encouraged the spirit of scientific investigation towards natural phenomena and have invented many good things worth of use & utility to the mankind viz. electrical and mechanical power, numerous sources of energy, medicines, information technology etc.

Before moving on to acknowledge the worthy persons who have helped a lot in author’s pursuit of study, author would like to incorporate the speech of **Carly Florina (2001)** who described about the significant contribution of the followers of Prophet Mohammad (S.A.W.) and believers of the Lord of the worlds, whose positive efforts and struggle has facilitated and in fact lead the social, scientific and technological advancements of the modern era. At the time when that civilization was flourishing and spreading over the globe, most part of the world including today’s developed countries (viz. Europe and USA) were rather living in the Dark Age. She stated that…

“There was once a civilization that was able to create a continental super-state that stretched from ocean to ocean and from northern climes to tropics and deserts. Within its dominion lived

hundreds of millions of people, of different creeds and ethnic origins. One of its languages became the universal language of much of the world, the bridge between the peoples of a hundred lands. The reach of this civilization's commerce extended from Latin America to China, and everywhere in between. And this civilization was driven more than anything, by invention. Its architects designed buildings that defied gravity. Its mathematicians created the algebra and algorithms that would enable the building of computers, and the creation of encryption. Its doctors examined the human body, and found new cures for disease. Its astronomers looked into the heavens, named the stars, and paved the way for space travel and exploration"

(Source: Speech of Carly Fiorina, Former CEO, HP (Hewlett Packard), **Minneapolis, Minnesota, September 26, 2001.** "Technology, Business and Our Way of Life: What's Next". Retrieved from http://www.hp.com/ hpinfo/ execteam/ speeches/ fiorina/ minnesota01.html/).

***** ***** ***** ***** *****

The author of this dissertation is particularly indebted to his kind and generous parents for their painstaking efforts during upbringing and educating him and for their unending blessings during entire life expecting nothing in return. Author wishes to express his love and affection towards his spouse, children, brothers & sisters, relatives, companions in studies and in works and all his countrymen for being generous in behavior and manner towards him.

Author is glad to acknowledge the guidance of his major advisor Dr. Raghunandan Swarnkar, Professor & Head of the FMPE department at CAET, AAU, Godhra and expresses sincere thanks for his encouraging involvement during the course of this study.

Many thanks are due to the advisory committee members namely Dr. M.L. Gaur, Minor Advisor and Professor of Soil & Water Engineering and Dr. A.N. Khokhar, Associate Professor of Agricultural Statistics, B.A. College of Agriculture, AAU, Anand, Dr. Pankaj Gupta, Associate Professor of Farm Machinery and Power Engineering and HoD and Dr. Navneet Kumar, Associate Professor of Process & Food Engineering and HoD, CAET, AAU, Godhra for their valuable suggestions and discussions during the course of study. Thanks are due to the seniors, colleagues and juniors who have directly or indirectly helped in numerous accounts.

Author wishes to extend his sincere thanks to the Principal (CAET, Godhra) and Dean of Agril. Engg. faculty, Director of Research and Dean of P.G. Studies and Registrar of Anand Agricultural University, Anand for providing opportunity &

facilities to research for the academic advancement in the area of study.

Policy directives by Hon'ble Vice Chancellor and statutory bodies of the Anand Agricultural University have been the driving force to fruitful realization of this research work as part of the post graduate study.

Place: Godhra (M D Vora)

Date: 24/04/2017

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviation / Symbol		Description
AAU	:	Anand Agricultural University
A.C.	:	Air Conditioning
AF	:	Audio Frequency
ANOVA	:	Analysis of Variance
BIS	:	Bureau of Indian Standards
CIAE	:	Central Institute of Agricultural Engineering
CAET	:	College of Agricultural Engineering and Technology
cc or c.c.	:	Cubic Capacity
CFMTTI	:	Central Farm Machinery Training & Testing Institute
CIRCOT	:	Central Institute for Research on Cotton Technology
CPS	:	Cycles per Second
CPM	:	Cycles per Minute
CV or C.V.	:	Coefficient of Variation
dB	:	Decibel or one tenth of a Bel.
dB-SPL	:	Decibel of Sound Pressure Level
dBA or dB(A)	:	Decibel (A-weighted)
°C	:	Degree Celsius
°F	:	Degree Fahrenheit
EL	:	Ear Level
etc.	:	et cetera (and so forth)
FFT	:	Fast Fourier Transform
g or G	:	Gravitational Acceleration
H	:	Hour

HCP	:	Hearing Conservation Program
HICs	:	High Income Countries
HP or hp	:	Horse Power
HTPP or http	:	Hyper Text Transfer Protocol
HVAC	:	Heating, Ventilation and Air Conditioning
Hz	:	Hertz
IEC	:	International Electro-technical Commission
IC	:	Internal Combustion
i.e.	:	that is
IIT	:	Indian Institute of Technology
ILO	:	International Labour Organization
ISO	:	International Standards Organization
kHz	:	kilo Hertz
km/hr	:	kilometer per hour
kPa	:	kilo-Pascal
kW	:	kilo Watt
lb.	:	Pound
LCD	:	Liquid Crystal Display
LICs	:	Low Income Countries
m	:	Meter
mA	:	Milli-Ampere
m/s^2	:	Meter per Second Squared
mm/s	:	Millimeter per Second
ms	:	Millisecond
NIAE	:	National Institute of Agricultural Engineering
NIOSH	:	National Institute for Occupational Safety and Health

NIHL	:	Noise Induced Hearing Loss
OSHA	:	Occupational Safety and Health Administration
OEM	:	Original Equipment Manufacturer
Pa	:	Pascal
%	:	Percent
PTO	:	Power Take-Off
LA_{eq}	:	Average Equivalent Level
RH	:	Relative Humidity
rms or RMS	:	Root mean square
ROPS	:	Roll-Over Protective Structure
RPM	:	Revolutions Per Minute
Rpm	:	Revolutions per minute
S.D.	:	Standard Deviation
SLM	:	Sound Level Meter
SPL	:	Sound Pressure Level
SPL_{power}	:	Sound Pressure Level in Power Unit
$SPL_{pressure}$	:	Sound Pressure Level in Pressure Unit
TWA	:	Time Weighted Average
WBV	:	Whole-Body Vibration
X-direction	:	Longitudinal Direction
Y-direction	:	Lateral Direction
Z-direction	:	Vertical Direction

Chapter-1

INTRODUCTION

Mechanical equipment is the most popular kind of farm power sources being used in current times in the field of agriculture. Majority of the farm operations connected with crop production processes are successfully adapted to mechanization. Tractor has remained at centre as a source of farm power and has played a vital role in agricultural mechanization. There are many other machine equipments too which are widely used to conduct various agricultural operations. Pumps, diesel engines, power tillers, reapers, mowers, combine harvesters, threshers, graders etc. are among them. All mechanical equipments produce noise and vibrations of different intensities. Vibrations and noises have been considered as damaging factors to both men and machines. When agricultural mechanization is becoming a common part of our societal life, we cannot ignore the right and wrong or positive and negative effects arising out of it. Continuous noisy environment can be potential threat to the efficiency of those who operate farm machinery and equipment. Even those who themselves do not operate the machine, may be subjected to this danger due to any excessive noise involved into the farm operations conducted with mechanical machines such as tractors taking place at the nearby places. Farmers/farm owners and farm workers are very much prone to getting exposed to this risk. Farm tractors in combination with different mountings and attachments and other farm machinery like combine harvester or mechanical thresher are the examples which operate continuously for long hours producing high noise thus causing negative impacts on operators and neighbours all around.

Though the mechanical technology has advanced much faster in recent past in all spheres of life including agriculture, several negative side effects have also emerged. As machines generate vibrations and sounds due to engine operation and frictions resulting out of mechanical movement of the internal and external components of the machinery they cause discomfort to the humans and ultimately leads to reduced efficiency and accuracy during work. Technological progress in agriculture has resulted in reduction of physical work but has increased mental burden to some extent. If not attended, the advantages of technology can negatively affect the benefits being reaped by us through mechanization and may lead to increased work-lead diseases and accidental death and injury events. In India, there are more than 200 million workers engaged in various agricultural and allied activities. According to Gite and Singh (1997), earlier, importance of ergonomics i.e. human engineering was well established and recognized in industry and military applications. However, now a day, it is being realized that ergonomics is equally important and relevant in agricultural and allied activities. Patrick and Peter (2006) stated that noise-exposed workers are employed in wide range of industries which include agriculture, mining, construction, manufacturing, transportation, and military.

In Indian agriculture, human workers operate all the tools/implements/machines. Therefore, application of ergonomics or human engineering can help in increasing the efficiency and productivity of the workers without jeopardizing their health. As Grandjean (1982) described that the scope of ergonomics application includes achieving greater efficiency, accuracy, safety, reduction in stress, and suitable environment to suit man's physical requirements etc. Due consideration to the factors stated by him reminds us that the protection of farm workers and operators against bad effects of noise and vibrations is very much desired in the countries like India which has tremendous potential and possibilities of increasing utilization of farm tractors and machinery. As there are more than 200 million agricultural workers in India those are exposed to various kinds of machine and work environmental hazards on every day, avoiding their safety and comfort factors may lead to discomfort at job, mental tiredness, low output of workers and reduction in safety.

The National Policy on Safety, Health and Environment at work place was declared by the Govt. of India on 20-02-2009. The fundamental purpose of the National Policy is not only to eliminate the incidences of the work related injuries diseases, fatalities, achievement of high level occupational safety and health but also to enhance the well-being of the employee and society at large (Anonymous, 2011). Pingle (2012) stated that the national policy on OSH at workplace, adopted by the government in 2009, is yet to be implemented. Some of the major occupational risks are accidents, pneumoconiosis, musculoskeletal injuries, chronic obstructive lung diseases; pesticide poisoning and noise induced hearing loss. He stressed the need of legislation to extend OSH coverage to all sectors of working life including the unorganized sector. In United States, because of the hearing loss occurrences among the workers, OSHA implemented the hearing conservation program (HCP) in 1989. The regulations required that the workers those are exposed to high level of noise should be tested for hearing loss and the noise should be eliminated or controlled by the use of engineering or administrative means. Earlier, the farms were not considered as an area for implementing the OSHA's regulation. But later as mechanization increased it was started to consider OSHA's regulations. Since the inception of regulation, studies found numerous noise exposures on the farms from machinery (Hagen, 2011).

1.1 SOUND

Physically sound is the oscillation of waves in the air. It moves through the air as waves pass with varying pressure intensities. The stronger is the pressure of wave, the louder will be the sound. Sounds are measured in the unit known as decibels symbolically denoted by dB. Decibels are measured by logarithmic scale. Increase of 10 decibels in the present sound level does not represent linear addition of 10 decibels but rather it represents 10 times increase in the strength of present sound waves. An increase of 20 decibels will result in twice the 10 times i.e. 10 multiplied again by 10 times resulting in effectively 100 times. Human hearing perception is also logarithmic (Anonymous, 2013a).

1.2 NOISE AND VIBRATIONS

1.2.1 Noise

Sound is a common part of our daily life. Many sounds which are unpleasant or unwanted or damaging can be called as "noise". Noise can be generated by men and machines. As stated on website of OSHA, Noise and vibration are both fluctuations in the pressure of air (or other media) which affect the human body. Vibrations that are detected by the human ear are classified as sound. We use the term 'noise' to indicate unwanted sound. Noise and vibration can harm workers when they occur at high levels, or continue for a long time. Noise exceeding the certain level can even cause permanent damage to hearing ability of human beings. However sound is the indispensable medium of communication for the life, when it takes form of "noise" it should be prevented at the source or in the environment where it spreads.

Noise causes corruption of communication, discomforts and reduction in physical and mental performance. Men exposed to high noise especially to that of machinery represents most severe form of acoustic dangers. Most people do not realize that sound can be a pollution too. But, over a period of time, after noticeable increase observed in the adverse effects of noise, it has been considered as an environmental pollution. Mechanical sounds produced by any reasons thereof results in ill effects on mental health, and hence it becomes a challenge for the technocrats and engineers in the field of mechanization to apply the laws of science to at least reduce, if not eradicate, the ill effects of noise on society and environment as we do in case of other pollutants. Sharma and Mukesh (2008) stated that almost all models of tractors manufactured in India produce noise level in the range of 88-100 dB(A). Noise levels of other mechanical farm machines ranged from 90-97 dB(A) during operations. The noise program's standards allow a noise accumulation of 90 dB(A) over an eight hour period.

1.2.2 Vibrations

The physical movement of any machinery during their operation may be referred to as vibration. A mechanical system or machine produces vibrations during its operation due to its moving components. Magnitude of vibration may be expressed through frequency and amplitude of vibration. Vibration is a kind of motion which repeats after an interval of time. Vibrations are in most cases considered as undesirable in a mechanical system. Mainly the rotating and reciprocating parts are responsible for the vibrations taking place in the engine systems of tractors and other farm machines. Prolonged exposure of a farm machine/tractor operator to the excessive vibrations can cause negative effects on human physiology, biology and psychology. Vibrations have also some mechanical implications. Vibrations cause loss of energy and damage to the machine components. Sharma and Shyam (1993) reported that in India the vibration levels of different components of most of indigenous tractors did not meet the BIS requirement. Vibrations taking place in different machine components due to engine operation also contribute in generation of noise. The excessive vibrations, apart from its own negative effects, also contribute largely to the noise levels at and around the tractor/machinery location. The existing vibration levels on different components of the farm tractor can be tested to determine the intensity of vibrations with the help of vibration meter. Normally in different investigations, the vibrations are represented in terms of acceleration values.

1.3 MITIGATION OF EXCESSIVE NOISE LEVELS PRODUCED BY TRACTORS

The exhaust mufflers play an important role into the mitigation of noise levels arising out of engine operation and the simultaneous vibratory motions during operation. The modification or alteration in the design of exhaust mufflers can be made in various constructional aspects such as length and breadth, the technique of muffling employed, the materials used inside etc. Investigating the effect of altered design of mufflers on the noise levels can be helpful for framing the strategy to mitigate the ill effects taking place on human health due to noise generated out of farm machinery operations at the work place like agricultural farms.

Jadhav and Ghatage (2000) reported that the suppression of engine exhaust noise has been a subject of interest for many years. Fortunately, however, this noise can be reduced sufficiently by means of a well-designed muffler. The exhaust noise can be reduced appreciably by providing resonance chambers to offset the noise wave effects. This is accomplished by the principle of the Helmholtz resonator. In principle, it comprises the exhaust pipe, which goes through the large volume of a chamber. The axial holes in the exhaust pipe enclosed by the chamber allow the gases to vibrate with the large mass of the gases in the chamber (forming a spring-mass vibrating system) and generate the sound of the same frequency but in opposite phase to that which has to be nullified (called anti-sound). Rahman et al (2005) stated that attaching a muffler in the exhaust pipe is the most effective means of reducing noise. However, muffler may require specific design and construction considering various noise parameters produced by the engine.

1.4 TYPES OF MUFFLER

The muffler or silencer can be broken into three fundamental types: absorptive (dissipative), reactive (reflective) and combination of reactive & absorptive both. Absorptive silencers reduce reflections from the walls of the tube or duct that contains the stream of fluid, and may be augmented by additional “splitters” placed within the stream. Reactive silencers depend on the reflection or expansion of sound waves with self-destruction as the basic noise-reduction mechanism.

The primary function of a reactive silencer is to reflect sound waves inside the pipes or tubes extended from the source. Energy is dissipated in the flow path resulting from internal reflections. Reactive silencers generally consist of several pipe segments that interconnect with a number of larger chambers. The noise reduction mechanism of reactive silencer is that the area discontinuity provides impedance for the sound waves traveling along the pipe. This impedance results in a reflection of part of the sound wave back toward the source or back and forth inside the chambers. The reflective effect of the silencer chambers and piping (typically referred to as resonators) essentially prevents some sound wave elements from being transmitted past the silencer. The reactive silencers are more effective at lower frequencies than at high frequencies, and are most widely used to attenuate the exhaust noise of internal combustion engines.

1.5 HISTORY OF EXHAUST MUFFLER AS NOISE ATTENUATION DEVICE

Anonymous (2014a) stated that a muffler, also called silencer in British English, is a device for reducing the amount of noise emitted by the exhaust of an internal combustion engine. The US Patent for an ‘Exhaust muffler for engines’ was awarded to Milton O. Reeves and Marshall T. Reeves of Columbus, Indiana of the Reeves Pulley Company on 11th May 1897. U.S. Patent Office application No. 582485 states that they “have invented certain new and useful improvements in Exhaust-Mufflers for engines”. Mufflers are installed within the exhaust system of most internal combustion engines, although the muffler is not designed to serve any primary exhaust function. The muffler is engineered as an acoustic soundproofing device designed to reduce the loudness of the sound pressure created by the engine by way of Acoustic quieting.

Fig. 1.1: Different exhaust silencers used in different makes of tractors

1.6 NEED OF THE HOUR

The examination of existing noise and vibration levels on farm tractors may provide useful data on the level of severity of noise and vibrations associated with farm tractor and machinery operations causing the unnoticed risks to the end users/operators in particular and farming community as a whole. Continued exposure of tractor noise causes harmful effects to the operator in terms of reduced comfort and efficiency. Human being as a source of farm power has comparatively very less potential but due to his/her ability of logical thinking and decision making he/she can act as a good controller of machines and equipment of very large capacities. Incorporation of human factors in design of machine can facilitate the operator to perform the task of operating the machines with better efficiency, comfort and safety. The design of mechanical components of tractor and other farm machines in a way to reduce or limit the noise levels is a challenging task for the engineers and technologists engaged in design, development and manufacturing of tractors and other farm machines. Field studies on excessive noise and vibration occurrences in farm tractor and machinery operations can provide a needed background for more concentrated efforts in this direction and can also provide platform for planning suitable engineering and administrative measures in respect of noise and vibration exposures. Apart from modification in the design of engines with a view to reduce the excessive noise, the role of noise attenuation device like that of exhaust silencer/muffler can be enhanced to arrive at the acceptable noise levels for a safer work place. Engine exhaust noise is controlled to a good extent through the use of silencers and mufflers. Reports (Anonymous, 2002a) say that in most applications, the final selection of an exhaust silencer is based on a compromise between the predicted acoustical, aerodynamic, mechanical and structural performance in conjunction with the cost of the resulting system.

A research study entitled **"Investigation on Noise Attenuation Performance of Exhaust Mufflers of Farm Tractors with Appropriate Design Alterations"** was proposed to study the existing noise levels of farm tractor operated at different engine speeds as affected by vibration characteristics and later to alter the design of existing muffler/silencer as a low cost engineering intervention to study its effect on noise attenuation. The study mainly focussed on the noise attenuation performance of the exhaust muffler as influenced by cost economical design alterations. Development of suitable sized cost economical muffler designs and their evaluation for their noise attenuation capability will be helpful in finding the cost effective solution that could be implemented in case of high noise exposure conditions utilising low cost materials particularly in cost sensitive rural farm-hold conditions of India.

1.7 OBJECTIVES

The objectives of research study were as under.

1. Evaluation of noise and vibration levels associated with different engine speeds of farm tractors under study.
2. Assessing feasible alterations in existing mufflers of farm tractors under study and exploring modified designs.
3. Comparative performance analysis of exhaust mufflers as mounted on selected farm tractors.

1.8 CONSTRAINTS AND SCOPE OF STUDY

It is ensured that engine and exhaust parts of farm tractor are those specified and provided by the respective manufacturers. The instrumentation is made on basis of existing facilities and standard instruments available at the department/college level. The BIS and global standards are given due consideration during the experimentation. The tractors with cab are neither in common use by the farmers in India nor it is available with the department, hence it could not be included as one of the treatments under present study. Observations however sometimes recorded on different days, the wind speed observations were taken into consideration to ensure similarity in environmental conditions so as to negate the effects of wind blows on sound level observations. The study is restricted to two sample of a specific kind or make of tractors. Sound level measurements are made for specific data acquisition periods. Time weighted average values (TWAs) are based on that for comparison with regulatory limits.

Issues of personal health and legal liability are an ongoing and increasing concern for all around the world. It is desirable for anyone involved in the field of farm machinery and power engineering to become familiar with the magnitude of the problem of exceeding noise and vibration levels as an occupational health hazard during the operations of most farm machinery and equipment. Among farm machineries, farm tractors are most important as they are very widely utilized for most farm operations and transportation of the agricultural produce. Testing centres across the country conduct standard tests on farm tractors. However, no specific kind of regulations are framed or imposed in the area of protecting the occupational health risks involved in farming operations in the country, they are desirable particularly in the coming era of high farm mechanization. In U.S., the Nebraska Testing Lab under the authority of the United States Department of Agriculture (USDA), tests each tractor make that is produced in that year in order to determine how much noise a tractor produces when it is newly manufactured. Along with noise, the tests determine all specifications each tractor possesses. The same is followed in the domestic testing centres established in the country. The standards of permissible noise exposure vary in different countries. Le and Henderson (2012) stated that the U.S. standards for permissible noise exposure (as regulated by the U.S. Occupational Safety and Health Administration) is significantly greater than that allowed in numerous other countries like Canada, China, Brazil, Mexico, and the European Union based on key differences in action level (85 dBA vs. 90 dBA) and exchange rate (3 dB vs. 5 dB).

Chapter-2

REVIEW OF LITERATURE

The review of literature has been conducted on various aspects of noise and vibrations that could be of most relevance to the problem of the proposed investigation. It has been classified under suitable headings and subheadings in an appropriate order.

2.1 DEFINITION OF SOUND, NOISE AND VIBRATION

2.1.1 Definition of Sound and Noise

Rajagopal (2008) stated that the term sound is ordinarily employed to denote the physiological sensation perceived by the ear. The musical sound produces a pleasing sensation which is due to its special properties like periodicity, regularity and continuity. The sound of complex nature having an irregular period and amplitude is called a noise.

The common sound pressure levels in dB-SPL are presented in the following Table (Anonymous, 2016).

Table 2.1: Common sounds with their decibel levels

Sound Type	Sound Level (dB-SPL)
Hearing Threshold	0
Whisper	30
Air Conditioner	50-70
Conversation	50-70
Traffic	60-85

Arude and Paralikar (2004) stated that the noise is commonly defined as unwanted sound and engineers classify it as wasted energy.

2.1.2 Definition of Vibration

According to Shreve (1994), vibration can be defined as simply the cyclic or oscillating motion of a machine or machine component from its position of rest.

Sharma and Mukesh (2008) defined vibration as an oscillatory motion of mechanical system. Vibration is characterized by frequency, amplitude and phase. In many cases it is undesirable and is a form of wasted energy. In tractors and farm machinery, vibrations cause the break-down of parts and transmit unwanted forces and movements to different components.

McPhee et al (2009) defined vibration as an oscillatory motion of solid body. Takács and Rohal (2012) defined vibrations as mechanical oscillations about an equilibrium position.

2.2 VIBRATIONS

2.2.1 Measurement of Vibrations

Shreve (1994) described that modern instrumentation for measuring vibration on rotating and reciprocating machinery not only minimizes the need for extensive experience, but makes it possible to detect developing problems that are outside the range of human senses of touch and hearing.

Gite and Singh (1997) reported that there is a strong need to carry out detailed measurements on vibrations received by the operator during work and to recommend proper procedure of measurement for incorporating in the relevant Indian Standards. Exhaustive work is thus needed to come out with measures for reducing the vibration problem faced by Indian tractor drivers during various operations.

Salokhe et al (2008) used accelerometers at different locations on brush cutter and on the operator's body for the measurement of vibration in longitudinal, lateral and vertical modes. The sound level of brush cutter was recorded by using a microphone.

Arude et al (2009) found maximum vibrations on hopper, swing lever, gearbox and seed chute of Double Roller (DR) gin. The average acceleration, velocity and displacement for different models of DR gin was found to be 18.47 m/s^2, 1.55 m/s and 9.72 $x10^{-5}$ m with the corresponding CV values of 35.28 %, 16.06% and 37.13%, respectively. The average acceleration for pre-cleaner and lint cleaner was 5.48 m/s^2 and 5.25 m/s^2 with the corresponding CV values of 16.79% and 21.26%, respectively. The different parts of the baling press were found to accelerate between 0.51–6.24 m/s^2 with an average acceleration of 2.80 m/s^2. The CV for different parts of the baling press was 74.78 per cent.

O'Haver (2014) stated that experimental measurements are never perfect, even with sophisticated modern instruments. Two main types or measurement errors are recognized: (a) systematic error, in which every measurement is consistently less than or greater than the correct value by a certain percentage or amount, and (b) random error, in which there are unpredictable variations in the measured signal from moment to moment or from measurement to measurement. This latter type of error is often called noise, by analogy to acoustic noise.

2.2.2 Characteristics of Vibration

As stated by Shreve (1994), there are four forces that determine the characteristics of vibration. (i) the exciting force, (ii) the mass of vibrating system, (iii) the stiffness of vibrating system, and (iv) the damping characteristics of vibrating system. The exciting force tries to cause vibration, whereas stiffness, mass and damping forces try to oppose the exciting force and control or minimize the vibration.

Gite and Singh (1997) described vibrations as one of the major sources of discomfort to the workers operating machines.

Sharma and Mukesh (2008) stated that vibrations could generate sound in a gas, fluid or solid medium. In tractors and farm machinery, vibrations generate noise.

McPhee et al (2009) stated that vibration arises from mechanical sources. Vibration energy can be passed on to the persons who have physical contact with the source. The vibration may give rise to adverse health effects if vibration energy is transmitted to the operators from vehicles being operated by them on rough roads or vibrating tools and machinery which they operate.

Takács and Rohal (2012) stated that there are cases when vibrations are desirable, such as in certain types of machine tools or production lines. However, most of the time the vibration of mechanical systems is undesirable as it wastes energy, reduces efficiency and may be harmful or even dangerous.

2.2.3 Effects of Vibration

McPhee et al (2009) discussed effects of vibration on human beings. They stated that vibration can be whole-body vibration (WBV) or segmental. In WBV, vibration is transmitted to the body as a whole by its supporting surface i.e. seat or floor. Segmental vibration is that which is transmitted to a specific segment of body such as hand/arm or foot/leg.

Takács and Rohal (2012) stated that passenger ride comfort in aircraft or automobiles is greatly affected by the vibrations caused by outside disturbances, such as aeroelastic effects or rough road conditions.

2.3 NOISE

2.3.1 Measurement of Noise

Chhatwal et al (1989) stated that the quantification of sound levels for the purpose of determining whether they have been hazardous to health and welfare or exceed local legally adopted limits can be a complex task.

Anonymous (2013a) stated that Class-1 and Class-2 SLMs are most widely used by acousticians, sound system professionals, industrial designers/ manufacturers and researchers in academia and government. Measurements made with these levels of accuracy are generally acceptable as evidence in the resolution of legal disputes. Class-3 SLMs are restricted to noise survey meters and dosimeters.

Anonymous (2013c) suggested that SLOW response time should be chosen to measure average sound levels and FAST to measure peak levels.

Tom Young (2013) stated that when measuring and logging sound levels to help resolve a dispute, both A and C weighted measurements should be provided. The distance from the source and any other detailed notes should be there.

Henderson and Hamernik (2012) stated that sound measurements are made with an A-scale weighting on the sound level meter. Low-frequency sounds (less than 500 Hz) are negatively weighted with the A scale because low-frequency sound energy is not as damaging to the ear as sounds above 500 Hz.

2.3.2 Characteristics of Noise

Jadhav and Ghatage (2000) stated that noise is a nuisance for present day urban society. The automobile is a major culprit in increasing unwanted sound level.

Hagen (2011) stated that calculating noise exposure can be a difficult undertaking. There are numerous factors that contribute to the different sound levels.

2.3.2.1 Noise levels and safe exposure durations

As per the international standard (IS 12207, 1987) and according to OSHA, the sound level for safe working limit is 90 dB(A) for 8 hr duration.

According to Antony and Laird (1994) and Arude and Paralikar (2004), OSHA standards for general industry are two staged. Hearing conservation measures are mandatory at 85 dBA, and feasible engineering or administrative noise controls are required when noise levels reach 90 dBA for an 8-hr day.

The ISO (1999) recommendation (IS: R-1999) specifies that for an 8 hour duration exposure the noise level should not exceed 90 dB(A). According to International Labour Organization (ILO), the harmful effect of noise on men is not only a function of time but also level. The duration at which harmful effects of noise begin are presented in the following table.

Table 2.2: Noise level and corresponding period when it becomes harmful

dB(A)	90	92.5	95	97.5	100	102.5	105	110	115
Period (h)	8	6	4	3	2	1.5	1	1/2	1/4

(Source: International Labour Organization)

Anonymous (2000) reported that the national standard for exposure to noise in the occupational environment is an average daily exposure level of 85 decibels. This is consistent with overwhelming scientific evidence which indicates that exposure levels above 85 decibels represent an unacceptable risk to the hearing of those exposed. Many other developed countries have introduced legislation based on this standard. For peak noise, the national standard is a peak sound pressure level of 140 decibels.

Anonymous (2013d) stated that the noise exposure should be controlled so that exposure is less than the combination of exposure level and duration.

2.3.2.2 Audio frequency

An audio frequency (AF) or audible frequency is characterized as periodic vibrations whose frequency is audible to the average human. Audio frequency is measured in hertz (Hz). The generally accepted standard range of audible frequencies is 20 to 20,000 Hz.

Generally the range of bass frequencies encompasses 20 to 500 Hz. The frequency range 500 to 5,000 Hz would be considered as midrange frequencies, and high frequencies would be 5,000 to 20 kHz. The range is often further divided into sub categories such as "midbass" and "upper midrange" (Anonymous, 2015a).

2.3.2.3 Frequency response graphs

Anonymous (2015c) stated that full understanding of sound frequency response charts requires knowledge of many variables involved with the application viz. the human ear hearing capability, interaction with other speakers/noises, enclosures/environment, and many other factors are necessary to take into account when interpreting a frequency response graph.

2.3.2.4 Frequency spectrum analysis

Applications like Spectrum-View or Plot-Spectrum takes the selected audio (which is a set of sound pressure values at points in time) and converts it to a graph of frequencies (the horizontal scale in Hz) against amplitudes (the vertical scale in dB). The Plot-Spectrum offers choices like Rectangular, Hanning, Hamming and others. For general audio analysis, the Rectangular window is least desirable, and the other options offer slightly different effects. It was suggested for most situations to use the default Hanning i.e. actually is a Hann window, but Hanning is widely accepted. The fundamental principle is that the way we observe data changes when we see through different windows. If a short interval of audio is selected (the short-time spectrum), the frequency resolution is limited by the observation window time. Hence, the result is affected by the spectrum of the window itself (Anonymous, 2015f).

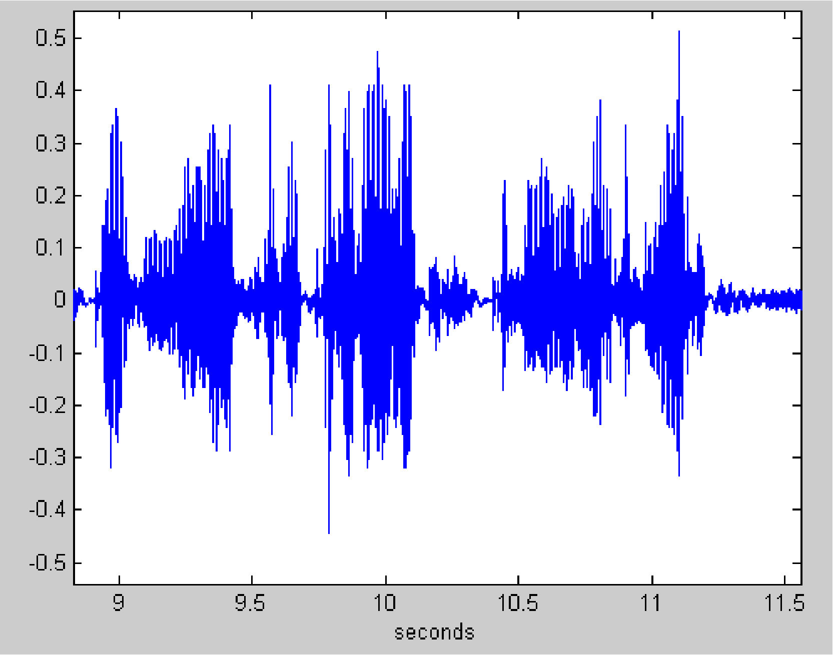


Fig. 2.1: Sound wave form

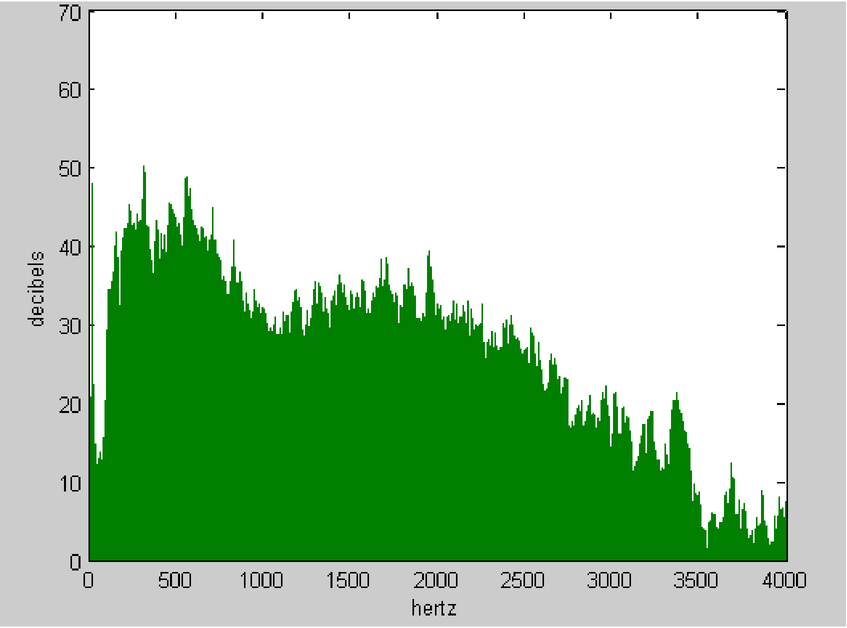


Fig. 2.2: Spectrum of a sound signal (15 seconds)

2.3.2.5 Frequency vs. dB display

According to Smith III (2007), in practical signal processing, it is common to choose the maximum signal magnitude as the reference amplitude i.e. the signal is normalized so that the maximum amplitude is defined as 1, or 0 dB. This convention is also used by ``sound level meters'' in audio recording. When displaying magnitude spectra, the highest spectral peak is often normalized to 0 dB to facilitate easily read lower peaks as so many dB below the highest peak.

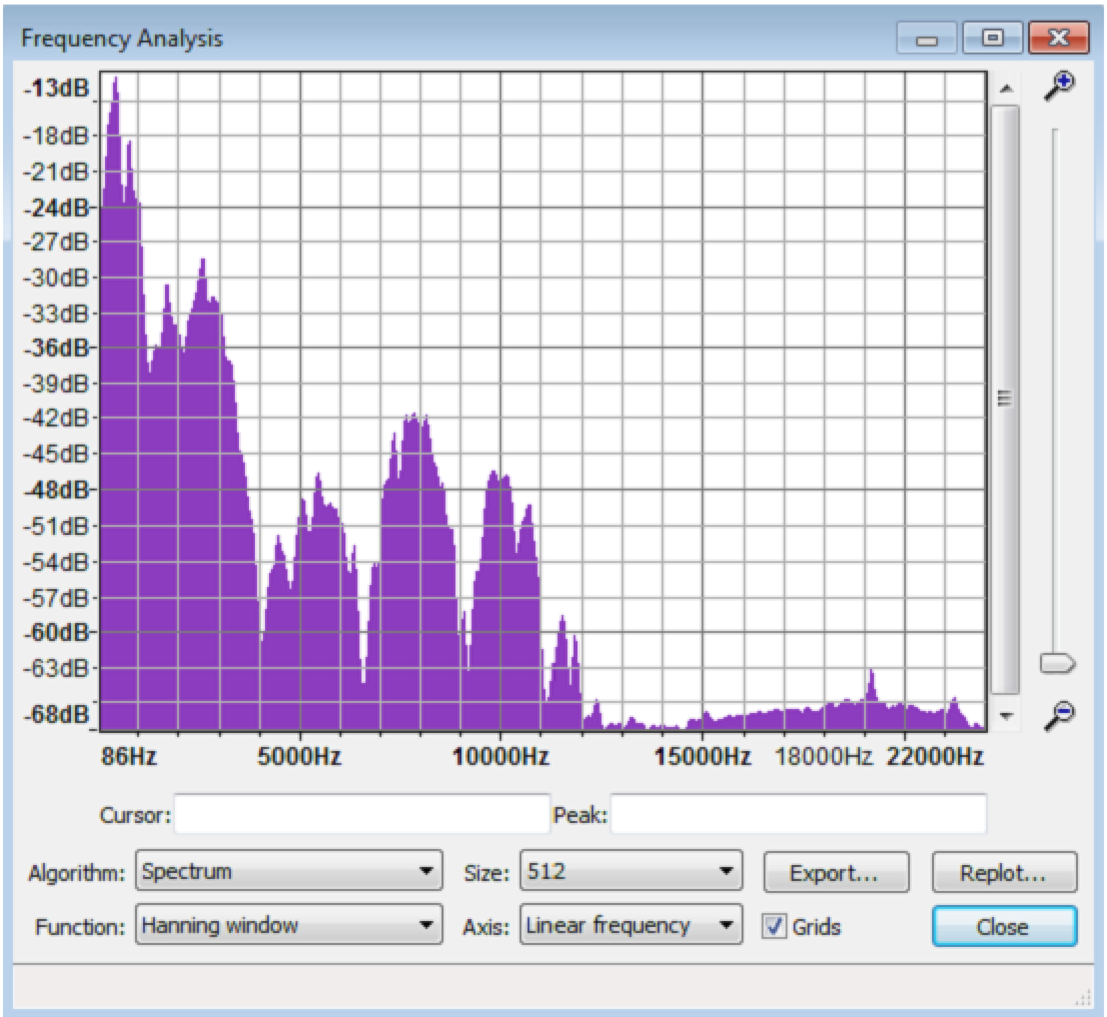


Fig. 2.3: Frequency analysis – frequency vs amplitude (dB)

2.3.2.6 Sound pressure levels (dB) and frequency (Hz or kHz)

Mehta et al. (1997) reported that the maximum sound pressure versus octave band frequency curves at rated engine speed indicated that sound pressure level was highest at 4000 Hz frequency. It was concluded that the tractor noise was predominant at low and medium frequencies for different mufflers.

2.3.3 Effects of Noise on Human Beings

OSHA (2013) suggested that while people react differently to noise, subjective responses should not be ignored because they may provide warnings that noise may be at unacceptable levels. Noisy conditions can make normal conversation difficult. When noise levels are above 80 decibels (dB), people have to speak very loudly. When noise levels are between 85 and 90 dB, people have to shout. When noise levels are greater than 95 dB, people have to move close together to hear each other at all. High noise levels can cause adverse reactions or behaviours.

2.3.3.1 Noise induced hearing loss

Henderson and Hamernik (2012) reported that the hearing loss is not related to only average level, but to the intermittent higher levels of the transients. Energy considerations alone ignore the temporal features of a noise exposure. They further stated the outcome of a series of experiments performed which showed that exposures with the same total A-weighted energy and spectrum but different degrees of kurtosis can produce very different amounts of hearing loss and cochlear damage.

Le Prell and Henderson (2012) stated that hearing loss attributed to noise is called noise-induced hearing loss (NIHL). They reported that in the United States, hearing impairment is the third-most-prevalent chronic disability with a major portion of the loss related to exposure to noise in the environment.

2.3.3.2 High frequency hearing loss

Kumar et al (2005), through audiogram analysis, observed high frequency hearing loss among tractor driving farmers as compared to non-tractor driving farmers.

2.3.3.3 Frequency relevance in hearing loss

Bean (2008) stated that the amount of hearing loss experienced is related not only to the loudness of the sound but also to the frequency (pitch) and to the duration of the exposure. Higher frequency sounds are much more damaging than low ones.

Thus, the inability of the ear to hear high frequencies is usually an indication of damage. People who are experiencing a hearing loss may first notice this as an inability to hear higher pitched sounds such as the notes of music.

2.4 TRACTOR AND MACHINE VIBRATIONS

Gite and Singh (1997) reported that the most important vibration component in tractor operation is due to vertical oscillations of the vehicle on its tires which as a result of their low inherent damping allow the vehicle to continue to oscillate significantly through several cycles when excited by the ground irregularities.

2.4.1 Measurement of Tractor and Machine Vibrations

Pawar (1979) carried out a study for measurement of vibrations in the frequency range of 20 to 250 Hz during field operations. He reported that centre frequency of 125 Hz was dominant with highest values of acceleration i.e. 2.4 to 3.5 G rms and 1.1 to 1.4 G rms in horizontal and vertical directions respectively and the levels increased with increase in engine speed. This frequency range is most likely to cause arm ailments.

Sam (2006) investigated that the terrain induced vibration of 8.95 kW power tiller was 1.38 to 23.07 percent more on farm road and 6.49 to 20.96 percent more on bitumen road as compared to 7.46 kW power tiller.

Arude et al (2009) measured the vibration levels on different commercial ginning machinery. The intensity of vibration for different parts of double roller gin in terms of acceleration, velocity and displacement varied between 3.29 - 47.85 m/s^2, 0.25-5.85 cm/s and 13 x10-5-28.53 x10-5 m, respectively. The coefficient of variation (CV) for acceleration varied from 48.8 to 69.7 per cent.

2.4.2 Vibration and the Human Sensitivity

The first published international recommendation concerned with vibration and the human body (ISO 2631-1978) sets out limitation curves for exposure times from 1 minute to 12 hours over the frequency range in which the human body has been found to be most sensitive, namely 1 Hz to 80 Hz. The recommendations cover cases where the human body as a whole is subjected to vibration in three supporting surfaces, namely the feet of a standing person, the buttocks of a seated person and the supporting area of a lying person. Three severity criteria are quoted: 1) A boundary of reduced comfort, applicable to fields such as passenger transportation etc. 2) A boundary for fatigue-decreased efficiency that will be relevant to vehicle drivers and machine operators, and 3) The exposure limit boundary, which indicates danger to health. (Anonymous, 1982).

2.4.3 Vibration Direction on Tractors

McPhee et al (2009) stated that for measurement reasons the direction of the vibration should be noted. Up and down vibration (z-axis) is the most common vibration to which people are exposed. An example of this is the vibration experienced when driving over pot holes or when trotting on a horse. There is also lateral or sideways vibration (y-axis), commonly experienced on rail vehicles. Lastly, there is forward vibration (x-axis), for example in front end loaders and dozers.

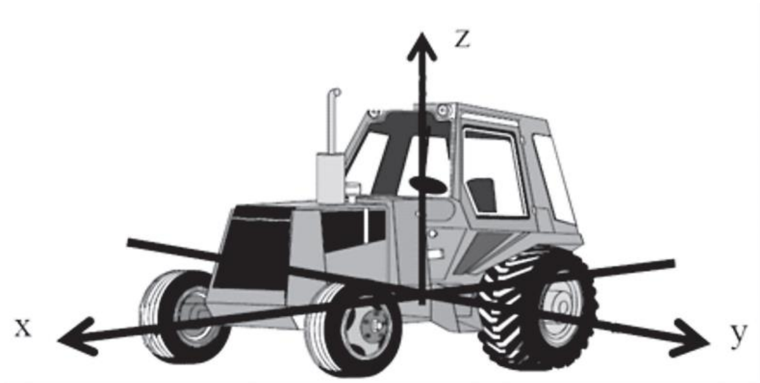


Fig. 2.4: Directions of vibration level measurements

2.4.4 Effects of Tractor and Machine Vibrations

Anonymous (1982) stated that researchers have been compiling data over the last 30 years on the physiological effects of vibrations. The "white finger" syndrome is well known among forest workers handling chain saws. A gradual degeneration of the vascular and nervous tissue takes place so that the worker loses manipulative ability and feeling in the hands.

Gite and Singh (1997) has reported that a survey in United Kingdom showed that discomfort due to vibrations caused the driver to limit his working speed which finally resulted in lower output. The medical surveys of tractor drivers in Germany

(NIAE, 1973) displayed evidence of increased probability of disorders of the stomach and spine.

Celen and Arin (2003) stated that hazards increase more when vibration problem joins with the noise in the agricultural tractor.

Mehta et al (1997) reported that the drivers experienced severe vibrations during ploughing operation and the vibration dose received exceeded the limits specified by the ISO standards for an 8-h work period in a day.

Selvan and Mehta (2008) reported that the tractor driving causes disorders of the spinal column and stomach due to prolonged vibrations. In addition to affecting the health of the tractor driver, it results in lowering of work output.

McPhee et al (2009) stated that the effect of vibration on human health depends on severity and length of exposures. Some studies have associated the degeneration of the lumbar spine with intense long-term exposure to WBV. However, despite this, not a lot is known about the specific effects of exposure to WBV (Whole Body Vibration) on the bones, muscles and joints particularly the spine.

2.4.5 Vibration Control Measures

Pawar (1979) opined that it is necessary to reduce the transmission of vibrations to arm either by isolation from source or by reducing the exposure time.

Prasad (1996) carried out a case study and developed a tractor seat having better vibration attenuation than those available on existing tractors.

Bansal and Thaper (2000) reported that experimentation studies of the vibration isolation characteristics of various tractor seats of Indian make was conducted. An isolation system with resilient springs and damper was found better than that of the existing systems.

Sam (2006) reported that provision of vibration isolators resulted in the reduction of hand-transmitted vibration by around 40 to 50 percent during field operation.

Takács and Rohal (2012) classified vibration control approaches as passive, semi-active and active.

Tewari et al (2013) revealed on basis of experimentation at IIT, Kharagpur that the isolator enhances the safe exposure time from 4 h to 6 h and hence it was recommended for use.

2.5 FARM MACHINERY AND TRACTOR NOISE

Huang and Suggs (1961) reported that farm machinery design has historically focused primarily on function and efficiency. However, in recent years, some emphasis has been shifted to safety, comfort and optimization of human performance. During the operation of these machines by human beings, the load on the operator and occupational hazards and diseases are found to have increased.

Simpson and DeShayes (1969) reported that tractor operators are subjected to noise and vibration levels that are hazardous to health and deleterious to performance.

2.5.1 Farm Machinery Noise Levels

Gupta et al (1981) found that the thresher operators suffered from considerable temporary threshold shift while working for an 8 hour day.

Bansal (1981) reported that the noise levels of threshers were quite high especially when they were run by diesel engines or tractors.

Sam (2006) conducted measurements of sound levels at different forward speeds of power tiller viz. 1.5, 1.8, 2.1 and 2.4 km/hr during field trials and 3.5, 4.0, 4.5 and 5.0 km/hr in transport mode. Each trial was replicated for 3 times with an acquisition period of 30s and the peak value arrived from the noise spectrum was averaged for each selected levels of forward speed for all operations. The results were statistically analyzed. The mean values were plotted in the occupational noise exposure standard curve to determine the safe exposure level of the power tiller operator.

2.5.2 Tractor Noise Levels

Gupta (1978) stated that test reports available from Central Farm Machinery Training and Testing Institute (CFMTTI), Budni showed that the noise levels in different makes of tractors ranged between 90 to 100 dB(A), which were above the safe limit for 8-hour work exposure.

Bansal et al (1982) reported that the overall noise level in the tractors was attributed mainly to combustion and cooling fan noise although other sources like bearings, gears, air suction, fuel injection, valve operating mechanism, etc. also contributed to it. The overall noise levels increased with engine speed and the power it generated. They reported noise levels of Indian tractors between 87 and 98 dB(A).

Kumar et al (2005) concluded in their study that tractor noise levels in India exceeded the recommended safe limits of OSHA and NIOSH prescribed standards. They noticed high frequency hearing loss among tractor driving farmers.

2.5.3 Tractor Noise Measurement

Selvan and Mehta (2008) measured noise levels of the tractors at operator's ear level at no load under laboratory condition, at no load on tar road during transport mode and during ploughing operation.

2.5.4 Tractor Exhaust Noise

Harris (1957) and Munjal (1987) stated that exhaust noise is by far the most significant component of engine noise. Analysis of exhaust noise pattern of a diesel engine showed large peaks just above and below its firing frequency.

Jadhav and Ghatage (2000) stated that an engine noise is mainly due to exhaust noise. They stated that exhaust noise is one of the major contributors to noise from vehicles powered by internal combustion engines. For the same power rating, diesel engines are noisier than gasoline engines, since the combustion characteristics of diesel engines produce more harmonics than slower combustion of gasoline. An unmuffled gasoline engine radiates exhaust noise in the range from 90 to 100 dBA while an unmuffled diesel engine under identical conditions radiates exhaust noise in the range from 100 to 125 dBA.

Evans et al (2004) explained that the main sources of noise on agricultural tractors are the engine / exhaust and the transmission. Any attached implement, especially PTO-driven, can also be a significant noise source but this is dealt with in a separate case study. According to them, forage harvesters are probably the noisiest machines to be used immediately behind tractors. Other potential attachments include disc mowers and power harrows. They further stated that the noisiest machines to be used immediately behind tractors do not pose any problem as long as the attached tractors are fitted with effective “Q-cabs” and are used with the rear windows closed. Average in-cab noise levels (LA_{eq}) during forage harvester operation were found to be 90 dB(A) with the rear window open and 74 dB(A) with the window closed i.e. a significant reduction.

Rahman et al (2005) stated that an inherent drawback of IC engines is that it is a major source of noise pollution. The sources of noise in an engine are the exhaust noise and the noise produced due to friction of various parts of the engine.

2.5.5 Ill Effects of Tractor Noise

Mathews (1977) reported that audiological surveys carried out abroad established that farm workers especially tractor drivers suffer from hearing loss due to tractor noise.

Selvan and Mehta (2008) concluded from several references that the occupational hazards of tractor driving included deafness by noise. It was also stated that the discomfort of the working environment results in lowering of work output.

2.6 NOISE ATTENUATION

Mehta et al. (1997) reported that when the HMT 3511 tractor was tested with conventional mufflers it contributed considerably to high frequency noise reduction, but was not very effective in reducing low frequency noise.

Jadhav and Ghatage (2000) reported that in order to comply with the law of environmental protection, the exhaust of vehicle including the noise and the burned gas should be strictly controlled.

Evans et al (2004) stated two possible phases during the course of noise transmission to the human ear through the air: 1. Air borne and structure borne. The available methods of noise reduction which can be applied to both of above are: 1. Reduction at source, 2. Sound barrier, 3. Vibration reduction, 4. Sound absorption, 5. Silencers, and 6. Active cancellation. Silencers or mufflers are a special case of absorption and reduce acoustic pressure fluctuations in streams of air or other fluid.

Selvan and Mehta (2008) suggested that better noise control features in tractors can make their use comfortable for the operator and agricultural workers. Therefore, initial efforts at tractor noise reduction should investigate exhaust muffler improvements.

Anonymous (2013b) stated that the sound and vibrations are closely related to each other. Sound waves are generated by vibrating components and pressure waves (sound waves) can also induce the vibration. Hence, attempting to reduce noise can be a similar problem to the attempting to reduce vibrations.

It was reported (Anonymous, 2014a) that a cab is the protective cabin that started to be more commonly added to tractors from the 1950s, but was often supplied by other firms as the main manufacturers did not see the need or demand at first. Then safety cab was started to be produced in 1960 after introduction of the legislation to protect driver from rollover accidents crushing them. Then over a period of time, H & S led to the Q cab or Quiet Cab to reduce the noise levels the driver was subjected to. The modern tractors come equipped with A.C., Suspension cabs with Air sprung seats, sound proofed, adjustable independent suspension systems, etc.

2.6.1 Noise Attenuation Features of Indian Tractors

Mehta et al. (1997) conducted a study to measure the noise levels on four tractors viz. HMT 3511, HMT 2511, Ford 3600 and MF 1035 at CIAE under laboratory and field conditions. They observed the effect of different types of mufflers on noise levels of tractors.

It was observed that the maximum sound pressure levels at operator's ear level on both the tractors at no load were within the recommended limit of 90 dB(A) for 8 h exposure time.

Indian tractors, as Kumar et al (2005) stated, do not have adequate vibration and noise attenuating design features.

2.6.2 Exhaust Noise Attenuation

Jadhav and Ghatage (2000) reported that mufflers are commonly used to minimize sound transmission caused by exhaust gases. Therefore muffler design becomes more and more important in noise reduction. The muffler is an important component of the modern vehicle exhaust system.

2.6.2.1 Exhaust Muffler Types

Munjal (1987) and Jadhav and Ghatage (2000) stated that for silencer or muffler system to be of high performance, it should be a combination of reactive and dissipative muffler to reduce high frequency sound and active attenuation to reduce low frequency sound.

Kumar (1994) studied the acoustic performance of mufflers of some tractors and tried to design a new one to get lower noise level. Jadhav and Ghatage (2000) conducted a study on noise attenuation of diesel engine with different types of mufflers of circular cross section and having expansion ratio of 16 using 20 gauge mild steel plate. Each was 600 mm long and made to fit on 38.1 mm exhaust pipe of engine.

Evans et al (2004) stated that there are two basic types of silencer: absorptive and reactive. Automotive applications, such as car or tractor exhaust systems, usually use a combination of both absorptive and reactive techniques. Heating, ventilation and air conditioning (HVAC) systems use absorptive, duct silencers which are incorporated in bends and louvers, and which may be applicable to fan and airflow noise in farm building applications.

Rahman et al (2005) reported that muffler technology has not changed very much over the past 100 years. The exhaust is passed through a series of chambers in reactive type mufflers or straight through a perforated pipe wrapped with sound deadening material in an absorptive type muffler. Both types have strengths and weaknesses.

2.6.2.2 Exhaust muffler performance

Jadhav and Ghatage (2000) conducted tests on three different models of mufflers, which were fitted onto the exhaust outlet of the engine and for each design the SPL was measured at a distance of 1 meter from the muffler outlet end and at an angle 45° to the axis of the muffler. SPL was also recorded at a distance 1 meter from the exhaust pipe outlet and at angle 45° to the axis of the exhaust pipe after disconnecting the muffler. The difference between the two readings was taken as the noise attenuation produced by the particular model.

Selvan and Mehta (2008) selected three mufflers (A, B and C) and evaluated for their noise reduction ability on two tractors (Tractor I & II) of 23 kW PTO power. The expansion chambers of these three mufflers were of different designs and shapes. They concluded that muffler B reduced noise levels considerably on both the tractors in conversational frequencies.

Chapter-3

MATERIALS AND METHODS

This chapter contains information on the materials and methods which are employed to conduct the experiment to meet the set objectives. Details of the machines and instruments used during the study are provided at length. Two tractors, one small sized (15 HP) and second one medium sized (60 HP) were selected to represent the two different categories of tractors namely mini (small) and medium sized tractors respectively which are presently in common use among Indian farmers. Both the tractors were availed from college (CAET) for the purpose of sound level and vibration level measurements with particular intention of testing the noise levels of different muffler designs at varying engine speeds (RPM). Sound level measurements were taken by use of sound level meter SL-4001 while vibration levels were measured with the use of vibration meter VB-8201HA, which were available at the department of farm machinery and power engineering at CAET, AAU, Godhra.

The initial sound level evaluation was conducted along with vibration level measurements, which was followed by preliminary noise level tests under different muffler installations. Later more trials on noise level measurements were conducted on selected mufflers only. In the later stage, the noise level measurements were conducted at three places i.e. an ear level, at 10 m distance and at 30 m distance away from the tractors.

Chapter 3 has been organized under following seven major headings.

3.1 Selection of Tractors

3.2 Measurement of Noise (SPL)

3.3 Measurement of Vibrations

3.4 Preliminary Test of Noise Level (SPL) Measurement of Farm Tractors under Different Muffler Designs

3.5 Measurement & Analysis of SPLs under Selected Muffler Designs on Farm Tractors

3.1 SELECTION OF TRACTORS

Two tractors, one of small sized and another of medium size, were selected for the experiment. It was ensured that the engine and exhaust parts of the farm tractors selected for the experiment are those specified and provided by the respective manufacturers. The major specifications of the tractors under test are tabulated. The tractors with cab are neither in common use by the farmers in India nor it was available with the department, hence it could not be included as one of the treatments under present study. The information of each of the tractors under test is presented in Table 3.1.

Table 3.1: Tractor model, year, horse power and condition

Sr. No.	Name of Tractor Model	Horse Power (HP)	Year of Purchase	Registration No.	Condition
1.	Yuvraj 215	15	2012	GJ-17-AE-1216	Good
2.	5900 DI TAFE	60	2012	GJ-17-D-9108	Good

3.1.1 Small Sized (Mini) Tractor (Tractor-1)

The small or mini tractor was powered with engine horse power capacity of 15 HP as stated by its manufacturer (Mahindra Tractors Pvt. Ltd., India). Tractor condition was normal for conducting all routine operations.

Fig. 3.1: Tractor-1 (Mini Tractor Model 215)

3.1.2 Medium Sized Tractor (Tractor-2)

The medium sized tractor was powered with an engine horse power capacity of 60 HP. It is manufactured by TAFE (Tractor and Farm Equipment Ltd.) based at Chennai in India. Tractor condition was normal for conducting all routine operations. Depending on engine size of the tractor, the 60 hp engine powered tractor may however fall into the medium category tractors, under Indian agricultural conditions it can be treated as a big tractor.

Fig. 3.2: Tractor-2 (Model 5900 DI)

3.1.3 Major Specifications of Tractor-1 and Tractor-2

The major specification details of Tractor-1 and Tractor-2 are tabulated in the Table 3.2.

Table 3.2: Technical Specifications of Tractor-1 (Mini Tractor) and Tractor-2

Sr. No.	Particulars	Tractors	
		Tractor-1 (Mini Tractor)	Tractor-2
1.	Model	215	5900
2.	Engine HP	15 HP	60 HP
3.	No. of Cylinders	1	4
4.	Rated RPM	2300	2300
5.	Breaks	Dry Disc Brake	Wet Disc Brake
6.	Clutch	Single Plate Dry Type	Dual with Clutch Lining
7.	Gear Box Type	Sliding Mesh	Constant Mesh Gear Box with Planetary gears
8.	Cubic Capacity	863.5 cc	3300 cc
9.	Air Cleaner	Wet type	Oil Bath Type
10.	Hydraulic Pump Type	Gear Pump	Gear Pump
11.	Bore/Stroke	88.9 / 110 mm	91.4 / 127
12.	PTO hp	12	56
13.	Front Tires	5.20-14, 8 Ply	7.50-16, 8 Ply

		Rating	Rating
14.	Rear Tires	8.00-18, 6 Ply Rating	16.9-28, 12 Ply Rating
15.	Turning Radius	2600 mm	3630 mm

The technical specifications indicate the information on tractor engine horse power capacity, number of cylinders, air cleaner, rated RPM, bore-stroke ratio etc.

3.2 MEASUREMENT OF NOISE (SPL)

The standard instruments available at the department / college are used for measurement of sound pressure and vibration levels. Sound level observations on a particular tractor were recorded in the similar environment and surroundings to negate the effects of an erratic environmental condition during measurement of sound pressure levels.

3.2.1 Sound Pressure Levels of Noise Produced by Tractors

As sound power level (SPL_{power}) is the measure of sound source itself and does not depend on source's surroundings, the quantity most often used to measure the intensity or strength of noise levels is sound pressure level ($SPL_{pressure}$) (Anonymous, 2002a). The sound power level is the total sound power radiated from a source with respect to a reference power. The combination of fluctuations in pressure and velocity can be used to form a measure of sound power. Sound pressure or acoustic pressure is the local pressure deviation from the ambient (average, or equilibrium) atmospheric pressure, caused by a sound wave. In air, sound pressure can be measured using a microphone, and in water with a hydrophone. The SI unit for sound pressure P is the Pascal (Pa) (Source: http:// en.wikipedia.org / wiki / Sound_pressure). Sound pressure level (SPL) or sound level is a logarithmic measure of the effective sound pressure of a sound relative to a reference value. It is measured in decibels (dB) above a standard reference level. The standard reference sound pressure in air or other gases is 20 μPa, which is usually considered the threshold of human hearing (at 1 kHz).

Noise is measured in units of sound pressure called decibels (dB), named after Alexander Graham Bell. The decibel notation is implied any time a "sound level" or "sound pressure level" is mentioned. Decibels are measured on a logarithmic scale: a small change in the number of decibels indicates a huge change in the amount of noise and the potential damage to a person's hearing. The decibel scale is convenient because it compresses sound pressures important to human hearing into a manageable scale. By definition, 0 dB is set at the reference sound pressure (20 micropascals at 1,000 Hz, as stated earlier). At the upper end of human hearing, noise causes pain, which occurs at sound pressures of about 10 million times that of the threshold of hearing. On the decibel scale, the threshold of pain occurs at 140 dB. This range of 0 dB to 140 dB is not the entire range of sound, but is the range relevant to human hearing. Decibels are logarithmic values, so it is not proper to add them by normal algebraic addition. (Source: https://www.osha.gov/dts/osta/otm/new_noise/).

The sound pressure level can be calculated using the following formula:

$$SL_{pressure} = 20\log_{10}\left(\frac{P}{P_{ref}}\right) \tag{3.1}$$

Where

$SL_{pressure}$ = Sound pressure level, dB

P = Sound pressure, Pa (N/m^2)

P_{ref} = Reference sound pressure (i.e. equal to 2×10^{-5} Pa)

In the above equation, the reference pressure represents the normal threshold of hearing for most human beings.

3.2.2 Use of A-weighting in Tractor Noise Measurement

The human ear is not equally sensitive at all frequencies. It is most sensitive in the 500 Hz to 6000 Hz range and least sensitive at extremely high and low frequencies outside this range. Three different standardized characteristics called the "A", "B", and "C" weighting networks have been developed to standardize results and comparisons. A-weighting in the SPL measurement is a measurement scale that approximates the "loudness" of tones relative to a 40-dB sound pressure level, 1,000-

Hz reference tone. A weighting is said to best fit the frequency response of the human ear: when a sound dosimeter is set to A-weighting, it responds to the frequency components of sound much like one’s ear responds. A-weighting has the added advantage of being correlated with annoyance measures and is most responsive to the mid-frequencies, 500 Hz to 4,000 Hz. The "A" network is widely used as it provides the best correlation to human hearing in subjective tests. Legislation and OEM documentation is most often written with reference to the "A" scale (Anonymous, 2002a). Hence, A-weighting scale is used during the study and accordingly dB is denoted by dB(A) or dBA throughout this dissertation.

3.2.3 Instrumentation and Recording of SPL (Sound Pressure Level)

In a study conducted by Arude and Paralikar (2004) on noise pollution in cotton ginneries at CIRCOT (Central Institute for Research on Cotton Technology), the sound level meter was used for measurement of noise which was a hand held, portable, battery operated, digital display type instrument with measurement range 20-140 dB with accuracy of 0.5 dB. Similar kind of digital sound level meter (viz. SL 4001 of IEC 61672 Class 2 type) is utilized during experimentation for measuring the noise levels during farm tractor operation.

Tractor engine is one major source of noise. The measurements of noise will normally be made at the operator’s ear level during field operations. The noise level observations will also be recorded at closer and distant locations of the farm tractors operating into the field to specifically assess the possibility of adverse effects on farm workers, farm family members/neighbors and bystanders as well. During preliminary tests, the observations of sound pressure levels (SPL) were taken at two places i.e. at ear level (approximately at 1 m away from the engine/exhaust) and at the distance of 10 m away from the tractor engine/exhaust. Later after selection of two muffler designs for each of the tractors, detailed measurements and analysis of the sound data was carried out which included one additional SPL measurement at 30 m distance away from the tractor.

3.2.3.1 Use of sound level meter

Sound level meters generally used for measuring sound pressure levels (SPLs) are equipped with accurate microphones containing flexible membrane or cartridge protected by a grill or screen. When sound waves fall on it they oscillate back and forth which produce electric signal or current from the membrane which is measured and converted into a decibel rating denoting the strength or volume of the sound (Anonymous, 2013b). Usually sound level meters (SLMs) are able to measure the sound levels to make sure that whether it is within safer limit or not. During the experiment, the sound level meter Lutron SL-4001 was utilized for measuring the noise levels taking place at different RPMs on two separate tractors under different muffler conditions.

As a single-function handheld test device, sound level meter (SLM) is intended to be held at arm's length during measurements (to reduce the effects of the body on the measurements) or secured to a tripod stand for more stability. As stated by Anonymous, 2013b, a sound level meter (SLM) is a device that is used to make frequency-weighted sound pressure level measurements displayed in dB-SPL. All SLMs feature an omnidirectional measurement quality condenser microphone, a mic preamp, frequency weighting networks, an RMS detector circuit, averaging circuits, the meter display, AC and DC outputs used to feed other measurement devices or for recording (see Figure at below).

Fig. 3.3: Sound level meter (Lutron SL 4001)

3.2.3.2 Logging of sound data

The volume of sound alone cannot signify the level of danger involved into it. The duration or repetition of certain level of sound is also important to determine the level of danger involved. Sound level meters are used to measure both sound logging and sound intensities. Sound level meters log or record the sound levels over a certain period of time and then calculate an average value of sound level. If the average is too high, the sound level is not safe. Also, they can store the information on sound level peak values to measure that whether a particular intensity of sound is going so high that it can cause immediate danger (Anonymous, 2013b).

3.2.3.3 Distance of noise measurement

In the measurement of noise levels (Sound Pressure Levels), the distance of the measuring microphone from a sound source should not be omitted. Omission of distance from sound source to the recording microphone during SPL measurements make the data useless. As stated on http:// en.wikipedia.org/ wiki/ Sound_pressure, distance of one metre (1 m) from the source is a frequently used standard distance. However, in case of measuring background noise, distance need not be quoted as there does not exist any single source, but when measuring the noise level of a specific equipment, the distance should always be stated.

3.2.4 Analysis of Sound Prssure Levels Measured on Farm Tractors (Tractor-1 & Tractor-2)

The sound pressure levels were recorded for both the selected tractors under different muffler installations. After conducting preliminary tests, two mufflers were finalized for each tractor for detailed experimentation which included sound pressure level observations at three locations i.e. ear level (EL), at 10 m and at 30 m distance from the tractors which were operated at different engine speeds.

The investigation on measuring noise levels generated by different tractors under study was carried out by observing the noise levels at different engine speeds. Sound level measurements were taken after **10 minutes** lapse period after starting of the tractors. Before recording actual observations, the **background noise level** was recorded. The observations of noise levels were made at operator’s ear level and 10 m

/ 30 m away from the tractors. Due care was taken that the wind direction and speed on the days of recording sound levels do not differ significantly. Each operational trial was replicated thrice with uniform data acquisition period of 30 (thirty) seconds in SLOW response mode of the SLMs to record the average of sound levels.

The tractor engine specifications like horse power capacity, number of cylinders, valve mechanisms, design of exhaust silencers, year of manufacturing, and make and model wise specific features etc. were taken into account during experimentation and analysis of results for evaluating their effects on generation of vibrations and noise levels. As Hagen (2011) had stated that it is the combination of the tractor's manufacturing year, style and size that creates the amount of noise it produces and what must be done to control the noise. The experimental analysis using split plot design was conducted for Tractor-1 and Tractor-2 under three muffler conditions viz. M-1 (No Muffler), M-2 (Standard Muffler) and M-3 (Muffler-C).

3.2.5 Specifications of Sound Level Meter

Technical specifications of the sound level meter Lutron SL 4001 (IEC 651 Type 2) have been provided here in Table 3.3.

Table 3.3: Specifications of the sound level meter SL 4001 (Lutron make)

Sr. No.	Particulars	Description
1.	Display	18 mm (0.7") LCD (Liquid Crystal Display)
2.	Range of Measurement	3 (Three) Min: 30 dB Max: 130 dB
3.	Resolution	0.1 dB
4.	Functions	dB Measurement (A & C Frequency Weighting) Time Weighting (Fast & Slow)

		Maximum Hold
5.	Accuracy	Accuracy in A weighting are as following. 31.5 Hz - ± 3 dB 63 Hz - ± 2 dB 125 Hz - ± 1.5 dB 250 Hz - ± 1.5 dB 500 Hz - ± 1.5 dB 1 kHz - ± 1.5 dB 2 kHz - ± 2 dB 4 kHz - ± 3 dB 8 kHz - ± 5 dB Calibrating Input Signal on 94 dB is 31.5 Hz to 8 kHz.
6.	Frequency Weighting	A & C
7.	A-weighting	The characteristic is simulated as "Human Ear Listening" response. Typically for making the environmental sound level measurement, A weighting is always selected.
8.	B-weighting	The characteristic is near the "FLAT" response. Typically it is suitable for checking the noise of machinery (Q.C. check) & knowing the sound pressure level of the tested equipment.
9.	Frequency	31.5 Hz to 8000 Hz

10.	Calibrator	B & K (Bruel & kjaer), multi-function acoustic calibrator, model: 4226.
11.	Microphone	Electric condenser microphone.
12.	Size of microphone	½ inch standard size
13.	Range selections	30 to 80 dB 50 to 100 dB 80 to 130 dB 50 dB on each step with over and under range indicating
14.	Time weighting	Fast: t = 200 ms Slow: t = 500 ms
15.	Calibration	Built in external calibration VR Easy to calibrate by external screw driver
16.	Output signal	AC output AC 0.5 V_{rms} DC output DC 0.3 to 1.3 V_{DC} 10 mV per dB Output impedence – 600 Ohm
17.	Operating temperature	0 to 50 °C (32 to 122 °F)
18.	Operating humidity	Less than 80% RH

19.	Power supply	DC 9 V battery (Heavy Duty Type)
20.	Power consumption	DC 6 mA
21.	Dimension	205 x 80 x 35 mm (8.1 x 3.2 x 1.4 inch)
22.	Weight	280 g/0.62 Lb (including battery)

3.2.6 Analysis of Sound Frequencies and Amplitudes

The sound level meter give us a single sound pressure level measured over a wide frequency band. In order to reveal the individual frequency components making up the wide-band signal we should perform a frequency analysis. In absence of filters, the recorded sound clips were analyzed with the help of two different software applications namely *Spectrumview* and *Spec* for getting the sound frequency spectrum particularly in the range of 20 to 20000 Hz which is the human hearing range. The peak frequencies at the interval of 0.5 seconds were recorded for each muffler for Tractor-1 and Tractor-2 under different engine speed conditions i.e. 1000, 1250, 1500, 1750 and 2000 RPMs at the specified places/locations. The *Spec* application was used to present the entire content of the frequencies and the amplitudes/intensities of different magnitudes. The analysis of graphs produced were interpreted to arrive at the appropriate inferences obtained with the different mufflers at same engine speeds of the particular tractors at the similar locations. The relative peak frequencies of the sound produced from the exhaust noise were measured on tractor-1 and tractor-2 with the different muffler conditions.

3.2.6.1 Sample rate and process gain

The sample rate is the speed at which the sound card captures the audio data. The sample rate can be set to 48000, 44100, 22050, 11025 and 8000 samples per second. The up/down arrows in the interface allow selection between the different sampling rates. One has to make sure to select a sample rate that is high enough to process the highest sound frequency being analyzed. A rule of thumb is to select a sample rate that is twice the highest audio frequency (Anonymous, 2015a).

The sound data may be processed at different gain settings. Each division of the gain control amplifies/attenuates the input signal by a factor of 1 dB. Higher gain settings can be used to obtain a brighter display.

3.2.6.2 Fast fourier transform (FFT)

Fast Fourier Transform (FFT) method is employed for conducting the analysis of the wave forms. The human ear automatically and involuntarily performs a calculation that can take the intellect years of mathematical education to accomplish (Anonymous, 2015e). The ear formulates a transform by converting sound waves of pressure travelling over time and through the atmosphere into a spectrum, the brain then turns this information into a perceived sound. A similar conversion can be done using mathematical methods on the same sound waves or virtually any other fluctuating signal that varies with respect to time. The Fourier transform is the mathematical tool used to make this conversion.

The Fourier transform converts waveform data in the time domain into the frequency domain. The Fourier transform accomplishes this by breaking down the original time-based waveform into a series of sinusoidal terms, each with a unique magnitude, frequency, and phase. This process, in effect, converts a waveform in the time domain that is difficult to describe mathematically into a more manageable series of sinusoidal functions that when added together, exactly reproduce the original waveform. Plotting the amplitude of each sinusoidal term versus its frequency creates a power/pressure spectrum, which is the response of the original waveform in the frequency domain.

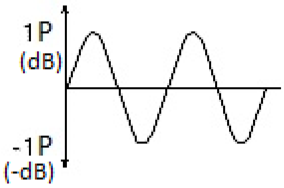
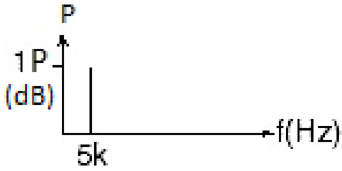
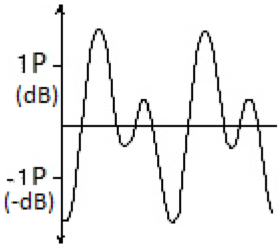
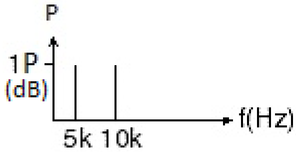
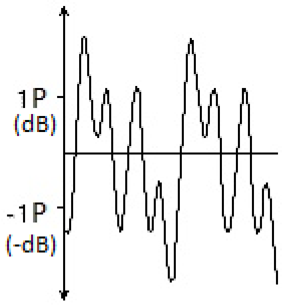
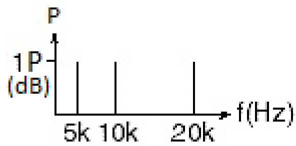
<u>Time Series</u>	<u>Fourier Expansion</u>	<u>Pressure Spectrum</u>
	P(t) = 1sin(ω1)t Where ω1 = 2π(5kHz)	
	P(t) = 1sin(ω1)t + 1sin(ω2)t Where ω1 = 2π(5kHz) ω2 = 2π(10kHz)	
	P(t) = 1sin(ω1)t + 1sin(ω2)t + 1sin(ω3)t Where ω1 = 2π(5kHz) ω2 = 2π(10kHz) ω3 = 2π(20kHz)	

Fig. 3.4: Illustration of Fourier Transform (Adapted from http://www.dataq.com)

The figure (Fig. 3.4) illustrates the time to frequency domain conversion concept. In sound waveform analysis, the Y-axis contains sound pressure levels (SPL) in dB and X-axis contains frequencies especially the sound frequencies in human hearing range. The power or pressure spectrum may also be termed as frequency spectrum. Hence, the Fourier transform converts waveform data in the time domain (time series) into the frequency domain (frequency spectrum).

The Fourier transform has been adapted for use on the personal computer. Algorithms have been developed to link the personal computer and its ability to evaluate large quantities of numbers with the Fourier transform to provide a personal computer-based solution to the representation of waveform data in the frequency domain.

3.2.6.3 Frequency spectrum analysis

Applications like Spectrum-view or Plot-Spectrum takes the selected audio (which is a set of sound pressure values at points in time) and converts it to a graph of frequencies (the horizontal scale in Hz) against amplitudes (the vertical scale in dB). A view of the display of Plot Spectrum is shown in the figure (Fig. 3.5). The lowest displayable dB range in the graph can be reduced by lowering the default -60 dB (or -92/-100) value for "Meter/Waveform dB range" in the Interface Preferences. Plots are made using a mathematical algorithm known as a Fast Fourier Transformor (FFT). It gives a value for each narrow band of frequencies that represents how much of those frequencies are present. All the values are interpolated to create the graph. In other words, Plot Spectrum take the audio in blocks of 'Size' samples, does the FFT, and averages all the blocks together (Anonymous, 2015f).

A sample view of the display of two Frequency Spectra is shown in the Fig. 3.5. In this figure, the spectra that is taken over the first and last 0.3 seconds of the sound file. In this spectra, the harmonics appear as equally spaced components (vertical lines).

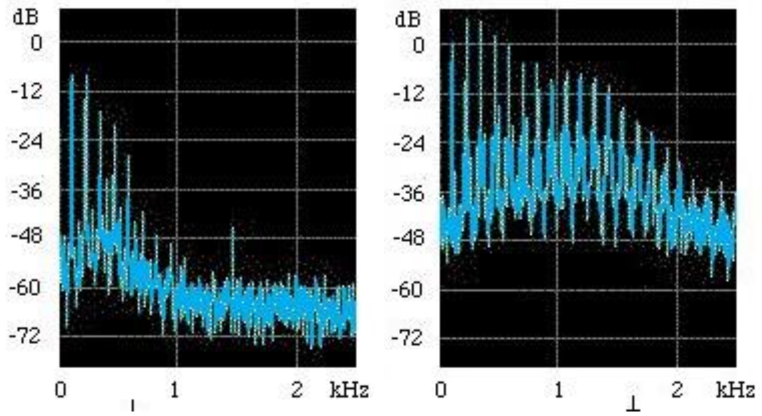


Fig. 3.5: Sample view of two frequency spectra

3.2.6.4 Audio spectrum analyzer software

Anonymous (2015e) stated that to use the Audio Spectrum Analyzer, input to Audio Spectrum Analyzer can be made from microphone or wave file. Audio Spectrum Analyzer has variable displays, Fast Fourier Transform (FFT) display, variable sample rates (8000 Hz, 11025 Hz, 22050 Hz, and 44100 Hz), variable transform sizes (1k, 2k, 4k, and 8k), adjustable upper and lower limits, continuous, averaged and peak hold, selectable foreground and backgrounds, variable markers, option to save a reference plot compare with the foreground plot, time display (oscilloscope), triggered sweep, and waterfall display (color or B/W).

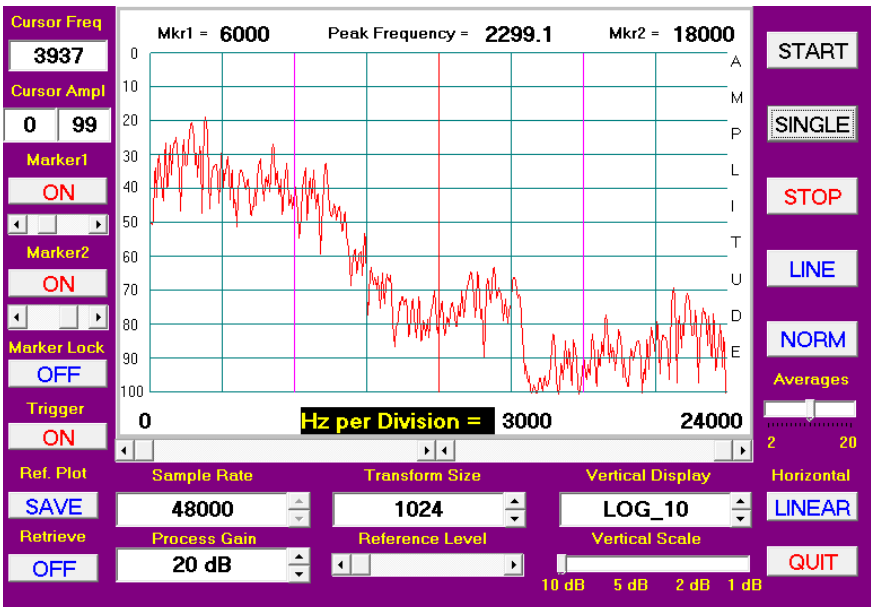


Fig. 3.6: Frequency analysis by Spectrumview (Frequency vs Amplitude (dB))

Fig. 3.6 depicts the form display of the output obtained by Audio Spectrum Analyzer. Figure displays graph of Frequency (Hz) versus Amplitude (dB). It can be seen that the peak dB magnitude has been normalized to zero, and the plot has been clipped at -100 dB. The sound frequency spectrum is spread over 0 to 24000 Hz frequency range. The sound frequency spectrum ranging from 20 to 20000 Hz was the prime area of interest as it contains the human hearing range.

3.2.6.5 True spectrum analysis

A spectrogram or "true spectrum" is a visual representation of sound. It displays the amplitude of the frequency components of the signal over time. The Spectogram of a sound clip would be computed over the entire clip and would provide very detailed frequency resolution but essentially no time resolution at all.

In otherwords, this "true spectrum" would offer an average frequency distribution over the entire recorded sound. If we select a short interval of audio, the short-time spectrum has frequency resolution limited by the observation window time and the result is affected by the spectrum of the window itself.

The spectrogram (Fig. 3.7) shows time on X axis, frequency on the vertical (Y) axis, and sound level (on a decibel scale) in false colour (blue is weak, red is strong).

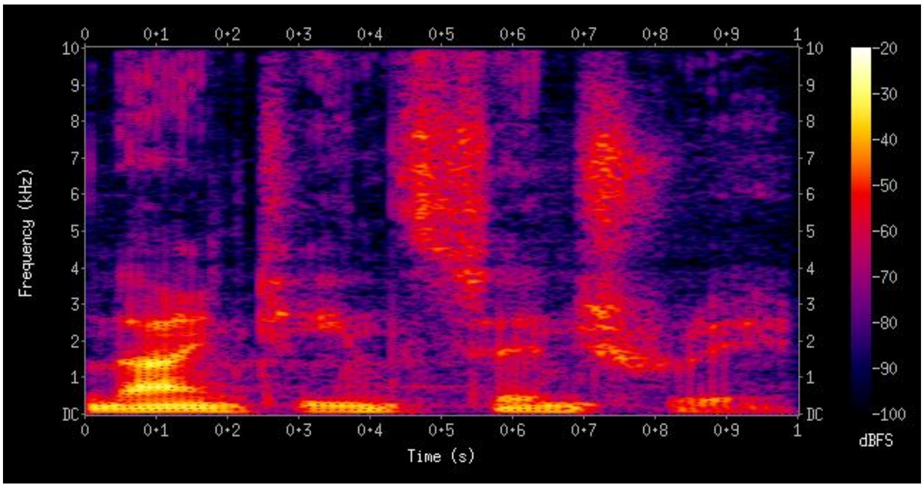


Fig. 3.7: Sample view of the spectrogram

(Source: https://en.wikipedia.org/wiki/Spectrogram#/media/File:Spectrogram-19thC.png)

An acoustic spectrum analyzer namely *Spek* is employed to analyze the sound clips of tractor noise and to generate the spectral representation of the noise audio files in a time-varying graph, usually called spectrogram. Spek is free and open source software licensed under GPLv3. The project is written in C++, the code is available on GitHub (https://github.com/alexkay/spek).

3.2.6.6 Amplitude ratio

A measure of the strength of a wave is its amplitude which is the vertical distance between the heights of the wave's peaks and the heights of the troughs. The table given below describes how the logarithmic scale can describe very big and very small numbers representing power, energy or amplitude ratios with much shorter notation. The decibel calculating formula is given by

$$dB = 20 \log_{10} N \qquad 3.2$$

Where dB = Number of Decibels and N = Aplitude Ratio

Human ears are very sensitive. You can hear everything from whisper at 10-meter distance to the noise of jet engines. In terms of power, the sound of a firecracker can be 100,000,000,000,000 times more powerful than the faintest sound that the typical human ear can detect (20 micro-pascal). That's a very big difference! Since the range of sound intensities that the human ear can detect is so huge, a logarithmic scale is used for measuring sound intensity. On the decibel scale, the faintest sound, also known as the threshold of hearing, is assigned a level of 0 decibels. A sound that is 10 times more intense is assigned a level of 20 decibels. A sound that is 100 times more intense is assigned a level of 40 decibels. The list below shows some common sounds and their decibel levels.

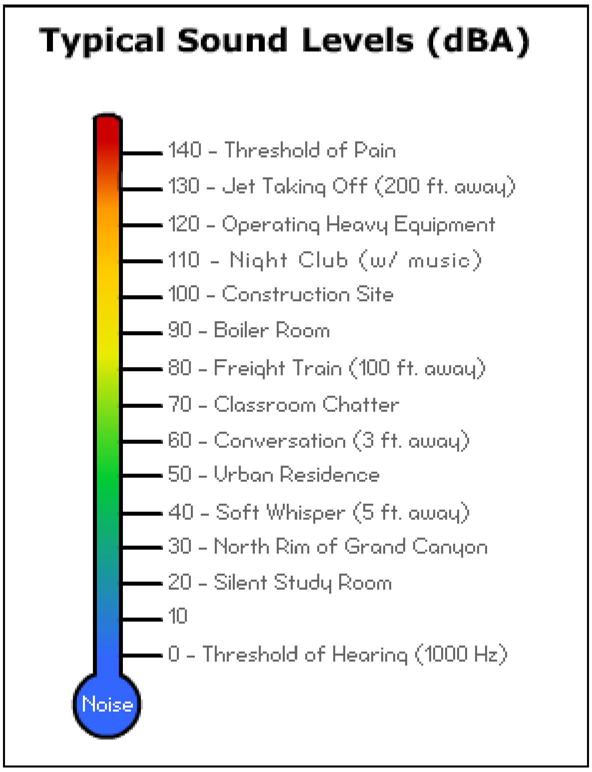


Fig. 3.8: Decibel scale

(Source: https://www.osha.gov/dts/osta/otm/new_noise/#decibles)

3.2.6.7 Percent amplitude levels

Anonymous (2016a) stated that most noise is not a pure tone, but rather consists of many frequencies simultaneously emitted from the source. To properly represent the total noise of a source, it is usually necessary to break it down into its frequency components. One reason for this is that people react differently to low-frequency and high-frequency sounds. Additionally, for the same sound pressure level, high-frequency noise is much more disturbing and more capable of producing hearing loss than low-frequency noise. Engineering solutions to reduce or control noise are different for low-frequency and high-frequency noise. As a general guideline, low-frequency noise is more difficult to control.

The percent amplitude levels were calculated using the comparative amount of the amplitudes of specific frequency ranges as contained in a certain noise clips as recorded during the experimentation on noise (SPL) measurements conducted on Tractor-1 and Tractor-2 under different muffler conditions. For this, the spectograms of the noise clips recorded for individual experimental setups (treatments) were analyzed visually to observe the decibel levels followed by their conversion into respective amplitude ratio and finally leading to per cent amplitude levels of the composed frequencies.

3.2.6.8 Frequency analysis of noise from spectrograms

In absence of octave band analyzers, the spectrograms of the tractor noise were used to analyze the several frequency bandwidths such as 0-2.5 kHz, 2.5-5.0 kHz and so on.

Anonymous (2016a) stated that octave bands, a type of frequency band, are a convenient way to measure and describe the various frequencies that are part of a sound. A frequency band is said to be an octave in width when its upper band-edge frequency, f_2, is twice the lower band-edge frequency, f_1: $f_2 = 2\ f_1$.

Each *octave band* is named for its center frequency (geometric mean), calculated as follows: $f_c = (f_1 f_2)^{1/2}$, where f_c = center frequency and f_1 and f_2 are the lower and upper frequency band limits, respectively. The center, lower, and upper frequencies for the commonly used octave bands are listed in Table 3.4.

Table 3.4: Octave band filters and frequency range

Lower Band Limit (Hz)	**Band Center Frequency (Geometric Mean in Hz)**	**Upper Band Limit (Hz)**
22	31.5	44
44	63	88
88	125	177
177	250	354
354	500	707
707	1,000	1,414

1,414	2,000	2,828
2,828	4,000	5,656
5,656	8,000	11,312
11,312	16,000	22,624
Each octave band is named for its center frequency.		

(Source: https://www.osha.gov/dts/osta/otm/new_noise/#decibles)

The width of a full octave band (its bandwidth) is equal to the upper band limit minus the lower band limit. For more detailed frequency analysis, the octaves can be divided into one-third octave bands; however, this level of detail is not typically required for evaluation and control of workplace noise. Electronic instruments called octave band analyzers filter sound to measure the sound pressure (as dB) contributed by each octave band. These analyzers either attach to a type 1 sound level meter or are integral to the meter (Anonymous, 2016a).

3.3 MEASUREMENT OF VIBRATIONS

People riding and operating farm tractors face vibrations. Anonymous (1982) stated that in some cases, certain frequencies and levels of vibration can permanently damage internal body organs. In vibration analysis, the frequency of periodic motion is nothing but the number of cycles per unit time that can be expressed as a function of time. The magnitude of the vibration in any mechanical system can be measured or explained in terms of displacement, velocity and acceleration. The velocity and acceleration are respectively the first and second derivatives of the displacement. Vibration is generally measured in acceleration (RMS) values. It is also convenient practice to express the acceleration in terms of g's i.e. $a_{RMS}/g = a_{RMS}/9.81$.

Taylor (2003) stated that the vibration can be measured by displacement, velocity, and acceleration. Displacement is measured with a contacting or non-contacting displacement transducer. Velocity is measured with a velocity transducer that has a relatively flat frequency response between 10 and 2,000 Hz. Acceleration is measured with an accelerometer. It is possible to measure displacement with an accelerometer, acceleration with a velocity transducer, etc. However, the signals must be either differentiated or integrated. The conversions can be calculated with the equations available or with the Vibration Calculator Program.

Shreve (1994) explained the simplest and easiest way to demonstrate and explain vibration and its measurable characteristics by following the example of the motion of a weight suspended by a spring. This can be a valid analogy since all machines and their components have weight (mass), spring-like properties (stiffness) and damping. The motion of the mass from top to bottom range and back to the initial starting position in the vertical direction is referred to as one cycle, and it has all the characteristics needed to define the vibration. Continued motion of the spring-mass system will simply be repeating these measurable characteristics. The characteristics needed to define the vibration include: (i) Frequency, (ii) Displacement, (iii) Velocity, (iv) Acceleration, and (v) Phase.

3.3.1 Vibration Frequency

The amount of time required to complete one full cycle of the vibration is called the period of the vibration. The frequency of a vibration is simply the "inverse" of the period of the vibration. The vibration frequency may be expressed in cycles per second or CPS but the common practice is to use the term Hertz (abbreviated Hz) in lieu of CPS. Although, vibration frequency can be measured and expressed in Hertz (Hz), for most machinery vibration work, vibration frequency is measured in cycles-per-minute, abbreviated CPM. Expressing vibration frequency in terms of CPM makes it much easier to relate this characteristic to the rotational speed of the machine that is normally expressed in revolutions- per-minute or RPM.

3.3.2 Vibration Amplitude

As stated by Shreve (1994), If the machine is operating smoothly, knowing the frequency or frequencies of vibration present is not important. The magnitude of vibration or how rough or smooth the machine vibration is, is expressed by its vibration amplitude. Vibration amplitude can be measured and expressed as: (i) Displacement, (ii) Velocity, and (iii) Acceleration.

3.3.2.1 Vibration displacement

The vibration displacement is simply the total distance traveled by the vibrating part from one extreme limit of travel to the other extreme limit of travel. This distance is alsocalled the "peak-to-peak displacement". Peak-to-peak vibration displacement is normally measured in the units like mils, where one mil equals one-thousandth of an inch (1 mil = 0.001 inch) or micometers (sometimes called microns), where one micrometer equals one-thousandth of a millimeter (1 micrometer = 0.001 millimeter).

3.3.2.2 Vibration velocity

As stated by Shreve (1994), the severity of a vibration depends not only on displacement but frequency as well. Displacement is simply a measure of the distance traveled and frequency is a measure of the number of times the "trip" is taken in a given period of time such as a minute or second. Thus, Velocity = Displacement x Frequency. However, the speed of the weight is constantly changing. At the upper and lower limits of travel, the velocity is zero (0), since the weight must come to a stop before it can go in the opposite direction. The velocity is the greatest or at its peak as the object passes through the neutral position. Velocity is definitely a characteristic of the vibration, but since it is constantly changing throughout the cycle, the highest or "peak" velocity is selected for measurement.

The benefits and advantages of measuring vibration velocity instead of vibration displacement include: 1. Vibration velocity is a direct indicator of fatigue since it takes into account both displacement and frequency, 2. It is not necessary to know the frequency of vibration in order to evaluate the severity of vibration velocity since frequency is already a part of velocity, 3. A measurement of overall vibration velocity is a valid indicator of the overall condition of a machine whether the vibration is simple (one frequency) or complex (more than one frequency). For the reasons listed above, vibration velocity has become the industry standard for evaluating machinery condition based on vibration.

3.3.2.3 Vibration acceleration

Vibration acceleration is another important characteristic of vibration that can be used to express the amplitude or magnitude of vibration. Technically, acceleration is simply the rate of change of velocity. As with velocity, since the value of vibration acceleration is constantly changing, the highest or peak acceleration is selected for measurement.

However, by international agreement, levels of machinery vibration acceleration are expressed in units of "G's", where one (1) "G" is the acceleration produced by the Earth's gravitational force at sea level. By international agreement, the values of 980.665 cm/sec/sec, 386.087 in/sec/sec and 32.1739 feet/sec/sec have been established as the standard acceleration values due to Earth's gravity at sea level. Thus, a measured vibration acceleration of 1-G peak would be approximately 386 in/sec/sec (980 cm/sec/sec). It should be kept in mind that the Earth's gravitational force (G) has little to do with a machine's vibration amplitude. A machine with mechanical and/or operational problems will vibrate regardless of where it is located - on Earth or in gravity-free outer space. The accepted practice of expressing vibration acceleration amplitudes in G's is simply one of convenience and familiarity (Shreve, 1994).

3.3.2.4 Phase

In addition to frequency (Hz or CPM) and amplitude (displacement, velocity, and acceleration), the third and final characteristic needed to describe a machine's vibration behavior is phase (Shreve, 1994). From a practical standpoint, phase is simply a convenient means of determining the "relative motion" of two or parts of a machine or vibrating system. The units of phase are degrees, where one complete cycle of vibration equals 360 degrees. To demonstrate phase, two vibrating weights A & B may be considered at the same amplitude and frequency; while weight "A" is at the upper limit of travel ready to move downward and, at the same instant, weight "B" is at the lower limit of travel ready to move upward. Phase can be used to express this comparison. By plotting once cycle of motion of these two weights, it can be seen that the points of peak amplitude are separated by a half cycle or 180 degrees (one complete cycle = 360 degrees). Therefore, these two weights are said to be vibrating 180 degrees "out of phase". However, this is not taken into account in the context of present experiment.

3.3.3 Measurement of Tractor Vibrations

Shreve (1994) stated that the magnitude or amplitude of machine vibration can be expressed in units of displacement, velocity, or acceleration. Whenever it is anticipated that vibration frequencies may be present at frequencies below 600 CPM (10 Hz), measurements of vibration displacement are recommended. As a general rule, fatigue failures typically result from vibration frequencies between approximately 600 CPM (10 Hz) and 120,000 CPM (2000 Hz). Therefore, when vibration frequencies within this range are anticipated, measurements of vibration velocity are recommended. Vibration acceleration measurements (G's) are recommended whenever vibration frequencies above 120,000 CPM (2000 Hz) are anticipated.

Arude et al (2009) used vibration meter for measuring the vibration levels on different commercial models of double roller gin, pre-cleaners, lint cleaner and baling press. The vibration meter was a battery operated, portable, and hand held instrument and measured displacement, velocity and acceleration. The vibration meter had the frequency range of 5-10,000 Hz. The Low and high ranges were provided for vibration measurement.

Accordingly, similar kind of vibration meter (viz. Lutron make Model VB-8201) was utilized for measurement of vibration levels in velocity and acceleration values. The measurements can be made in RMS and Peak values. Maximum and minimum values can be recorded for specific durations. The X-axis vibrations are measured in the forward direction of motion, while Y–axis measurements are in lateral direction (perpendicular to the direction of motion) and the Z–axis vibration are made in the vertical direction (Fig. 3.8).

Fig. 3.9: Vibration meter Model VB-8201HA (ISO-9001, IEC1010)

The vibration measurements should be conducted on different crucial components, which are subjected to excessive vibrations generated out of heavier motions of reciprocating or rotating type components. The vibration level measurements have been made during the tractor operation at different engine speeds and on specific places such as bonnet, front axle and foot rest of the tractor. Vibration level observations were recorded in terms of **velocity** (m/s) and **accelerations** (m/s^2) with minimum of 10 (ten) observations in each replication. The tractor was operated at three different engine speeds i.e. 1000, 1500 and 2000 rpm on ground surface of the open fields.

Two tractors, one small sized (<20 HP) and second one medium sized (> 20 HP), were taken as primary treatment variables while tractor parts viz. bonnet, front axle and foot rest, engine-speeds viz. 1000, 1500, & 2000 RPMs were treated as secondary parameters. The vibration level observations included velocity (mm/s) and acceleration (m/s^2). The ten number of individual observations were taken in three separate trials (replications) amounting to the total of 30 (thirty) observations.

3.3.4 Vibration Meter (VB-8201 HA)

Vibration meter Model VB-8201HA (ISO-9001, IEC1010) has been employed for conducting vibration measurements on tractors under test in velocity (mm/s) and acceleration (m/s^2) units.

3.3.4.1 Main components of vibration meter (VB-8201 HA)

A digital Vibration meter VB-8201HA available at the FMPE laboratory consisted of the following main components:

1. Probe connector
2. RS-232 Connector
3. LCD Display
4. Function switches and pushbuttons
5. Probe
6. Magnetic base
7. Protective rubber meter jacket
8. Battery compartment (on rear)
9. Vibration sensor
10. BNC socket of meter

3.3.4.2 Specifications of vibration meter (VB-8201 HA)

Technical specifications of the vibration meter VB-8201HA (ISO-9001, IEC1010) have been provided here in Table 3.5.

Table 3.5: Specifications of the vibration meter VB-8201 HA (ISO-9001, IEC1010)

Sr. No.	Particulars	Description
1.	Dispaly	61 mm x 34 mm LCD display. 15 mm (0.6”) digit size.
2.	Measurement	Velocity & Acceleration RMS value

		Peak value Data hold Max. & Min. value.
3.	Range	Velocity : 200 mm/s (0.5 to 199.9 mm/s)
		Acceleration :200 m/s^2 (0.5 to 199.9 m/s^2)
4.	Frequency range	10 Hz to 1 kHz (Sensitivity meet ISO 2954 relative to frequency range)
5.	Calibration point	Velocity : 50 mm/s (160 Hz)
		Acceleration : 50 m/s^2 (160 Hz)
6.	Memory	Maximum & Minimum value.
7.	Sampling time	1 second
8.	Operating temperature	0 to 50 °C (32 to 122 °F)
9.	Operating humidity	Less than 80% RH
10.	Power supply	DC 9V battery (Alkaline or heavy duty type)
11.	Power consumption	DC 6 mA
12.	Weight	Meter: 274 g/0.60 lb.
		Probe with magnetic base: 38 g/0.08 lb.
13.	Dimensions	Main instrument : 185 x 78 x 38 mm (7.3 x 3.1 x 1.5 inch)

		Vibration sensor probe: Round 16 mm Dia. x 29 mm.
14.	Required accessories	Vibration sensor (VB-81A)…... 1 PC. Cable... 1 PC. Magnetic base............................ 1 PC.

Fig. 3.10: Cut section models of exhaust mufflers at FMPE lab of CAET, AAU, Godhra.

3.4 PRELIMINARY TEST OF NOISE LEVEL (SPL) MEASUREMENT

Farm tractors of different makes are mounted with ten mufflers (or silencers) of different designs. Other than standard muffler, mufflers designed were similar in sizes and shapes. However, internal configurations differed. A preliminary test on noise levels was conducted with noise level measurements on the tractors mounted with standard or built-in mufflers which were company fitted.

From the outcomes of the preliminary tests, three muffler designs were finalized for experimentation on the small (mini) and medium sized tractors. For each design, the SPLs were measured at three locations. The first location namely ear level (EL) did correspond to the operator’s ear level which were 1.2 and 1.5 m away from the engine exhaust for mini and medium tractor respectively. The second and third locations included measurement of SPLs at 10 and 30 m distance away from the tractor. The SPL for each design at each place was measured by keeping the Sound Level Meter (SLM) at an angle 45° to the axis of the source of exhaust noise viz. muffler. The SPLs were also recorded after dismounting the exhaust muffler. The difference between the two readings was taken as the noise attenuation produced by the particular muffler design.

3.4.1 Design Alterations in the Exhaust Muffler

Anonymous (2014a) stated that a muffler, also called silencer in British English, is a device for reducing the amount of noise emitted by the exhaust of an internal combustion engine. The US Patent for an ‘Exhaust muffler for engines’ was awarded to Milton O. Reeves and Marshall T. Reeves of Columbus, Indiana of the Reeves Pulley Company on 11th May 1897. U.S. Patent Office application No. 582485 states that they “have invented certain new and useful improvements in Exhaust-Mufflers for engines”. Mufflers are installed within the exhaust system of most internal combustion engines, although the muffler is not designed to serve any primary exhaust function. The muffler is engineered as an acoustic soundproofing device designed to reduce the loudness of the sound pressure created by the engine by way of acoustic quieting.

Kumar (1994) studied the acoustic performance of mufflers of some tractors and tried to design a new one to get lower noise level. Selvan and Mehta (2008) selected three mufflers A, B and C (as shown in Fig. 3.11) and evaluated for their noise reduction ability on two tractors (Tractor I & II) of 23 kW PTO power.

The expansion chambers of these three mufflers were of different designs and shapes. They concluded that muffler B reduced noise levels considerably on both the tractors in conversational frequencies. Evans et al (2004) stated that the basic techniques for silencer design have been known for many years. Improvements have generally resulted from the availability of materials that are more durable, or have more consistent properties. At first instance, the existing designs of conventional exhaust mufflers as available were studied for their constructional and functional features. Based on these features of the existing mufflers, the kind of modification or alteration in the design of exhaust mufflers was decided.

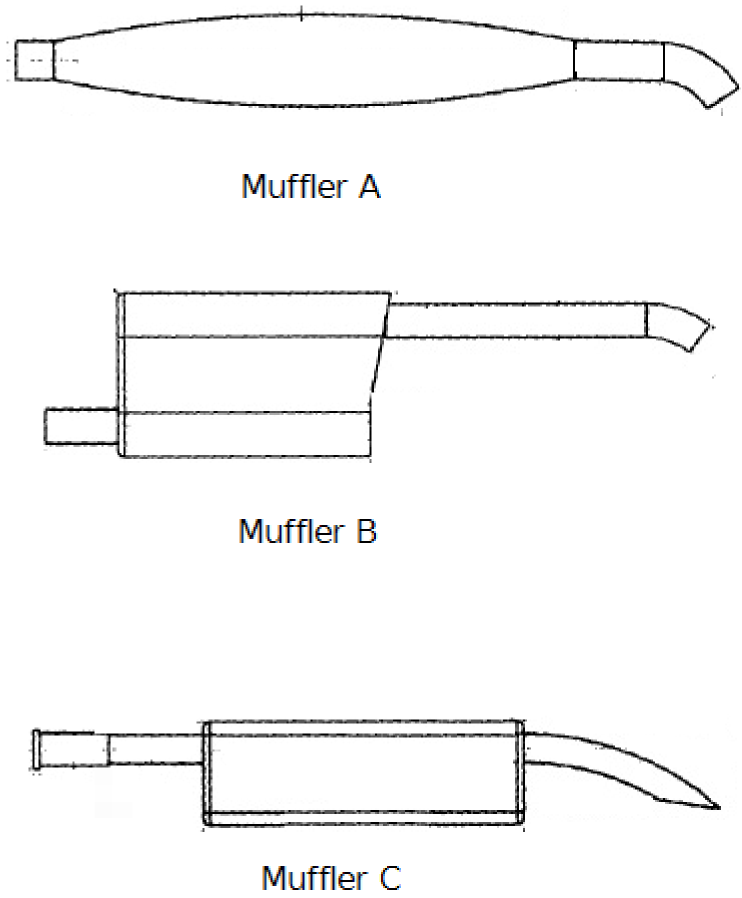


Fig. 3.11: Evaluated muffler designs (Selvan and Mehta, 2008)

As stated in the literature (Anonymous, 2014a), the majority of the sound pressure produced by the tractor engine is emanated out of the tractor using the same piping used by the exhaust gases. In most cases resonating chamber causes the destructive interference wherein the reflected sound waves are turned into opposite sound waves and cancel out each other. In the alternate way or sometimes additionally, the sound waves are absorbed by a series of passages and chambers lined with roving fiberglass insulation. On basis of the few initial trials based on the suitable methods of suppressing the sound waves, the kind of alteration in the design of existing mufflers were finalized.

Various configuration / design involving variation in the number of split / resonator chamber and arrangement of perforated / intermediate pipe / tube are worked out without variation in the outside dimension of the whole muffler assembly. Different mufflers were then mounted on tractor to measure the generated sound levels at different engine speeds (RPM) to evaluate their performance and rank them (in order of noise attenuation performance levels) accordingly. Three optimal configurations were selected for in-depth trials. The attempt was made to recommend a specific design of exhaust muffler on basis of its performance for each one of small and medium sized farm tractors under test.

Preliminary noise level measurement test was conducted on each of the mufflers by mounting on the two tractors of different horsepower capacity. One medium size and one small size tractors of familiar brands were selected for preliminary testing and evaluation of the mufflers containing various alterations in the internal configuration. The conceptual drawings of the internally altered configurations of the exhaust mufflers are presented in the Fig. 3.12 to Fig. 3.21.

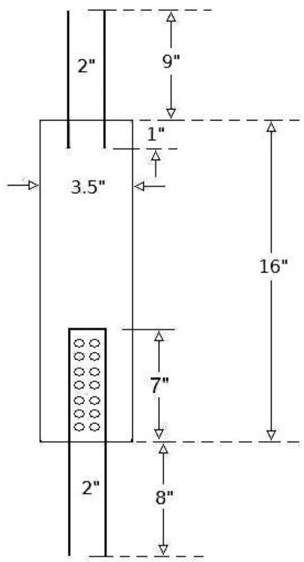


Fig. 3.12: Conceptual drawing of Muffler-1

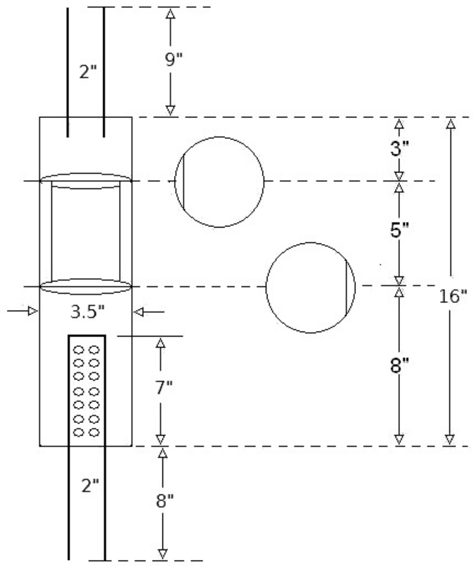


Fig. 3.13: Conceptual drawing of Muffler-3

(*Note: Muffler-2 was replaced by Muffler-11 during the experimentation)

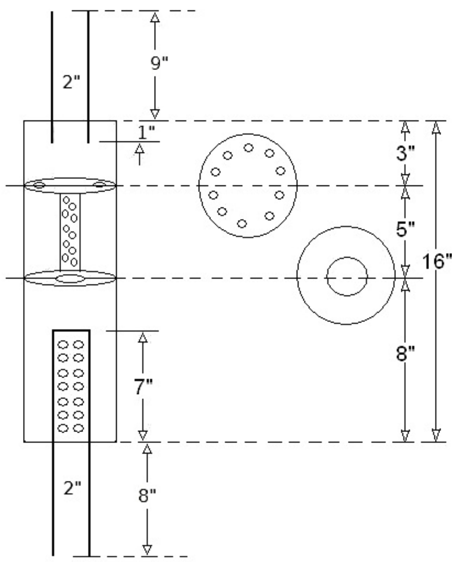


Fig. 3.14: Conceptual drawing of Muffler-4

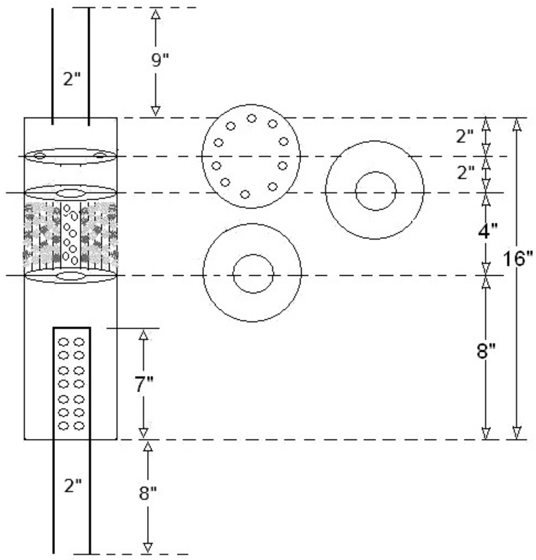


Fig. 3.15: Conceptual drawing of Muffler-5

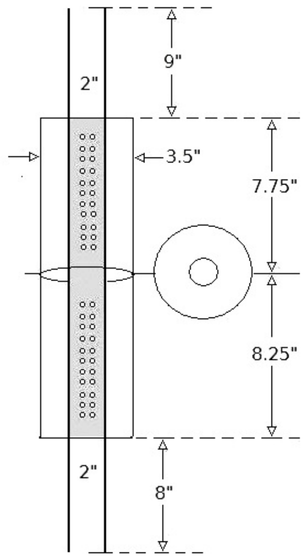


Fig. 3.16: Conceptual drawing of Muffler-6

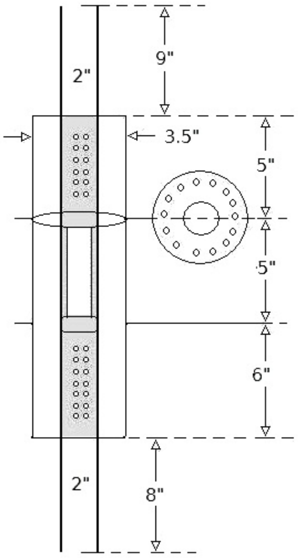


Fig. 3.17: Conceptual drawing of Muffler-7

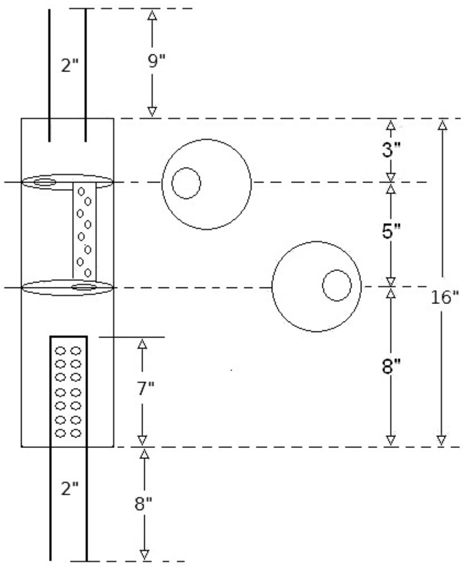


Fig. 3.18: Conceptual drawing of Muffler-8

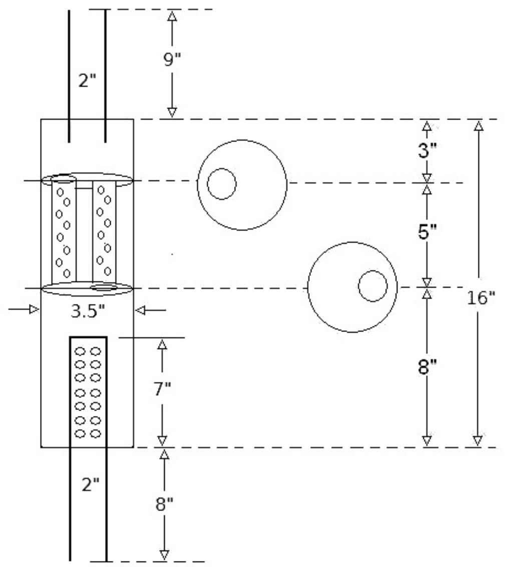


Fig. 3.19: Conceptual drawing of Muffler-9

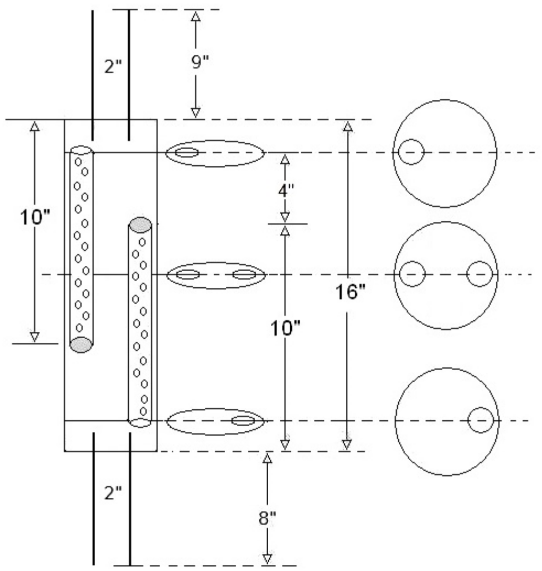


Fig. 3.20: Conceptual drawing of Muffler-10

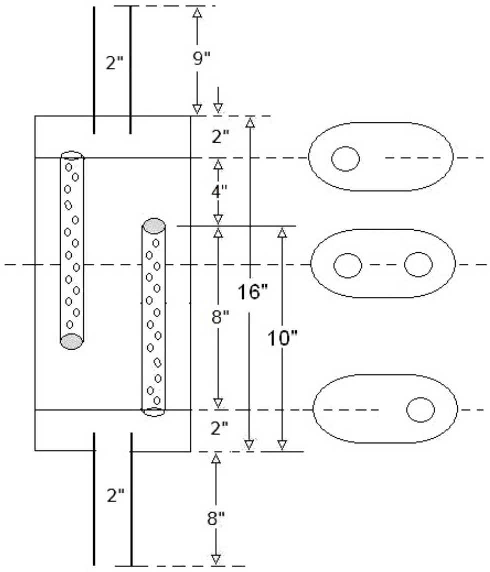


Fig. 3.21: Conceptual drawing of Muffler-11

3.4.2 Preliminary Noise Level Measurement on Tractor-1 and Tractor-2

Noise levels in terms of SPLs in the unit of dBA were measured on Tractor-1 & Tractor-2 under differently configured exhaust muffler mountings (along with standard muffler and the no-muffler mounting). Sound pressure levels measured during the tractor engine operation of two different sized tractors were measured with the help of sound level meter SL-4001. The noise levels were recorded for equal periods of data acquisition. Two places of recording sound levels were (i) at ear level (about 1 m away from engine exhaust) and (ii) 10 m away from the tractor. In the secondary stage of the experiment, the SPL measurements at 30 m distance were also included. The mean sound pressure levels along with s (standard deviation) and C.V. (coefficient of variation) in percent were observed at different RPMs on Tractor-1 and Tractor-2. The results are presented and discussed in chapter 4 (section 4.2) for making appropriate selection of muffler designs for Tractor-1 (Mini Tractor) and Tractor-2. Two mufflers for each of the tractor under test were selected in such a way that at least one of them was common for both Tractor-1 & Tractor-2. Three selected mufflers were coded as Muffler-A, Muffler-B and Muffler-C.

3.4.3 Detailed Noise Level Measurements on Tractor-1 and Tractor-2

Detailed noise level measurements were made at three places viz. (i) ear level (EL), (ii) at 10 m distance from thre tractor, and (iii) at 30 m distance from the tractor.

The results were tabulated and graphically presented for their interpretation and drawing inferences.

Fig. 3.22: Exhaust outlet of Tractor-1 (Mini Tractor)

Fig. 3.23: Exhaust outlet of Tractor-2

Fig. 3.24: Speed indicator on dashboard of Tractor-1 (Mini Tractor)

Fig. 3.25: Speed indicator on dashboard of Tractor-2

Fig. 3.26: Noise SPL testing of Tractor-1 (Mini Tractor) under different mufflers

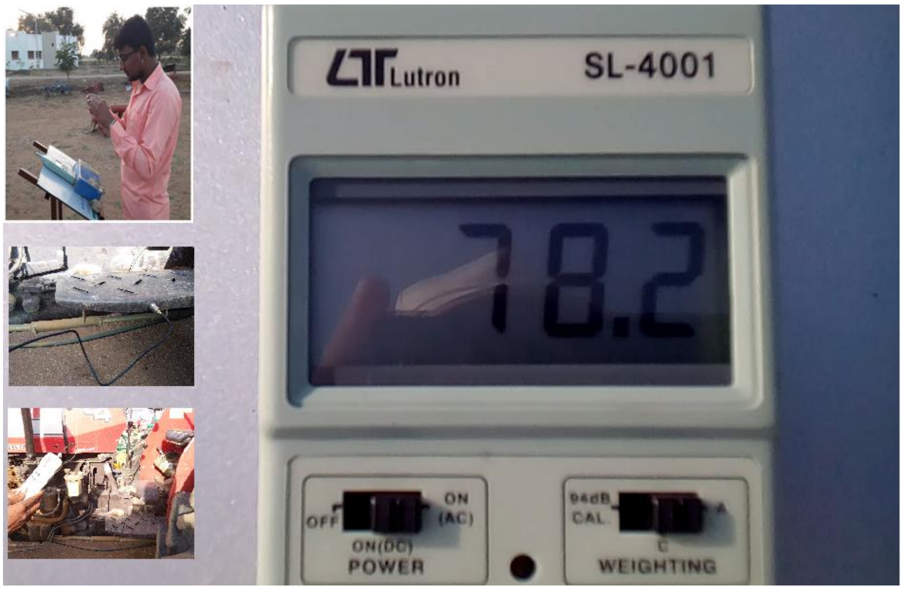


Fig. 3.27: SPL (Sound Pressure Level) observation being recorded on sound level meter (SL-4001) and vibration measuring on footrest

3.5 MEASUREMENT OF NOISE LEVEL (SPL) UNDER SELECTED MUFFLERS

The two mufflers for each tractor under test were selected on basis of preliminary tests for detailed tests and analysis of the noise attenuation performances along with company mounted standard mufflers. The noise levels were measured in terms of SPLs in the unit of decibels in A-weighting. The noise level observations were recorded for three different muffler mountings at three places of SPL observations viz. ear level, at 10 m distance, and at 30 m distance for both the tractors under test i.e. Tractor-1 (Mini Tractor) and Tractor-2. Noise level observations are however recorded in dBA units, they were later converted into micro pascals. Noise attenuation performance under different muffler installations was compared through appropriate tabulation of data and relevant graphical presentations. Later, noise level (SPL) observations recorded on both of the tractors under three different muffler mountings namely (i) no muffler (M-1), (ii) standard muffler (M-2), and (iii) selected muffler (M-3) were analyzed using split plot design.

3.6 STATISTICAL ANALYSIS OF DATA

3.6.1 Standard Deviation

The standard deviation is a statistical measure used to quantify the amount of variation or dispersion among a set of data values. It is represented by a quantity expressing by how much the observations of a group differ from the mean value for the group.

Standard deviation of the population is denoted by the Greek letter sigma, σ and standard deviation for the sample is denoted by s.

The formulae of the standard deviation are as below:

$$\sigma = \sqrt{\frac{1}{\mathrm{N}}\sum_{i=1}^{N}(x_i - \overline{x})^2} \qquad 3.3$$

Where

σ = standard deviation of the population

x_i = each value of population dataset

$\overline{x}$ = arithmetic mean of the population data

N = total number of data points in the population

The formula for the standard deviation of the sample observations is following.

$$s = \sqrt{\frac{1}{\mathrm{N-1}}\sum_{i=1}^{N}(x_i - \bar{x})^2} \qquad 3.4$$

Where

s = standard deviation of the sample

x_i = each value of sample dataset

$\bar{x}$ = arithmetic mean of the sample data

N = total number of data points in the sample

3.6.2 Variance

Variance is a measurement of the spread between numbers in a data set. The variance measures how far each observation in the set is from the mean.

$$\sigma^2 = \frac{\sum(X - \mu)^2}{N} \qquad 3.5$$

Where

σ^2 = variance of the sample

x_i = each value of sample dataset

μ = arithmetic mean of the sample data

N = total number of data points in the sample

However a drawback to variance is that it gives added weight to numbers far from the mean, since squaring these numbers can skew interpretations of the data.

3.6.3 Coefficient of Variation

The coefficient of variation (CV), also known as relative standard deviation (RSD), is a standardized measure of dispersion of a frequency distribution.

It is often expressed as a percentage, and is defined as the ratio of the standard deviation σ to the mean μ.

C.V. for population

$$\text{C.V. (\%)} = \frac{\sigma}{\mu} \text{ x } 100 \qquad 3.6$$

C.V. for sample

$$\text{C.V. (\%)} = \frac{s}{\bar{x}} \text{ x } 100 \qquad 3.7$$

The C.V. is useful in comparison to the standard deviation because the standard deviation of data is understood in the context of the mean while the value of CV is independent of the unit in which the measurement has been taken. Hence, for comparison between data sets with different units or with different means the coefficient of variation should be used in place of standard deviation.

The standard deviation of an exponential distribution is equal to its mean, so its coefficient of variation is equal to 1. Distributions with CV < 1 (such as an Erlang distribution) are considered low-variance, while those with CV > 1 (such as a hyper-exponential distribution) are considered high-variance.

3.6.4 Standard Error of Mean

The standard error of the mean is nothing but the standard deviation of the mean. It is a method which is used to estimate the standard deviation of a sampling distribution. The standard error of the mean (SEM) uses the sample mean as a method of estimating the population mean. The standard error of the mean (SEM) is the standard deviation of those sample means over all possible samples (of a given size) drawn from the population.

Standard error is a statistical term that measures the accuracy with which a sample represents a population. In statistics, sample mean deviates from the actual mean of a population; this deviation is the standard error. The standard error and standard deviation are not same. The standard error of the sample mean is an estimate of how far the sample mean is likely to be from the population mean, whereas the standard deviation of the sample is the degree to which individuals within the sample differ from the sample mean.

Instead of taking the mean by one measurement, we prefer to take several measurements and take a mean each time. This is a sampling distribution. The standard error of the mean now refers to the change in mean with different experiments conducted each time.

Mathematically, the standard error of the mean formula is given by:

$$\sigma_M = \frac{\sigma}{\sqrt{N}} \tag{3.8}$$

Where

σ_M	=	Standard error of the mean
σ	=	Standard deviation of the original distribution
N	=	Sample size

It can be seen from the formula that the standard error of the mean decreases as N increases. This is expected because if the mean at each step is calculated using a lot of data points, then a small deviation in one value will cause less effect on the final mean. The standard error of the mean tells us how the mean varies with different experiments measuring the same quantity. Thus if the effect of random changes are significant, then the standard error of the mean will be higher. If there is no change in the data points as experiments are repeated, then the standard error of mean is zero.

3.6.5 Least Significant Difference

The difference between two groups is statistically significant if it cannot be explained by chance alone. Usually, statistical significance is determined by calculating the probability of error (p value) by the t ratio. When test of significance indicates that difference between different treatments is non-significant it is enough to show the standard errors in the chart or table. In case of significant treatment difference, depicting the treatment difference with standard error does not convey the complete meaning. CD (Critical Difference) or LSD (Least Significant Difference) can be shown in a table or graph. Sometimes reviewers ask authors to show CD or LSD as a line or a bar depending on the style of data presentation.

3.6.6 Two-Way ANOVA

A Two-way ANOVA is useful for comparison of the effect of multiple levels of two factors having multiple observations at each level. The two-way analysis of variance is an extension to the one-way analysis of variance. There are two independent variables hence the name two-way is given. (Anonymous, 2016b & Anonymous, 2016c)

The two independent variables in a two-way ANOVA are called factors. There are two variables, factors, which affect the dependent variable. Each factor will have two or more levels within it, and the degrees of freedom for each factor is one less than the number of levels.

Treatment groups are formed by making all possible combinations of the two factors. For example, if the first factor has 3 levels and the second factor has 2 levels, then there will be 3 x 2 = 6 different treatment groups.

3.6.7 Split Plot Design

A split-plot experiment is a blocked experiment, where the blocks themselves serve as experimental units for a subset of the factors (Jones and Nachtsheim, 2009). In split plot design, there are two levels of experimental units viz. blocks are referred as whole plots and experimental units within blocks are called split plots or split units. An example of the layout of a split plot agricultural experiment is shown in the Fig. 3.28.

Factor A and factor B as shown in the figure are respectively whole-plot factor and split-plot factor. The standard ANOVA model for the balanced two-factor split plot design is given by following equation.

$$Y_{ijk} = \mu + R_{i+} A_j + \alpha_{ij} + B_k + (AB)_{jk} + \varepsilon_{ijk}$$

Where, $i=1,2,\ldots,r$ $j=1,2,\ldots,a$ $k=1,2,\ldots,b$

Y_{ijk}= Observation from the i^{th} replication, j^{th} main plot and k^{th} sub plot

μ = General Mean

R_i= i^{th} replication effect

$A_{j=}$ j^{th} main plot treatment effect

α_{ij}= main plot error or error (a)

B_k= k^{th} sub plot treatment effect

$(AB)_{jk}$ =interaction effect

ε_{ijk} = error component for sub-plot and interaction Error (b)

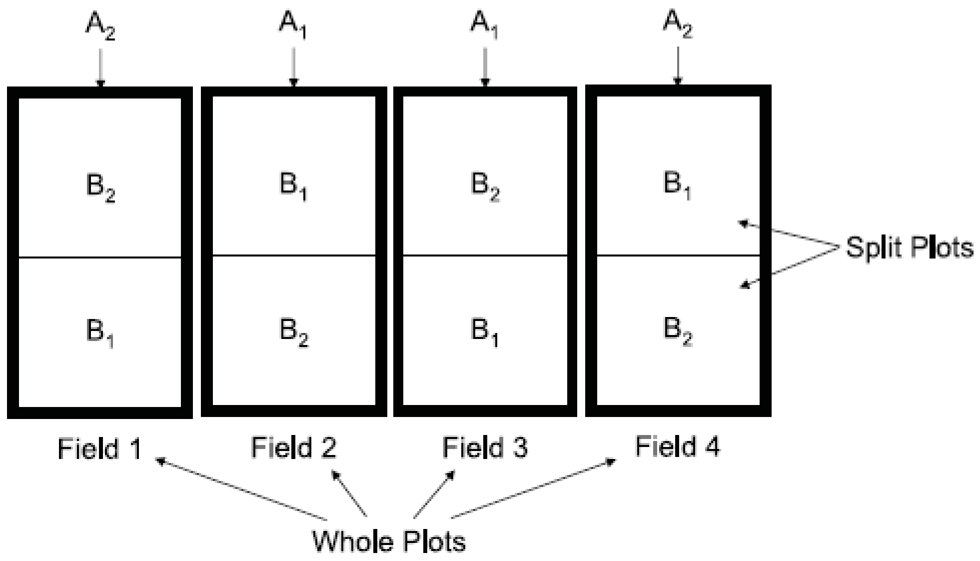


Fig. 3.28: Layout of an agricultural experiment in Split-Plot Design

3.7 EXPERIMENTAL DETAILS

The experiment was conducted in three phases on two tractors of different sizes. In first phase (**Phase-I**), noise and vibration levels were measured on two different sized farm tractors. Noise level measurements were conducted under standard mufflers at three engine speeds at two places of noise level measurements. Noise levels were recorded in decibel (SPL) units. Vibration level measurements were conducted on three different parts of the tractors namely (i) front axle, (ii) bonnet and (iii) foot rest. Vibration levels were measured in two different modes (i) Vibration velocity (mm/s) and (ii) Vibration acceleration (m/s^2).

In second phase (**Phase-II**), ten conceptual designs of mufflers were utilized to fabricate the exhaust mufflers. After that, a preliminary noise level test was conducted by mounting newly fabricated mufflers on both tractors to select the appropriate design of mufflers for each tractor for detailed experimentation to investigate the effect of muffler design alterations on the noise attenuation performance of mufflers. Ten kinds of alterations into the internal configuration of the exhaust muffler were established in the uniform outer casing to carve out different designs of exhaust mufflers. Preliminary noise level test was conducted by mounting all mufflers on both tractors. Noise levels (SPL) were recorded at two places (i) ear level and (ii) at 10 m distance away from the tractor. After conducting preliminary noise level test, two mufflers for each tractor were selected for detailed experimentation to evaluate the noise attenuation performance of the exhaust mufflers having different reactive types of design alterations by mounting them on two different sized farm tractors.

In **Phase-III**, suitably replicated trial was carried out at three different places of noise level measurements. The experimental details viz. treatment variables, levels, replications and observations are tabulated below (Table 3.6).

Table 3.6: Experimental details for evaluation of altered design of exhaust mufflers

(A) Number of Tractors	:	2 (Two)
		(i) Tractor-1 (Mini Tractor)
		(ii) Tractor-2
(B) Exhaust Muffler Mountings (Main Treatments)	:	3 (Three)
		(i) M-1 Muffler-S i.e. Standard Muffler
		(ii) M-2 Muffler-A for Tractor-1 Muffler-B for Tractor-2
		(iii) M-3 Muffler-C

(C) Engine Speed Variables (Sub Treatments)	:	5 (Five)
		(i) 1000 RPM
		(ii) 1250 RPM
		(iii) 1500 RPM
		(iv) 1750 RPM
		(v) 2000 RPM
(D) Location of Noise Level Measurements	:	3 (Three)
		(i) Operator's Ear Level
		(ii) At 10 m distance away from tractor
		(iii) At 30 m distance away from tractor
(E) Replications	:	3 (Three)
(F) Design of Experiment	:	Split Plot Design
(G) Observation	:	Noise Level (SPL), dBA

In **Phase-IV**, the amplitude levels of different sound frequencies were analyzed for three muffler mountings namely (i) No muffler mounting, (ii) muffler-S & (iii) muffler-C. Muffler-S referred to standard company mounted mufflers of Tractor-1 (mini tractor) and Tractor-2. Muffler-C was selected muffler of altered design which was mounted on both the tractors. Details of observations are tabulated (Table 3.7).

Table 3.7: Details of frequency and amplitude observations for selected exhaust mufflers

(A) Number of Tractors	:	2 (Two)
		(i) Tractor-1 (Mini Tractor)
		(ii) Tractor-2 (Medium Tractor)
(B) Exhaust Muffler Mountings	:	3 (Three)
		(i) M-1 No Muffler Mounting
		(ii) M-2 Muffler-S
		(iii) Muffler-C (M-3)
(C) Engine Speeds	:	5 (Five)
		(i) 1000 RPM
		(ii) 1250 RPM
		(iii) 1500 RPM
		(iv) 1750 RPM
		(v) 2000 RPM
(D) Locations of Noise Level Measurement	:	2 (Two)
		(i) Operator's Ear Level
		(ii) At 10 m distance away from tractor

(E) Replication	:	No
(F) Observations	:	(i) Peak Frequency (Hz) (ii) Amplitude level (%)

Chapter-4

RESULTS AND DISCUSSION

Tractor noise is largely contributed by the engine noise and engine noise mainly comprise of the exhaust noise. Tractor vibrations also contribute towards total noise generation resulting out of tractor operation. Earlier researchers have emphasized the role of exhaust noise as major source of engine noise. Harris (1957) and Munjal (1987) reported that the exhaust noise has been the most significant component of engine noise. It was found from the analysis of exhaust noise pattern of a diesel engine that large peaks were observed just above and below its firing frequency. Jadhav and Ghatage (2000) stated that an engine noise is mainly due to exhaust noise. They conducted tests on different muffler models and worked out noise attenuation produced by each individual muffler. The present experiment is mainly aimed at investigating the exhaust noise characteristics as influenced by installation of altered design of exhaust mufflers.

The experimental outcomes are discussed here under different heads and subheads as associated with them. The main headings of this chapter are as under.

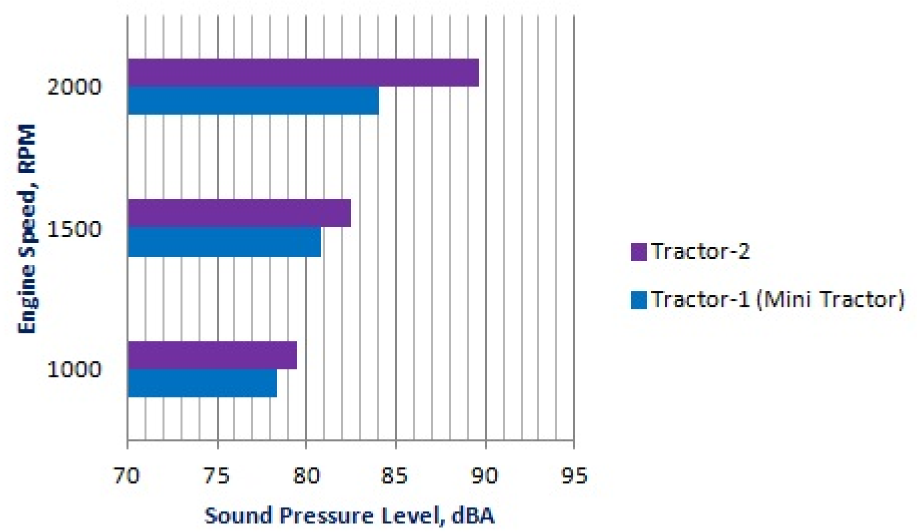
1. Noise and Vibration Levels Associated with Farm Tractors
2. Selection of Mufflers for Tractor-1 (Mini Tractor) and Tractor-2
3. Constructional Parameters of Selected Mufflers
4. Influence of Muffler Design Alteration & Engine Speed on Noise Levels of Tractor-1 and Tractor-2
5. Relative Noise Attenuation Performance of Selected Mufflers on Tractor-1 (mini tractor) and Tractor-2
6. Amplitude Levels of Tractor Noise Frequencies

4.1 NOISE AND VIBRATION LEVELS ASSOCIATED WITH FARM TRACTORS

Tractor noise was composed of mainly two kinds of noises (i) noise due to motion of the machine parts & vibrations and (ii) noise created by explosions into the cylinder which was delivered out through exhaust that was termed as exhaust noise. The effect of tractor vibrations on noise has been evaluated in this section.

4.1.1 Noise Levels (SPL) Associated with Farm Tractors

The noise levels were observed on Tractor-1 and Tractor-2 with an installed muffler of the standard make during preliminary tests at an ear level (1.2 m & 1.5 m away from exhaust outlet for Tractor-1 and Tractor-2 respectively). Tractor-1 produced 78.4, 80.8 & 84.1 decibel levels (dBA) at tractor engine speed of 1000, 1500 & 2000 RPM respectively. Tractor-2 produced 79.5, 82.5 & 89.7 dBA at tractor engine speed of 1000, 1500 & 2000 RPM respectively. The graphical display (Fig. 4.1) reveals that sound pressure level increases with the increase in tractor engine speed. At same levels of engine speed, the resulting SPL are different on Tractor-1 (Mini) and Tractor-2. The SPL observed in dBA on medium sized tractor at 1000, 1500 and 2000 RPM are found higher than that observed on small tractor by 1.2 (1.5%), 1.0 (1.2%) and 3.5 (4.1%) dBA respectively.



	1000	1500	2000
Tractor-2	79.5	82.5	89.7
Tractor-1 (Mini Tractor)	78.4	80.8	84.1

Fig. 4.1: Engine speed (RPM) wise noise levels in SPL (dBA) on Tractor-1 and Tractor-2

4.1.2 Vibration Levels Associated with Farm Tractors

The results are displayed graphically to analyze both the quantum and pattern of vibrations under different engine speeds and over different surfaces. The vibration levels were observed on Tractor-1 and Tractor-2 at different engine speeds on different tractor surfaces viz. tractor bonnet, front axle and foot rest. The vibration measurements were made in two units namely velocity in mm/s and acceleration in m/s^2. The average observations are tabulated and analyzed graphically.

4.1.2.1 Vibration levels on tractor-1 (mini tractor)

4.1.2.1.1 Vibration levels in velocity on tractor-1 (mini tractor)

Vibration levels recorded in velocity (mm/s) on different tractor components at different RPM in longitudinal (X), lateral (Y) and vertical (Z) directions on Tractor-1 are tabulated and discussed (Tabe 4.1).

Table 4.1: Vibration levels recorded in veocity (mm/s) on Tractor-1

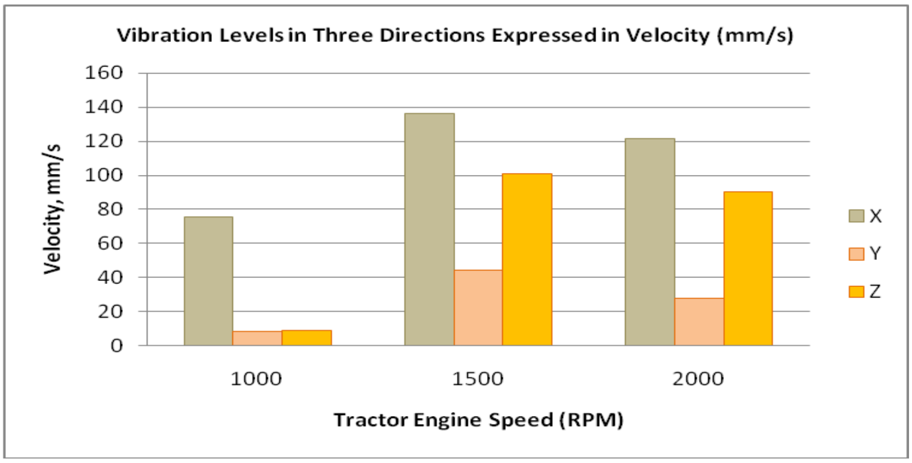
Engine Speed (RPM)	Front Axle			Bonnet			Foot Rest		
	X	Y	Z	X	Y	Z	X	Y	Z
1000	75.3	8.3	8.9	33.6	17.4	33.2	44.3	41.3	35.2
1500	136.4	44.2	101.2	68.4	66.6	68.9	31.0	46.6	27.9
2000	121.5	27.7	90.2	55.1	43.8	50.6	73.2	71.5	58.9
Mean	111.1	26.7	66.8	52.4	42.6	50.9	49.5	53.1	40.7

It is seen from the Table 4.3, on tractor-1, the vibration levels in velocity units are found maximum (136.4 mm/s) at 1500 RPM on front axle in longitudinal direction (direction of forward motion) followed by 121.5 mm/s on the same place (front axle) and in the same direction (X). Minimum vibration levels of 8.3 & 8.9 mm/s were also observed on the same place (front axle) but in lateral and vertical directions respectively at 1000 RPM.

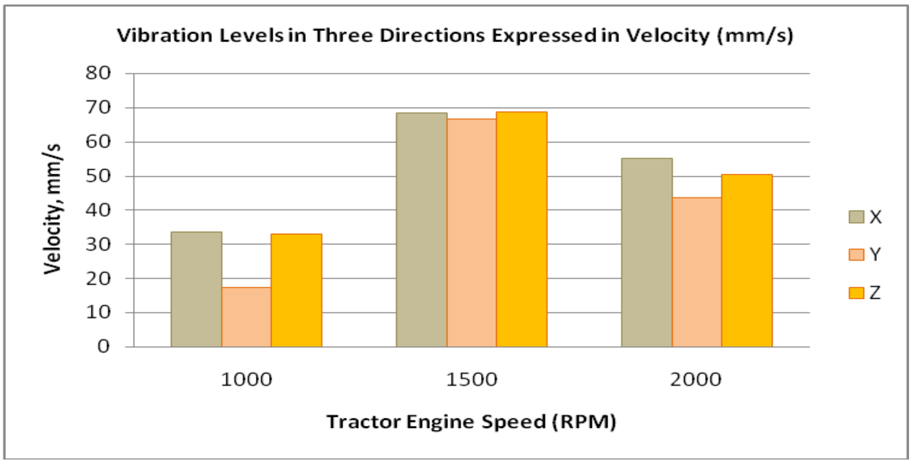
The noticeable observation has been, as recorded, the velocity levels, after initial sharp increase from 1000 to 1500 RPM, were rather reduced with increase in engine speed from 1500 to 2000 RPM on both front axle and bonnet in all three directions. Which however did not comply with the noise levels recorded at higher engine speed of tractor. But, on foot rest, velocity observations increased with increase in speed from 1500 to 2000 RPM that was in compliance with the greater noise and greater vibrations at higher engine speeds.

Fig. 4.2 (a), (b) & (c) exhibits the vibration velocity levels observed on front axle, bonnet and foot rest at three engine speeds in three directions which are expressed through bar graphs.

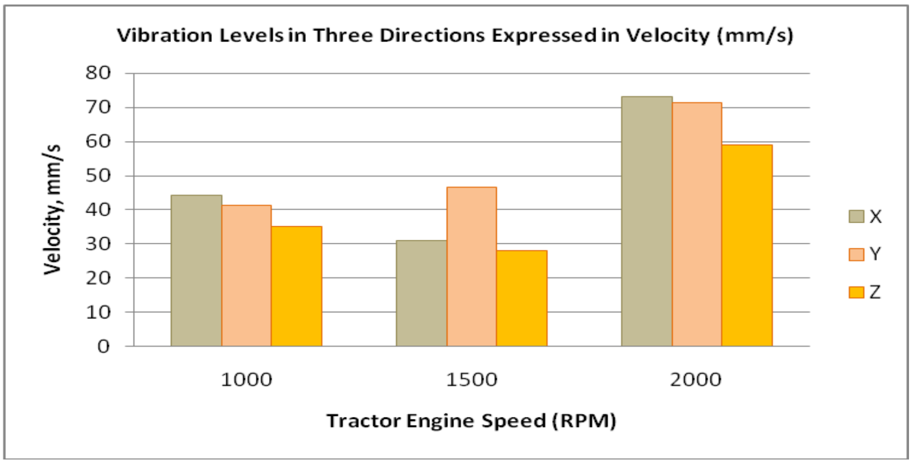
Fig. 4.2 (a) indicates that at 1000 RPM, longitudinal vibration was observed higher in comparison to the lateral and vertical vibrations. On front axle it was too high than the rest. Else, front axle vibration velocities in all directions were maximum at 1500 RPM and minimum at 1000 RPM with moderate levels at 2000 RPM. When tractor engine was speeded up to the speed of 1500 RPM, the vibrations increased on front axle in all directions but they decreased during further speed-up from 1500 to 2000 RPM. Fig. 4.2 (b) indicated vibration velocity pattern observed on the bonnet surface which also showed maximum levels in all directions at 1500 RPM and minimum at 1000 RPM with moderate levels at 2000 RPM. When tractor engine was speeded up to the speed of 1500 RPM, the vibrations increased on front axle in all directions but they decreased during further speed-up from 1500 to 200 RPM. However, foot rest vibrations as shown in Fig. 4.2 (c) indicated maximum levels in all directions at 2000 RPM.



(a) Vibration levels in velocity (mm/s) observed on front axle

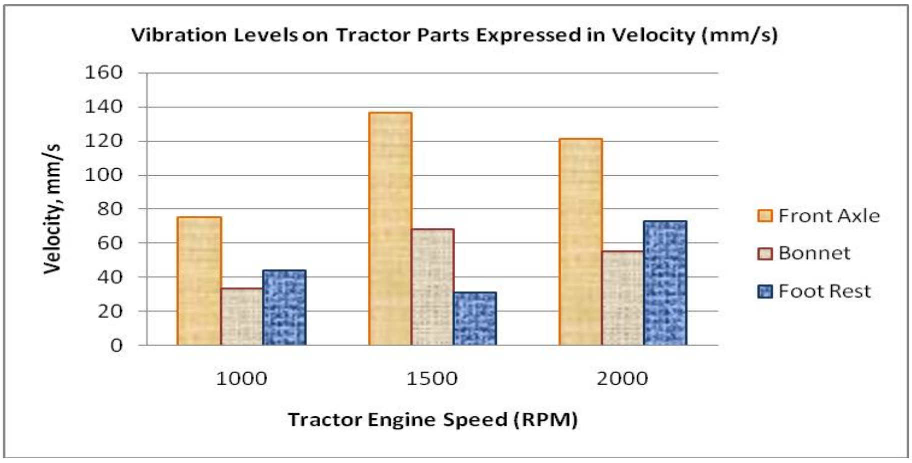


(b) Vibration levels in velocity (mm/s) observed on bonnet

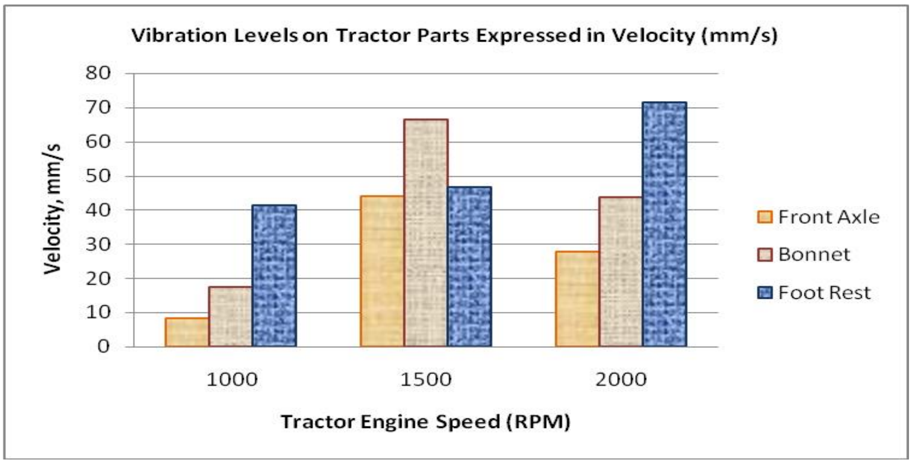


(c) Vibration levels in velocity (mm/s) observed on foot rest

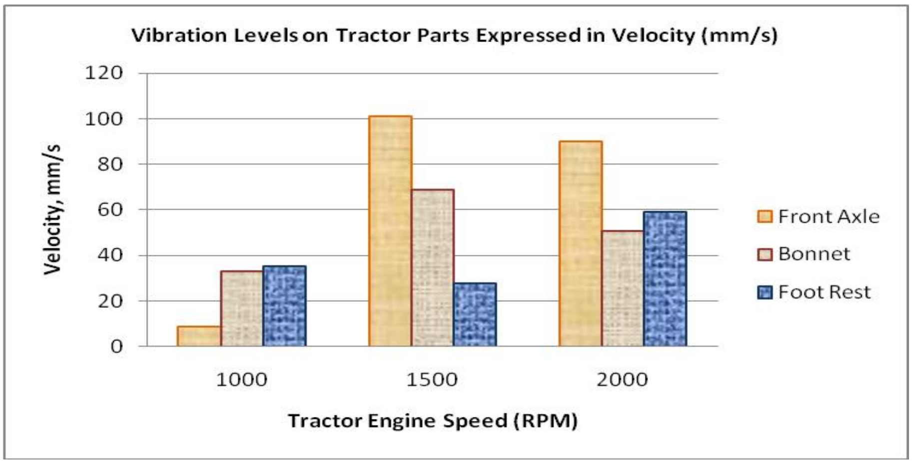
Fig. 4.2: Vibration levels measured in velocity (mm/s) on (a) front axle, (b) bonnet and (c) foot rest in three directions (Tractor-1) at different engine speed (RPM)



(a) Vibration levels in velocity (mm/s) in longitudinal (X) direction



(b) Vibration levels in velocity (mm/s) observed in lateral (Y) direction



(c) Vibration levels in velocity (mm/s) observed in vertical (Z) direction

Fig. 4.3: Vibration levels measured in velocity (mm/s) in (a) longitudinal, (b) lateral and (c) vertical directions on three surfaces (Tractor-1) at different engine speed (RPM)

Fig. 4.3 (a), (b) & (c) respectively exhibits the vibration velocity levels observed in longitudinal (X), lateral (Y) and vertical (Z) directions observed at three engine speeds on three parts of tractor which are expressed through bar graphs. Fig. 4.3 (a) indicates that in longitudinal (X) direction vibration velocity on front axle and bonnet increased with increase in speed from 1000 to 1500 RPM while foot rest vibration level (in velocity) reduced during this speed change period. During change in engine speed from 1500 to 2000 RPM, the velocity vibration levels on front axle and bonnet rather reduced with rise in engine speed. While foot rest vibration levels displayed reverse trend as it increased with increment in the speed from 1500 to 2000 RPM. Fig. 4.3 (b) indicates that in lateral (Y) direction only foot rest vibrations increased continually during rise in the engine speed from 1000 to 1500 and 1500 to 2000 RPM both. While front axle and bonnet vibration levels in lateral direction first increased during speed increase from 1000 to 1500 and later reduced during speed increase from 1500 to 2000 RPM. Hence, in lateral direction, maximum velocity was observed at 1500 RPM on front axle and bonnet but maximum foot rest vibrations took place at 2000 RPM again showing compliance with the corresponding noise levels. Fig. 4.3 (c) depicts the trend of velocity levels in vertical (Z) direction which indicated similar pattern of the changes on both front axle and bonnet as observed in longitudinal (X) and lateral (Y) directions while foot rest vibration velocities in vertical were similar to that observed in longitudinal (X) direction i.e. reduction in velocity level during rise of engine speed from 1000 to 1500 but later increase in the velocity with increase in engine speed from 1500 to 2000 RPM. The common thing observed above showed that (i) on front axle and bonnet surfaces, velocity levels were found maximum at 1500 irrespective of the direction of motion and (ii) on foot rest maximum level in velocity was observed at 2000 RPM in all directions.

4.1.2.1.2 Vibration levels in acceleration on tractor-1 (mini tractor)

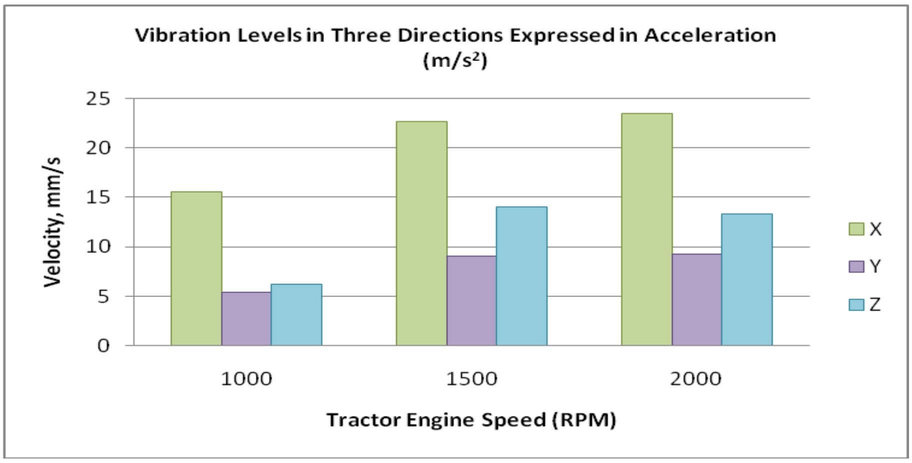
Vibration levels recorded in acceleration (m/s^2) on different tractor components at different RPM in longitudinal (X), lateral (Y) and vertical (Z) directions on Tractor-1 are tabulated below (Table 4.2).

Table 4.2: Vibration levels recorded in acceleration (m/s^2) on Tractor-1 (Mini Tractor)

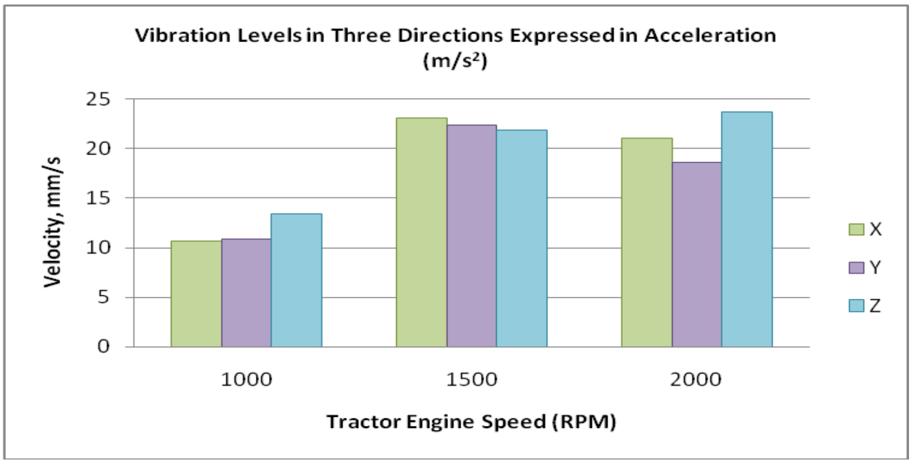
Engine Speed (RPM)	Front Axle			Bonnet			Foot Rest		
	X	Y	Z	X	Y	Z	X	Y	Z
1000	15.5	5.4	6.2	10.7	10.9	13.4	11.2	12.6	9.3
1500	22.7	9.0	14.0	23.1	22.4	21.8	10.0	13.2	8.5
2000	23.5	9.2	13.3	21.0	18.6	23.7	17.6	18.8	17.3
Mean	20.6	7.9	11.2	18.3	17.3	19.6	12.9	14.9	11.7

The vibration analysis conducted on mini sized tractor (Tractor-1) revealed that normally vibration accelerations increased with increase in the engine speed of the tractor in stationery mode however with certain exceptions (Table 4.3). This was true for engine speed rise from 1000 RPM to 1500 RPM for front axle and bonnet surface vibrations with different trend in foot rest vibrations. With engine speed rise from 1500 RPM to 2000 RPM, foot rest vibration levels (acceleration values) apparently increased in all directions. However, acceleration levels on front axle and bonnet did not increased apparently in all directions when engine was speeded up from 1500 to 2000 RPM.

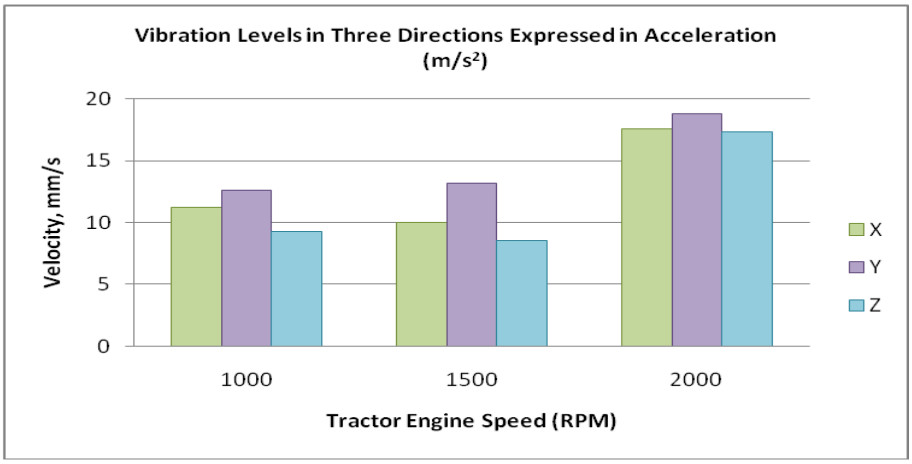
On front axle, maximum vibration levels were recorded in longitudinal (X) direction while on bonnet and foot rest, maximum vibration levels (m/s^2) were recorded in vertical (Z) and lateral (Y) directions respectively. The noticeable observation has been, as recorded, the acceleration levels initially increased with increase in speed on both front axle and bonnet later with no much increment or decrement from 1500 to 2000 RPM. But on foot rest, the acceleration levels have sharply increased when engine was speeded up from 1500 to 2000 RPM.



(a) Vibration levels in acceleration (m/s^2) on front axle

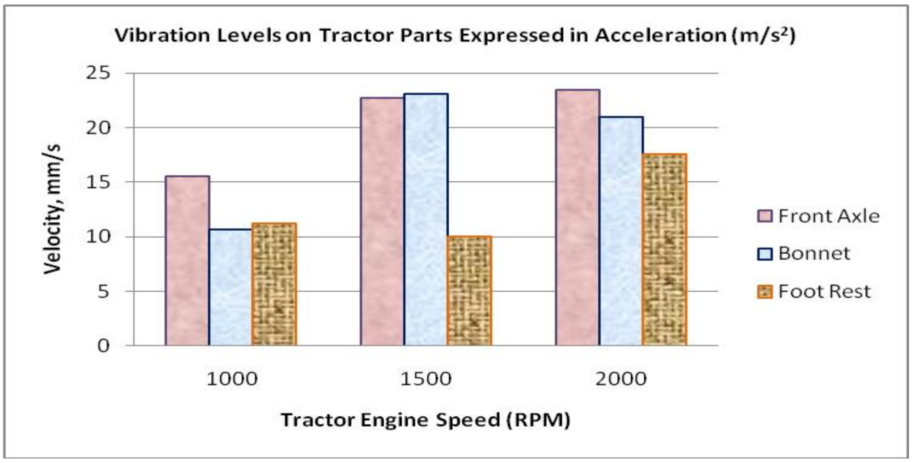


(b) Vibration levels in acceleration (m/s^2) observed on bonnet

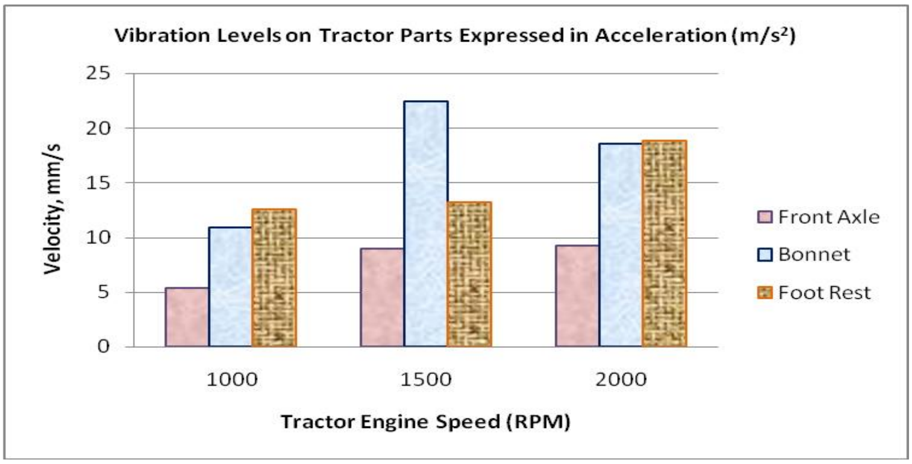


(c) Vibration levels in acceleration (m/s^2) observed on foot rest

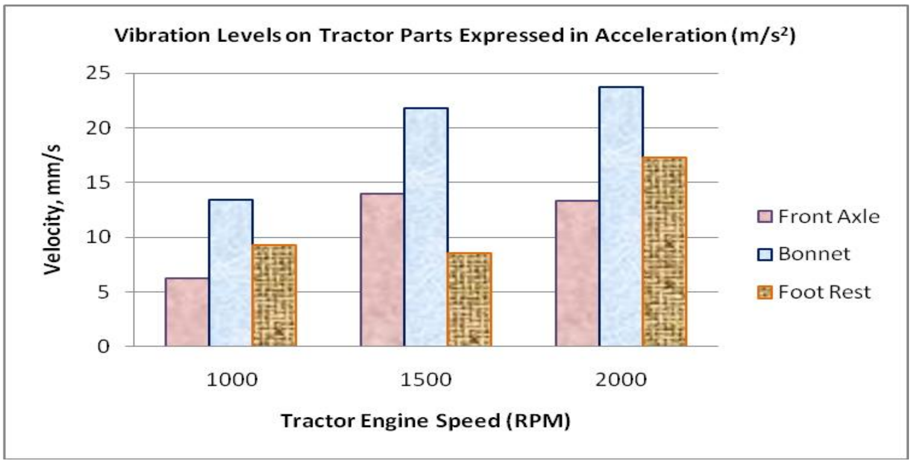
Fig. 4.4: Vibration levels measured in acceleration (m/s^2) on (a) front axle, (b) bonnet and (c) foot rest in three directions (Tractor-1) at different engine speed (RPM)



(a) Vibration levels in acceleration (m/s^2) in longitudinal (X) direction



(b) Vibration levels in acceleration (m/s^2) observed in lateral (Y) direction



(c) Vibration levels in acceleration (m/s^2) observed in vertical (Z) direction

Fig. 4.5: Vibration levels measured in acceleration (m/s^2) in (a) longitudinal, (b) lateral and (c) vertical directions on three surfaces (Tractor-1) at different engine speed (RPM)

Fig. 4.4 & Fig. 4.5 shows the vibration levels measurred in the unit of acceleration (m/s^2) which are expressed through bar graphs shown engine-speed wise. Fig. 4.6 (a) indicated that at front axle, increase in vibration accelerations was observed in all directions when engine speed was increased from 1000 to 1500 RPM. But that did not continue during increasing the engine speed from 1500 to 2000 RPM particularly in case of vertical (Z) directional vibrations. Fig. 4.4 (b) indicated that on bonnet vibration accelerations increased in all directions when speed was increased from 1000 RPM to 1500 RPM. However, during increase in the engine speed from 1500 to 2000 RPM except vertical (Z) vibrations, other directional (longitudinal and lateral) vibration accelerations were rather reduced on bonnet. Fig. 4.4 (c) indicated that on foot rest, longitudinal (X) and vertical (Z) vibration acceleration levels reduced when engine speed was increased from 1000 to 1500 RPM. Only lateral (Y) vibrations increased with increase in speed. However, when engine speed was raised from 1500 to 2000 RPM, all directional vibration acceleration levels increased on foot rest.

Fig. 4.5 (a) depicts vibration levels measured in acceleration (m/s^2) in longitudinal (X), lateral (Y) and vertical (Z) directions at three engine speeds as noticed on three different tractor components. At 1000 RPM, maximum longitudinal acceleration was observed on front axle (Fig. 4.5 (c)) but at 1500 RPM longitudinal acceleration was greater on bonnet surface. At 2000 RPM, front axle vibrations were found dominating in longitudinal direction. Fig. 4.5 (b) indicated maximum lateral accelerations observations on foot rest at 1000 RPM, on bonnet at 1500 RPM and on foot rest at 2000 RPM. Fig. 4.5 (c) showed maximum vertical accelerations on bonnet at all three engine speeds.

4.1.2.2 Vibration levels on tractor-2

4.1.2.2.1 Vibration levels in velocity on tractor-2

Vibration levels recorded in veocity (mm/s) on different tractor components of Tractor-2 at different RPM in longitudinal (X), lateral (Y) and vertical (Z) directions are tabulated below (Table 4.3).

It is seen from the Table 4.3, on tractor-2, the vibration levels in velocity units are found maximum at 2000 RPM on front axle, bonnet and foot rest in all directions (X, Y and Z) followed by that at 1500 RPM and least at 1000 RPM.

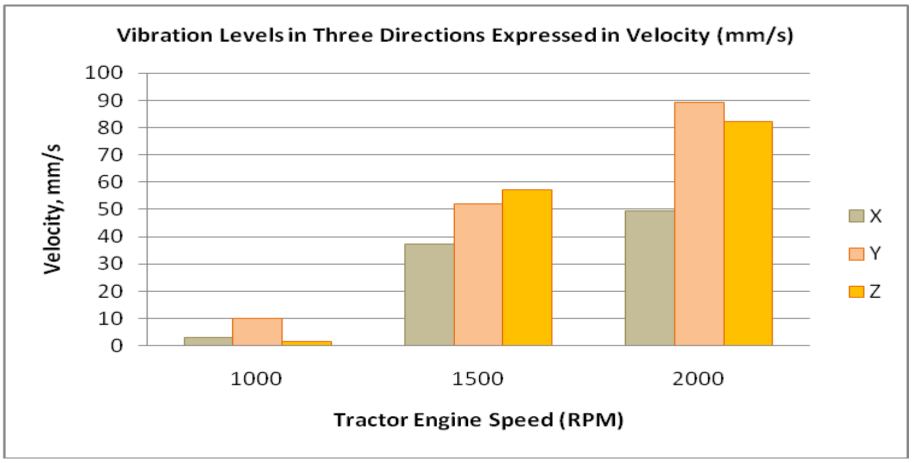
Table 4.3: Vibration levels recorded in veocity (mm/s) on Tractror-2

Engine Speed (RPM)	Front Axle			Bonnet			Foot Rest		
	X	Y	Z	X	Y	Z	X	Y	Z
1000	2.9	10.1	1.6	16.1	14.1	10.3	0.7	3.9	4.6
1500	37.4	51.9	57.3	63.4	39.1	15	2.2	13.4	13.7
2000	49.6	89.3	82.3	81.8	47.4	55.1	38	70.9	81.9
Mean	30.0	50.4	47.1	53.8	33.5	26.8	13.6	29.4	33.4

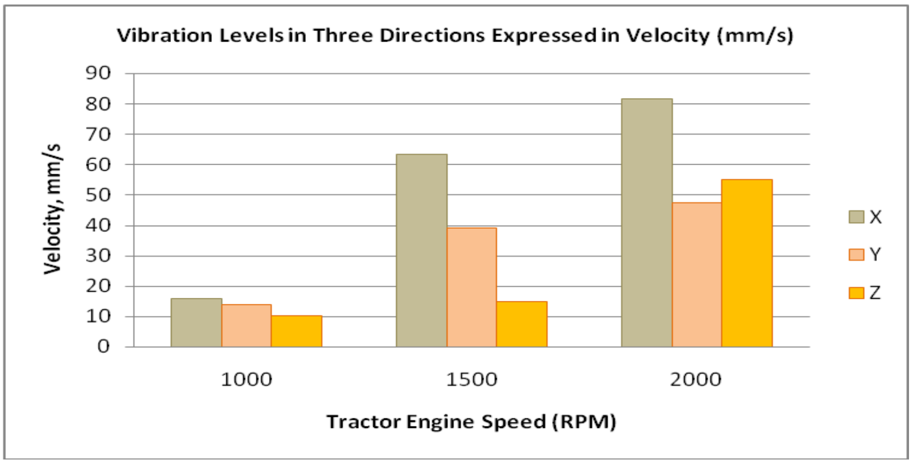
Fig. 4.6 (a), (b) & (c) shows the vibration velocity (mm/s) levels measurred on front axle, bonnet and foot rest surfaces of Tractor-2 at three engine speeds in three directions which are expressed through bar graphs.

Fig. 4.6 (a) indicates that on front axle at 1000 RPM, longitudinal (X), lateral (Y) and vertical (Z) vibrations were noticed in very small intensity which considerably increased at 1500 RPM and further increased at 2000 RPM in all directions. Similar pattern was observed in Fig. 4.6 (b) and (c) showing the intensity of vibration velocities on bonnet and foot rest. On front axle, maximum vibrations were observed in lateral (Y) direction followed by vertical (Z) and longitudinal (X) vibrations on 2000 RPM. However on bonnet maximum vibration velocity was observed in longitudinal (X) direction at 2000 RPM but on foot rest maximum vibration velocity was observed in vertical (Z) direction at 2000 RPM. Overall, the vibration velocity pattern was following the noise level changes on tractor-2.

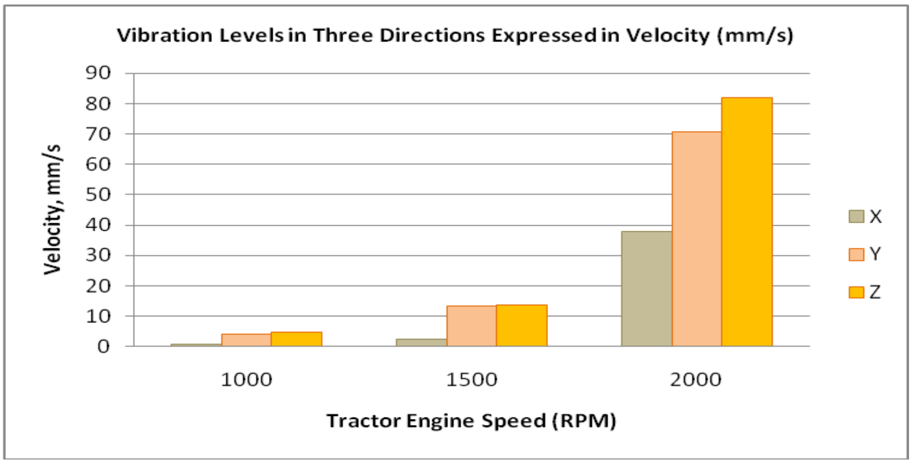
Fig. 4.7 (a), (b) & (c) exhibits the vibration velocity levels observed in longitudinal (X), lateral (Y) and vertical (Z) directions on Tractor-2 at three engine speeds on three tractor parts which are expressed through bar graphs.



(a) Vibration levels in velocity (mm/s) observed on front axle

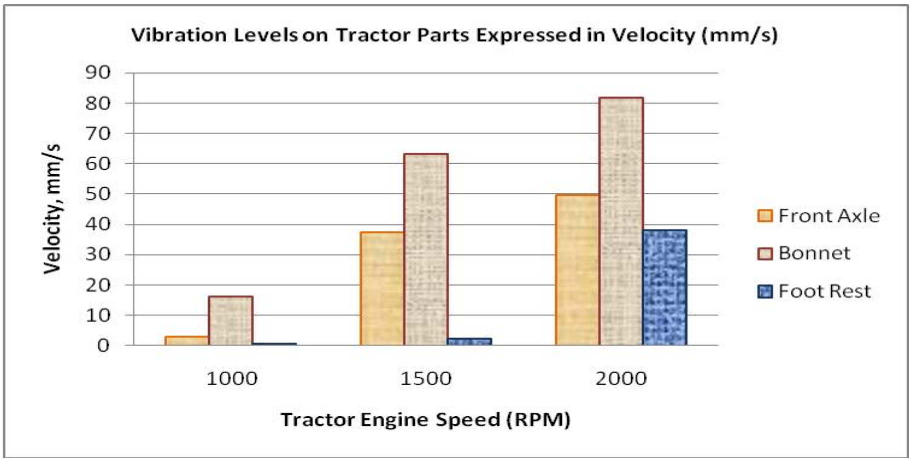


(b) Vibration levels in velocity (mm/s) observed on bonnet

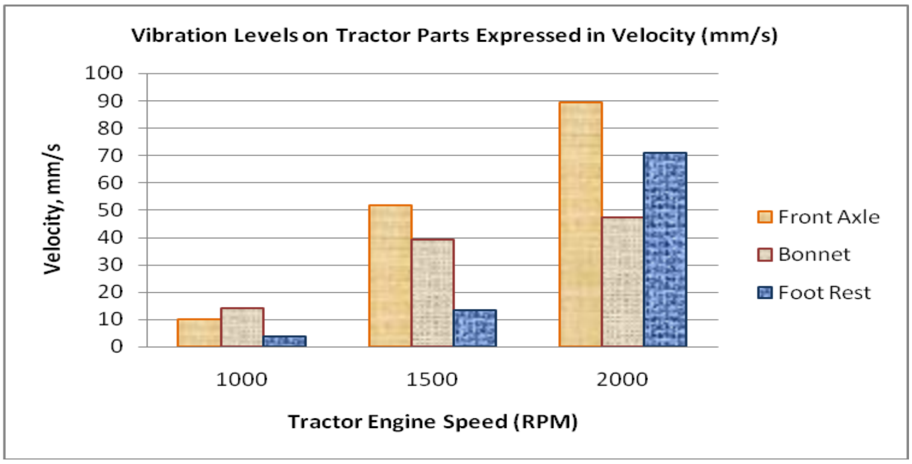


(c) Vibration levels in velocity (mm/s) observed on foot rest

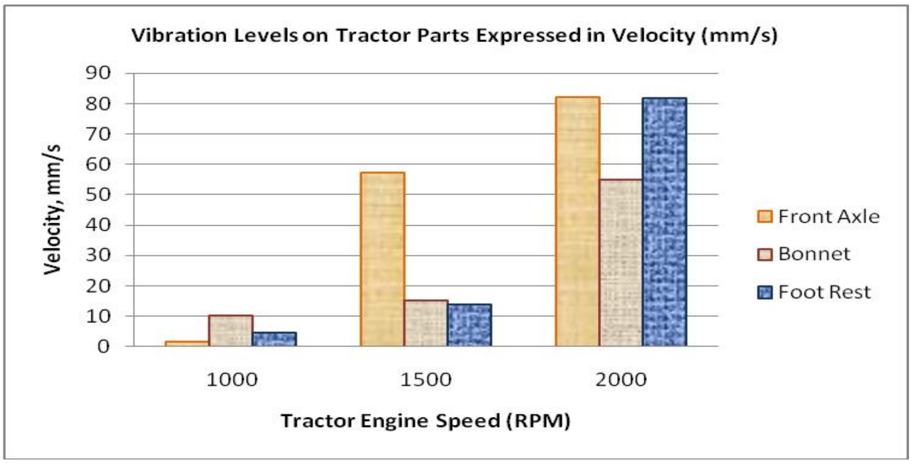
Fig. 4.6: Vibration levels measured in velocity (mm/s) on (a) front axle, (b) bonnet and (c) foot rest in three directions (Tractor-2) at different engine speed (RPM)



(a) Vibration levels in velocity (mm/s) in longitudinal (X) direction



(b) Vibration levels in velocity (mm/s) observed in lateral (Y) direction



(c) Vibration levels in velocity (mm/s) observed in vertical (Z) direction

Fig. 4.7: Vibration levels measured in velocity (mm/s) in (a) longitudinal, (b) lateral and (c) vertical directions on three surfaces (Tractor-2) at different engine speed (RPM)

Fig. 4.7 (a), (b) and (c) indicated the increasing pattern of change in the vibration velocities in all directions which was also in compliance with the noise level increase with increase in the engine speed. Secondly, maximum increase was noticed in the front axle vibrations irrespective of the directions. In longitudinal (X) direction, maximum vibration velocity was observed on bonnet at 2000 RPM while in lateral (Y) and vertical (Z) directions front axle vibrations were found maximum followed by foot rest vibrations at second place. Overall pattern of vibration velocity observations were following the pattern of noise level changes with more or less variations in the intensity on different component and different directions.

4.1.2.2.2 Vibration levels in acceleration on tractor-2

Vibration levels recorded in acceleration (m/s^2) on different tractor components at different RPM in longitudinal (X), lateral (Y) and vertical (Z) directions on Tractor-2 are tabulated below (Table 4.4).

Table 4.4: Vibration levels recorded in acceleration (m/s^2) on Tractor-2

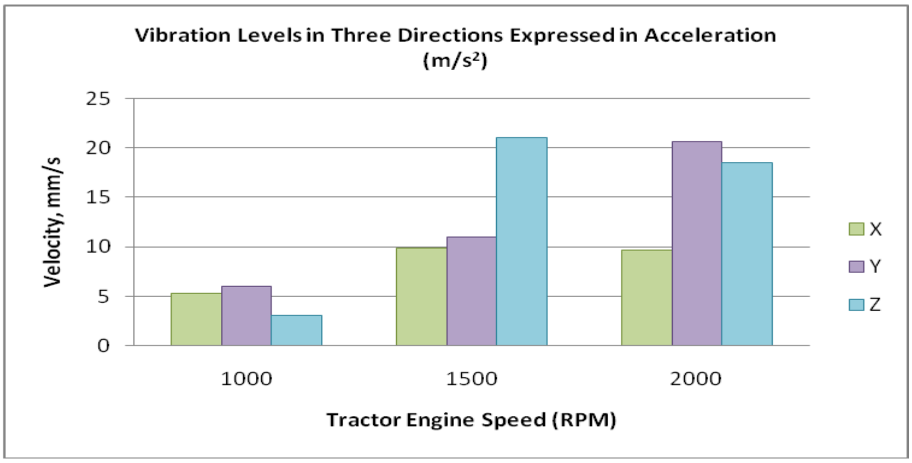
Engine Speed (RPM)	Front Axle			Bonnet			Foot Rest		
	X	Y	Z	X	Y	Z	X	Y	Z
1000	5.3	6	3	11	7.4	7.6	2.9	7.7	8.4
1500	9.9	11	21	21.2	16.1	10	6.1	11.3	12.8
2000	9.7	20.6	18.5	32.4	18.5	21.8	12.3	20.6	20.5
Mean	8.3	12.5	14.2	21.5	14.0	13.1	7.1	13.2	13.9

The vibration analysis conducted on Tractor-2 revealed that normally vibration accelerations increased with increase in the engine speed of the tractor in stationery mode however with certain exceptions (Table 4.4). This was completely true in case of foot rest vibrations in all three directions. However, for engine speed rise from 1000 RPM to 1500 RPM, front axle and bonnet surface vibrations increased in all three directions but during engine speed rise from 1500 to 2000 RPM, X and Z-direction vibrations on front axle did not rise.

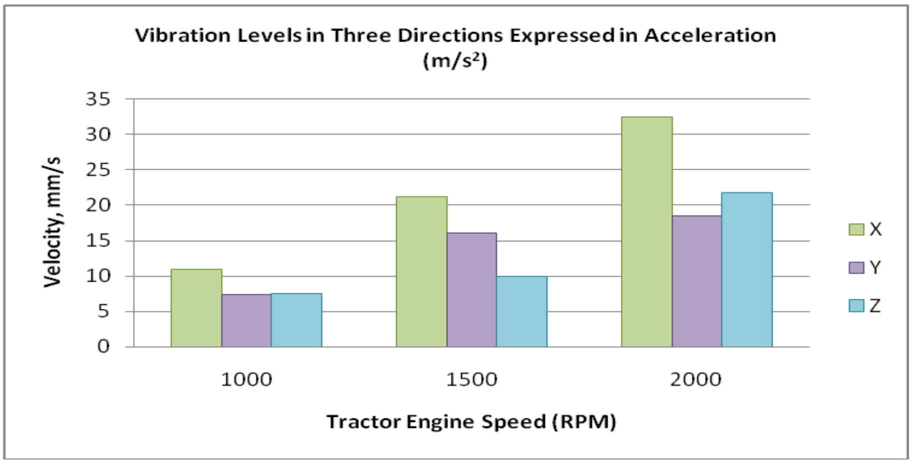
Fig. 4.8 (a) indicated that on front axle of tractor-2, increase in engine speed from 1000 to 1500 RPM caused increase in accelerations in all three directions but later when speed was increased from 1500 to 2000 RPM, vertical vibration levels in terms of acceleration were reduced. Fig. 4.8 (b) and (c) shows increase in accelerations on bonnet and foot rest respectively in all directions with increase in engine speed.

Fig. 4.9 (a) and (b) shows increase in longitudinal (X) and lateral (Y) accelerations with increase in engine speed from 1000 to 1500 RPM and 1500 RPM to 2000 RPM on all surfaces.

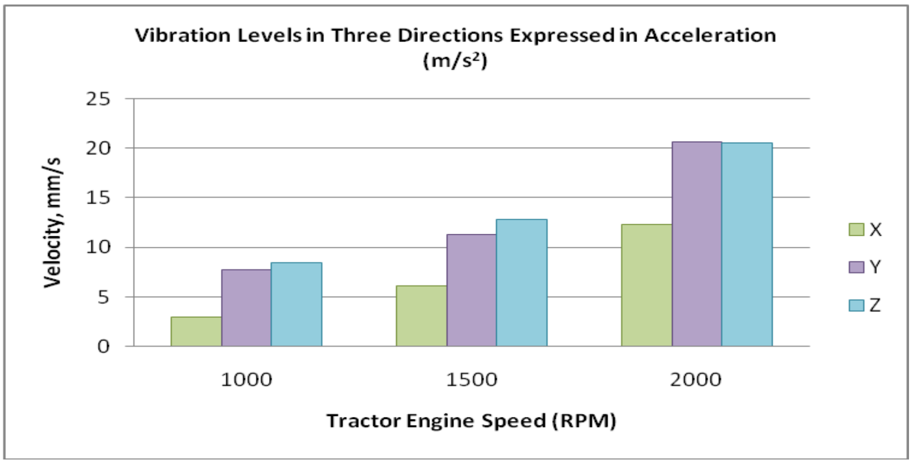
Fig. 4.9 (c) shows that when engine speed was increased from 1000 to 1500 RPM, the vertical accelerations increased on all three surfaces but when engine speed was increased from 1500 to 2000 RPM, the acceleration levels on front axle reduced which was the deviation in the observation.



(a) Vibration levels in acceleration (m/s^2) on front axle of Tractor-2

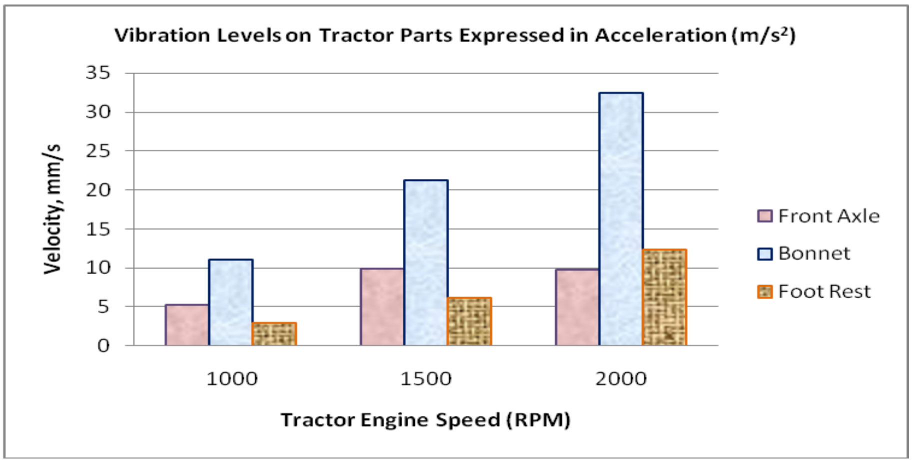


(b) Vibration levels in acceleration (m/s^2) observed on bonnet of Tractor-2

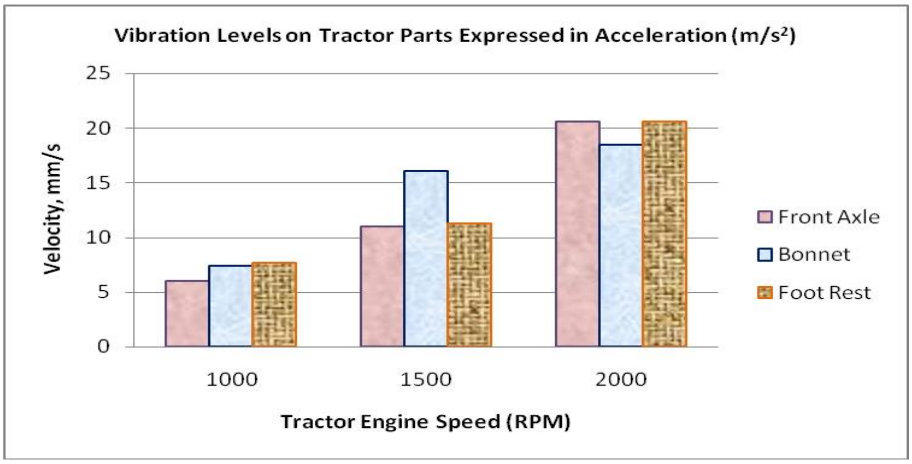


(c) Vibration levels in acceleration (m/s^2) observed on foot rest of Tractor-2

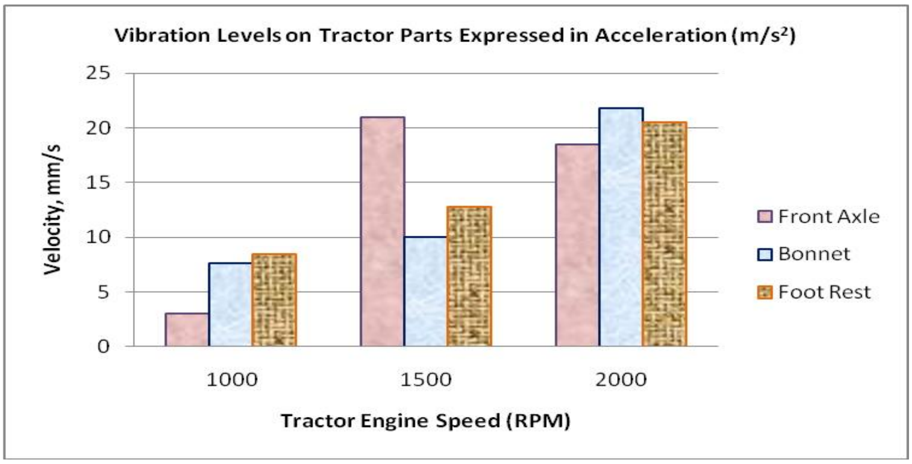
Fig. 4.8: Vibration levels measured in acceleration (m/s^2) on (a) front axle, (b) bonnet and (c) foot rest of Tractor-2 at different engine speed (RPM)



(a) Vibration levels in acceleration (m/s^2) in longitudinal (X) direction



(b) Vibration levels in acceleration (m/s^2) observed in lateral (Y) direction



(c) Vibration levels in acceleration (m/s^2) observed in vertical (Z) direction

Fig. 4.9: Vibration levels measured in acceleration (m/s^2) in (a) longitudinal, (b) lateral and (c) vertical directions on Tractor-2 at different engine speed (RPM)

4.1.3 Characteristics of Noise and Vibration Levels Associated with Farm Tractors

Though, exhaust noise has been considered as main constituent of the tractor noise, moving machinery components also contribute towards noise recorded by SLM. Thus, to study the level of impact the vibrations make upon noise levels, regression analysis was conducted. The effect of X, Y and Z vibrations on the noise levels recorded in dBA is discussed in the following sub sections.

4.1.3.1 Regression analysis of noise (SPL) and vibration velocity

4.1.3.1.1 Noise (SPL) and vibration velocity associated with tractor-1 (mini tractor)

The graphical presentation of data displayed the kind and extent of relation between vibration velocity levels in X, Y and Z directions with respective noise levels recorded (Fig. 4, 5 & 6).

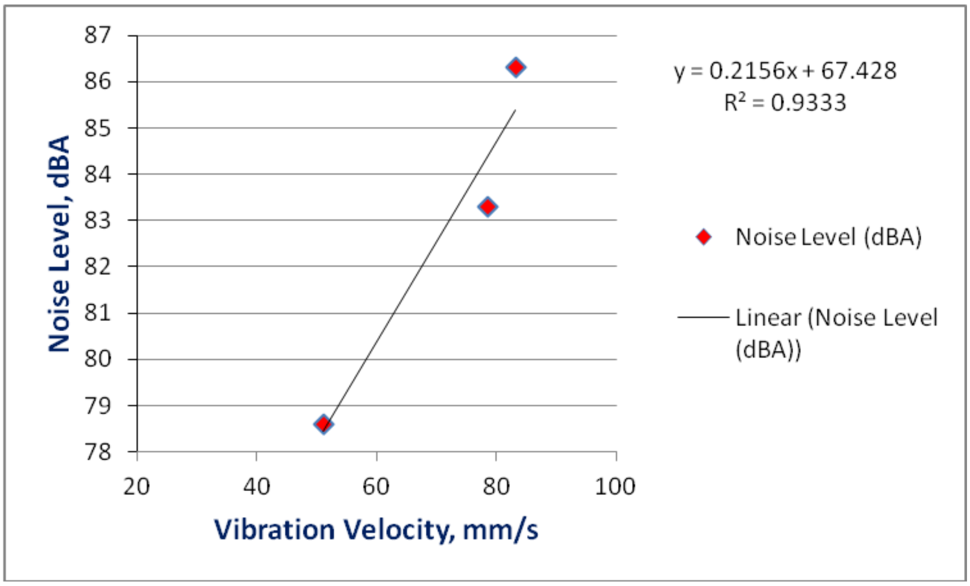


Fig. 4.10: Vibration velocity in X-direction versus noise levels recorded on Tractor-1 (mini tractor) (Tractor-1)

Fig. 4.10 depicts relationship between the vibration velocity (mm/s) in longitudinal (X) direction and the corresponding noise levels (dBA) with a linear fit. Noise levels in terms of respective longitudinal vibration velocity levels could be expressed by linear equation y = 0.2156x + 67.428 with R^2 value of 0.9333.

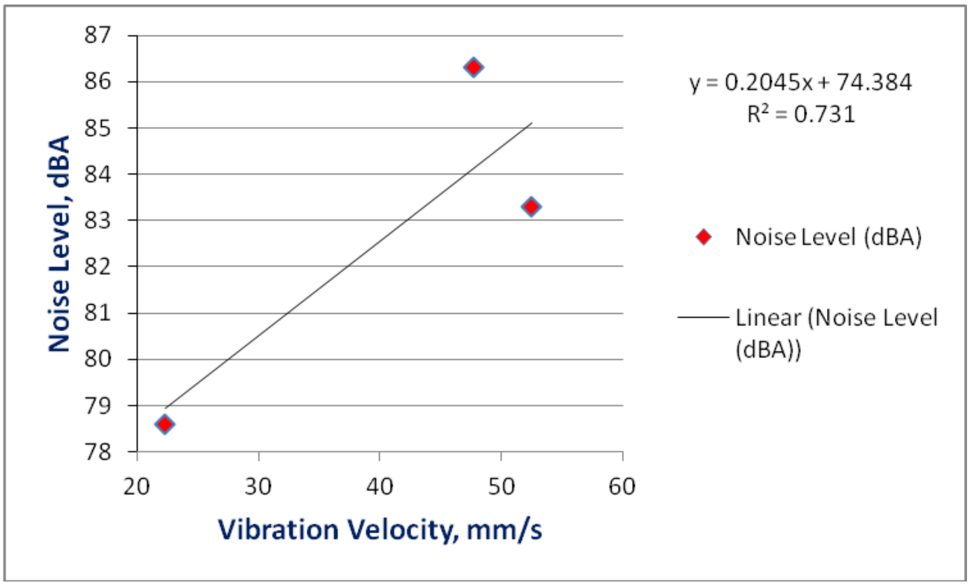


Fig. 4.11: Vibration velocity in Y-direction versus noise levels recorded on Tractor-1 (mini tractor) (Tractor-1)

Fig. 4.11 depicts relationship between the vibration velocity (mm/s) in lateral (Y) direction and the corresponding noise levels (dBA) with a linear fit. Noise levels in terms of respective lateral vibration velocity levels could be expressed by linear equation y = 0.2045x + 74.384 with R^2 value of 0.731.

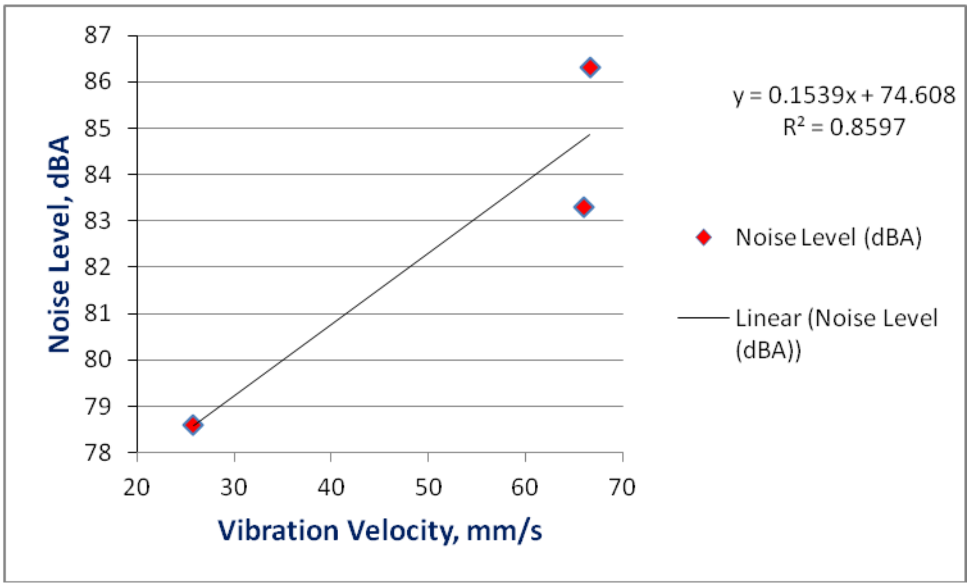


Fig. 4.12: Vibration velocity in Z-direction versus noise levels recorded on Tractor-1 (mini tractor)

Fig. 4.12 depicts relationship between the vibration velocity (mm/s) in vertical (Z) direction and the corresponding noise levels (dBA) with a linear fit. Noise levels in terms of respective vertical vibration velocity levels could be expressed by linear equation y = 0.1539x + 74.608 with R^2 value of 0.8597.

4.1.3.1.2 Noise (SPL) and vibration velocity associated with tractor-2

The vibration velocities observed in different specific directions on Tractor-2 are compared with noise levels observed at respective engine speeds. The graphical presentation of data displayed the kind and extent of relation between them in the following figures (Fig. 4.13, 4.14 & 4.15).

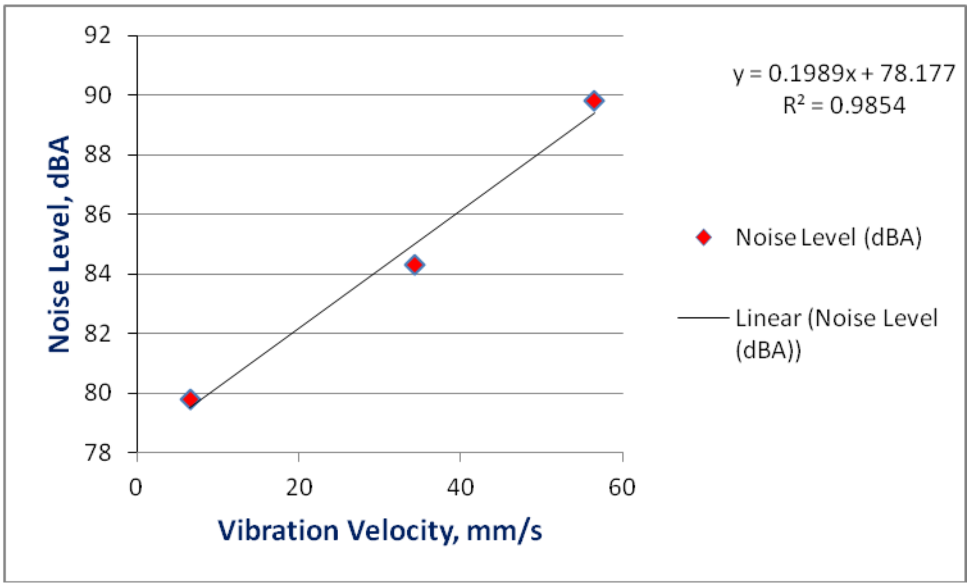


Fig. 4.13: Vibration velocity in X-direction versus noise levels recorded on Tractor-2

Fig. 4.13 depicts relationship between the vibration velocity (mm/s) in longitudinal (X) direction and the corresponding noise levels (dBA) with a linear fit. Noise levels in terms of respective longitudinal vibration velocity levels could be expressed by linear equation y = 0.1989x + 78.177 with R^2 value of 0.9854.

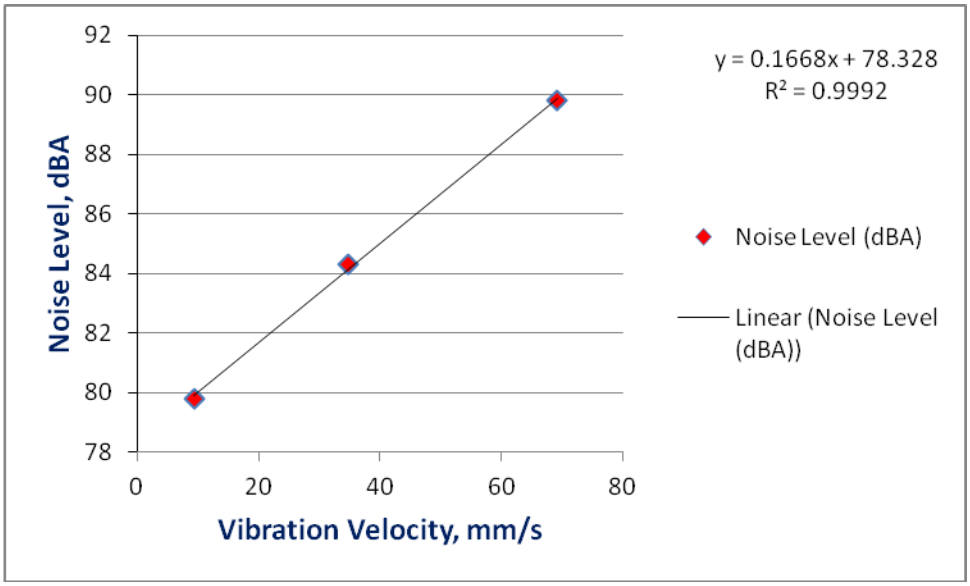


Fig. 4.14: Vibration velocity in Y-direction versus noise levels recorded on Tractor-2

Fig. 4.14 depicts relationship between the vibration velocity (mm/s) in lateral (Y) direction and the corresponding noise levels (dBA) with a linear fit. Noise levels in terms of respective lateral vibration velocity levels could be expressed by linear equation y = 0.1668x + 78.328 with R^2 value of 0.9992.

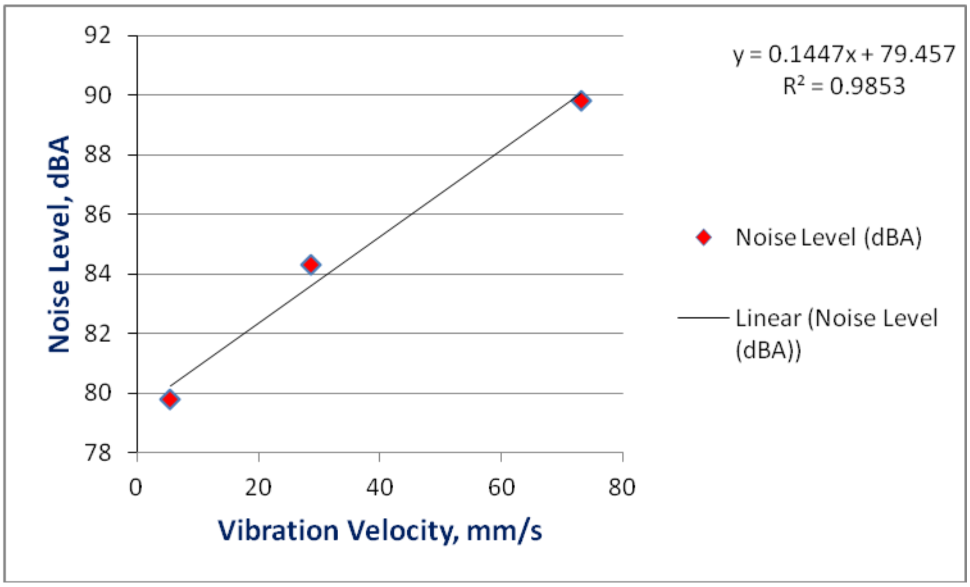


Fig. 4.15: Vibration velocity in Z-direction versus noise levels recorded on Tractor-2

Fig. 4.15 depicts relationship between the vibration velocity (mm/s) in vertical (Z) direction and the corresponding noise levels (dBA) with a linear fit. Noise levels in terms of respective vertical vibration velocity levels could be expressed by linear equation y = 0.1447x + 79.457 with R^2 value of 0.9853.

4.1.3.2 Regression analysis of noise (SPL) and vibration acceleration

4.1.3.2.1 Noise (SPL) and vibration acceleration associated with tractor-1 (mini tractor)

The graphical presentation of data displayed the kind and extent of relation between vibration acceleration levels in X, Y and Z directions with respective noise levels recorded (Fig. 4.16, 4.17 & 4.18).

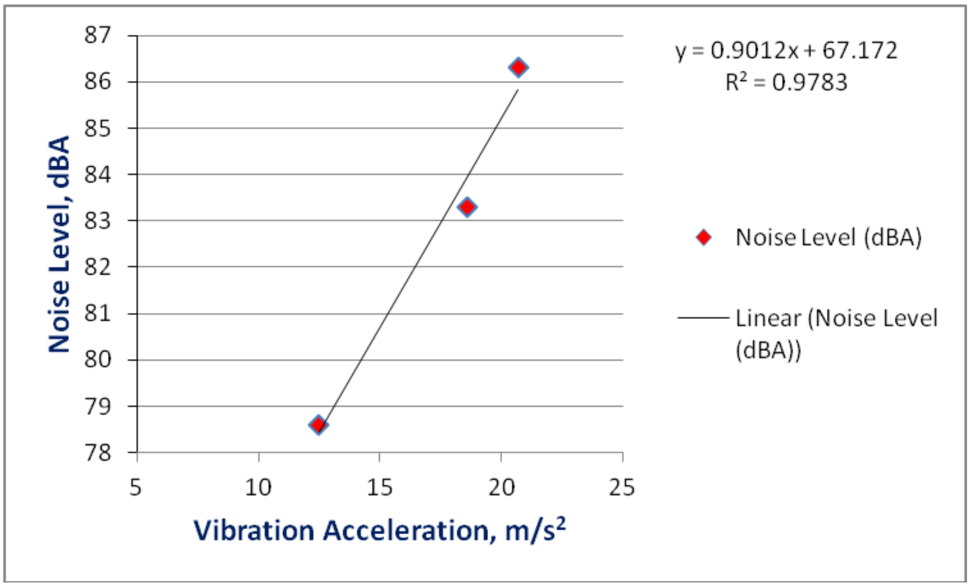


Fig. 4.16: Vibration acceleration in X-direction versus noise levels recorded on Tractor-1 (mini tractor)

Fig. 4.16 depicts relationship between the vibration acceleration (m/s^2) in longitudinal (X) direction and the corresponding noise levels (dBA) with a linear fit. Noise levels in terms of respective longitudinal vibration accelerations could be expressed by linear equation $y = 0.9012x + 67.172$ with R^2 value of 0.9783.

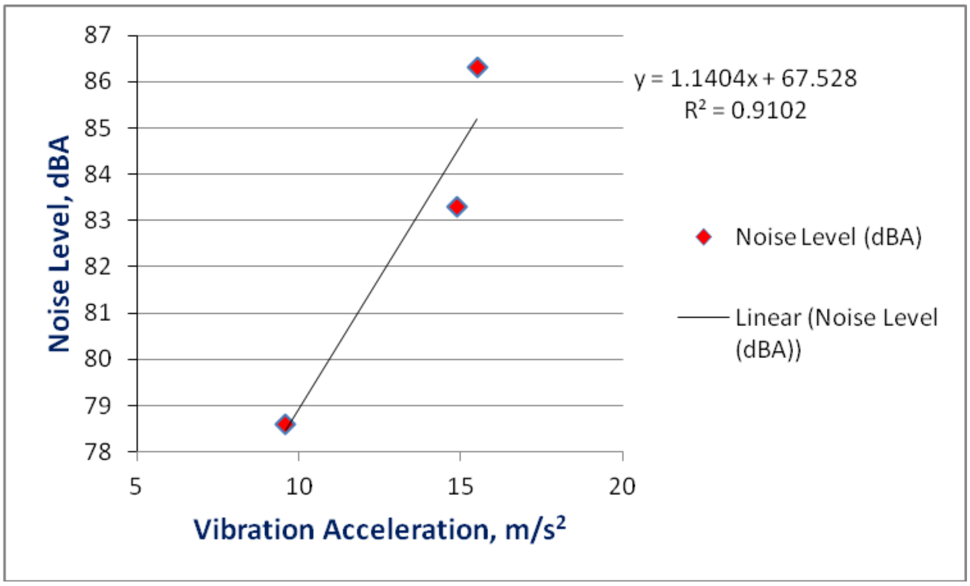


Fig. 4.17: Vibration acceleration in Y-direction versus noise levels recorded on Tractor-1 (mini tractor)

Fig. 4.17 depicts relationship between the vibration acceleration (m/s^2) in lateral (Y) direction and the corresponding noise levels (dBA) with a linear fit. Noise levels in terms of respective lateral vibration accelerations could be expressed by linear equation y = 1.1404x + 67.528 with R^2 value of 0.9102.

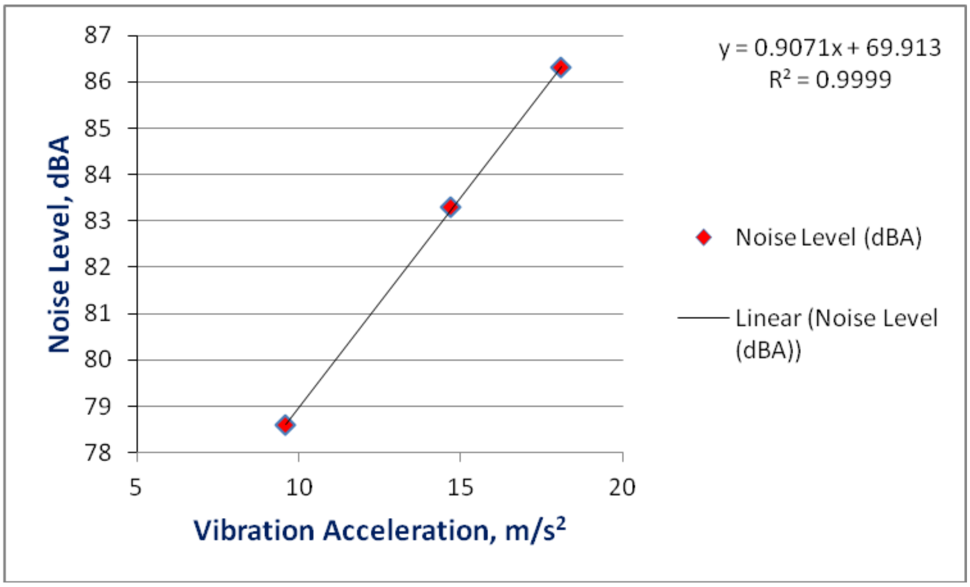


Fig. 4.18: Vibration acceleration in Z-direction versus noise levels recorded on Tractor-1 (mini tractor)

Fig. 4.18 depicts relationship between the vibration acceleration (m/s^2) in vertical (Z) direction and the corresponding noise levels (dBA) with a linear fit. Noise levels in terms of respective vertical vibration acceleration levels could be expressed by linear equation y = 0.9071x + 69.913 with R^2 value of 0.9999.

4.1.3.2.2 Noise (SPL) and vibration acceleration associated with tractor-2

The vibration velocities observed in different specific directions on Tractor-2 are compared with noise levels observed at respective engine speeds. The graphical presentation of data displayed the kind and extent of relation between them in the following figures (Fig. 4.19, 20 & 21).

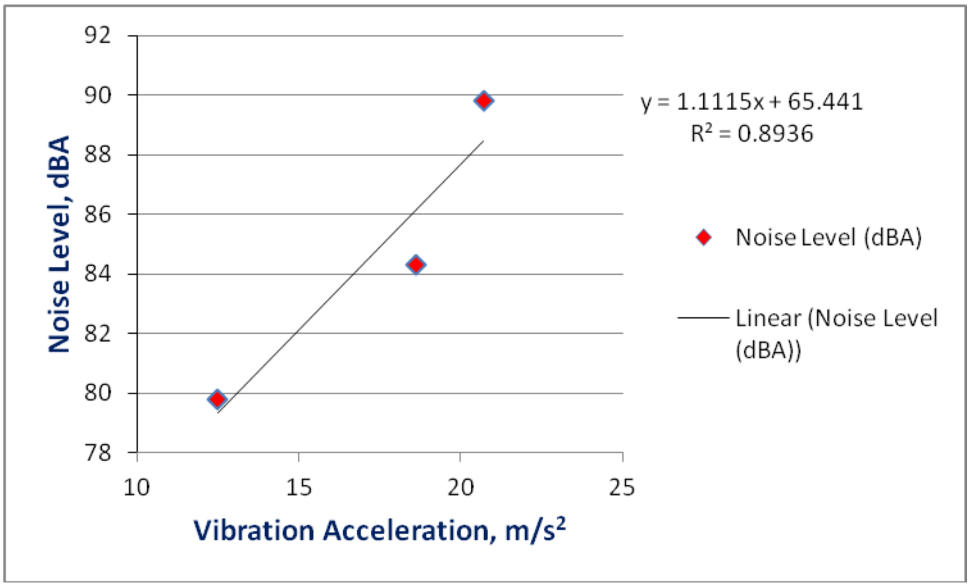


Fig. 4.19: Vibration acceleration in X-direction versus noise levels recorded on Tractor-2

Fig. 4.19 depicts relationship between the vibration acceleration (m/s^2) in longitudinal (X) direction and the corresponding noise levels (dBA) with a linear fit. Noise levels in terms of respective longitudinal vibration acceleration levels could be expressed by linear equation y = 1.1115x + 65.441 with R^2 value of 0.8936.

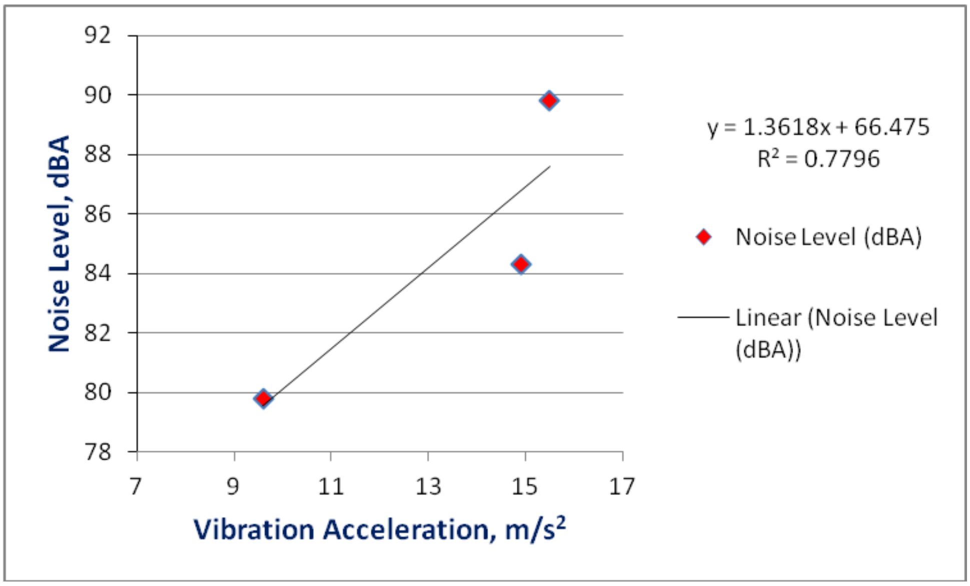


Fig. 4.20: Vibration acceleration in Y-direction versus noise levels recorded on Tractor-2

Fig. 4.20 depicts relationship between the vibration acceleration (m/s^2) in lateral (Y) direction and the corresponding noise levels (dBA) with a linear fit. Noise levels in terms of respective lateral vibration acceleration levels could be expressed by linear equation y = 1.3618x + 66.475 with R^2 value of 0.7796.

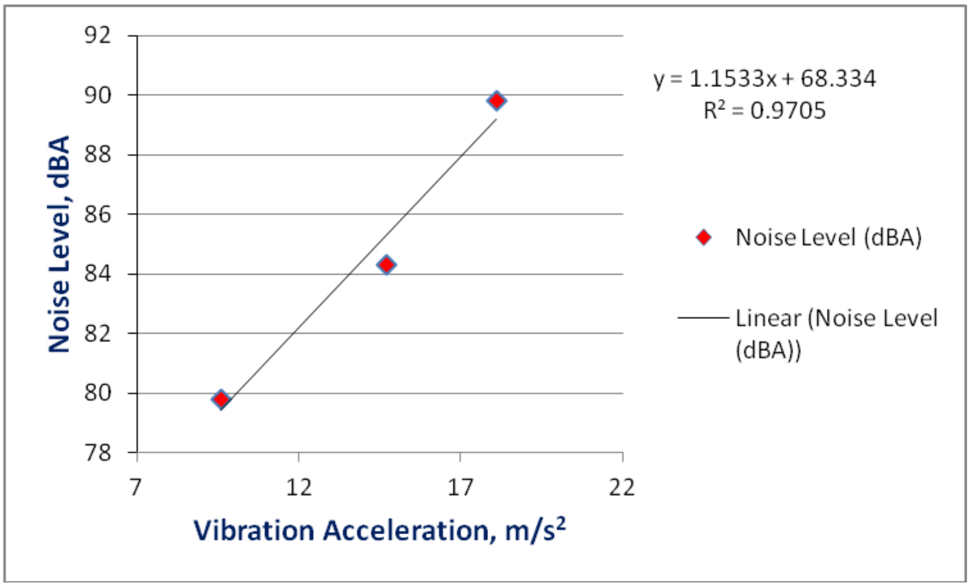


Fig. 4.21: Vibration acceleration in Z-direction versus noise levels recorded on Tractor-2

Fig. 4.21 depicts relationship between the vibration acceleration (m/s^2) in vertical (Z) direction and the corresponding noise levels (dBA) with a linear fit. Noise levels in terms of respective vertical vibration acceleration levels could be expressed by linear equation y = 1.1533x + 68.334 with R^2 value of 0.9705.

4.2 SELECTION OF MUFFLERS FOR TRACTOR-1 (MINI TRACTOR) AND TRACTOR-2

The preliminary test of SPL measurements were conducted on ten conceptual designs of different inside muffler configuration. Sound pressure levels in dBA or dB(A) were recorded on two tractors at different engine speeds viz. 1000, 1500 and 2000 RPM.

4.2.1 Noise Level (SPL) Test under Different Mufflers on Tractor-1 (Mini Tractor)

Initially ten numbers of exhaust mufflers having different inside configurations were employed to test the effects of different mufflers on exhaust noise and on that basis detailed stduy was restricted to few selected mufflers only. The noise level observations in terms of sound pressure levels in the units of dB(A) were recorded under different muffler conditions at 1000, 1500 and 2000 RPM at ear level (EL) and at 10 m distance.

4.2.1.1 Noise levels (SPL) on tractor-1 (mini tractor) under different mufflers at ear level

Table 4.5 consists of mean SPL values observed at ear level under different muffler conditions at 1000, 1500 & 2000 RPM on Tractor-1. Muffler-S (standard muffler), muffler-1 & muffler-4 were found to have generated the lowest three noise levels at 1000 RPM. At 1500 RPM, muffler-1, muffler-3 & muffler-4 were found to have generated the lowest three noise levels. At 2000 RPM, muffler-3, muffler-6 & muffler-7 were found to have generated the lowest three noise levels.

Table 4.5: Noise levels measured under different mufflers at different engine speed (RPM) on Tractor-1 (at ear level)

Sr. No.	Muffler	Mean SPL (dBA) at 1000 RPM	Mean SPL (dBA) at 1500 RPM	Mean SPL (dBA) at 2000 RPM
1.	No-Muffler	79.6	85.5	89.9
2.	Standard Muffler	78.4	83.2	86.2
3.	Muffler-01	78.0	82.2	86.3
4.	Muffler-03	78.2	82.1	85.8
5.	Muffler-04	78.3	82.5	85.6
6.	Muffler-05	78.8	82.6	85.8
7.	Muffler-06	78.8	82.3	85.6
8.	Muffler-07	78.7	82.9	85.5
9.	Muffler-08	78.6	82.9	85.9
10.	Muffler-09	78.3	83.2	86.2
11.	Muffler-10	79.0	83.4	86.1
12.	Muffler-11	78.4	82.8	85.7

At 1000 RPM, Tractor-1 produced the lowest noise SPL of 78.0 dBA at ear level under muffler-1 among all mufflers. At 1500 RPM, Tractor-1 produced the lowest noise SPL of 82.1 dBA at ear level under **muffler-3** among all mufflers. At

2000 RPM, Tractor-1 produced the lowest noise SPL of 85.5 dBA at ear level under **muffler-7** among all mufflers.

4.2.1.2 Noise levels (SPL) on tractor-1 (mini tractor) under different mufflers at 10 m distance

Table 4.6 consists of mean SPL values observed at 10 m distance from the tractor under different muffler mountings at 1000, 1500 & 2000 RPM on Tractor-1. Muffler-1, muffler-3, muffler-8 & muffler-9 were found to have generated the lowest three noise levels at 1000 RPM. At 1500 RPM, muffler-S (standard muffler), muffler-3, & muffler-5 were found to have generated the lowest three noise levels. At 2000 RPM, muffler-S, muffler-7 & muffler-8 were found to have generated the lowest three noise levels.

Table 4.6: Noise levels measured under different mufflers at different engine speed (RPM) on Tractor-1 (at 10 m distance)

Sr. No.	Muffler	Mean SPL (dBA) at 1000 RPM	Mean SPL (dBA) at 1500 RPM	Mean SPL (dBA) at 2000 RPM
1.	No-Muffler	65.2	70.1	75.3
2.	Standard Muffler	64.0	<u>66.6</u>	<u>70.4</u>
3.	Muffler-01	<u>63.3</u>	67.9	72.3
4.	Muffler-03	<u>63.3</u>	<u>67.5</u>	71.1
5.	Muffler-04	63.5	67.8	71.4
6.	Muffler-05	64.0	<u>67.5</u>	71.4
7.	Muffler-06	63.4	67.6	71.6
8.	Muffler-07	63.5	67.9	<u>70.9</u>

9.	Muffler-08	<u>63.3</u>	68.1	<u>71.0</u>
10.	Muffler-09	<u>62.8</u>	67.9	71.5
11.	Muffler-10	63.9	68.7	72.1
12.	Muffler-11	63.6	68.0	71.5

At 2000 RPM, Tractor-1 produced the second lowest noise SPL of 70.9 dBA under **muffler-7** after 70.4 dBA under standard muffler being lowest at 10 m distance among all mufflers. On basis of the results depicted in Table 4.5 & 4.6, **muffler-3 & muffler-7** were selected for Tractor-1 for further detailed trials along with **standard muffler**.

4.2.1.3 Selection of mufflers for tractor-1 (mini tractor)

Further averaging of the noise levels found during preliminary tests provided supplementary information for selection of mufflers for Tractor-1. At ear level, minimum average noise level (82.0 dBA) has been found under muffler-3 on Tractor-1 (Mini Tractor). At 10 m distance from the tractor (exhaust noise source), minimum average noise level (67.0 dBA) has been found under standard muffler on Tractor-1 (Mini Tractor). On basis of the inferences drawn in section 4.2.1.1 and 4.2.1.2, **muffler-3 & muffler-7** were finally selected for detailed noise level test on Tractor-1 (Mini Tractor).

4.2.2 Noise Level (SPL) Test under Different Mufflers on Tractor-2

As on Tractor-1, ten numbers of exhaust mufflers having different inside configurations were employed to test the effects of different mufflers on exhaust noise and on that basis detailed stduy was restricted to few selected mufflers only. The noise level observations in terms of sound pressure levels in the units of dB(A) were recorded under different muffler conditions at 1000 RPM at ear level and at 10 m distance.

4.2.2.1 Noise levels (SPL) on tractor-2 under different mufflers at ear level

Table 4.7 consists of mean SPL values observed at ear level under different muffler conditions at 1000, 1500 & 2000 RPM on Tractor-2. Muffler-7, muffler-8 & muffler-9 were found to have generated the lowest three noise levels at 1000 RPM. At 1500 RPM, muffler-S, muffler-3, muffler-4 & muffler-6 were found to have generated the lowest three noise levels among all muffler mountings. At 2000 RPM on Tractor-2., muffler-1, muffler-3 & muffler-4 were found to have generated the lowest three noise levels.

Table 4.7: Noise levels measurement under different mufflers at 1000, 1500 & 2000 RPM on Tractor-2 (at ear level)

Sr. No.	Muffler	Mean SPL (dBA) at 1000 RPM	Mean SPL (dBA) at 1500 RPM	Mean SPL (dBA) at 2000 RPM
1.	No-Muffler	79.9	87.2	93.2
2.	Standard Muffler	79.9	<u>82.5</u>	89.7
3.	Muffler-01	77.9	83.4	<u>89.1</u>
4.	Muffler-03	77.9	<u>82.4</u>	<u>89.3</u>
5.	Muffler-04	77.1	<u>82.6</u>	<u>88.6</u>
6.	Muffler-05	77.2	83.0	90.1
7.	Muffler-06	77.2	<u>82.6</u>	91.3
8.	**Muffler-07**	<u>76.6</u>	82.8	90.8
9.	Muffler-08	<u>76.9</u>	83.1	91.0
10.	Muffler-09	<u>77.0</u>	83.7	91.6

11.	Muffler-10	80.9	85.3	90.3
12.	Muffler-11	77.4	86.7	90.3

Table 4.7 revealed that Tractor-2 produced the lowest noise SPL of 76.6 dBA under muffler-7 at ear level among all mufflers at 1000 RPM. At 1500 RPM, Tractor-2 produced the lowest noise SPL of 82.4 dBA at ear level under muffler-3 among all mufflers. At 2000 RPM, Tractor-2 produced the lowest noise SPL of 88.6 dBA at ear level under muffler-4 among all mufflers.

4.2.2.2 Noise levels (SPL) on tractor-2 under different mufflers at 10 m distance

Table 4.8 consists of mean SPL values observed at 10 m distance from the tractor under different muffler mountings at 1000, 1500 & 2000 RPM on Tractor-2. Muffler-7, muffler-9 & muffler-11 were found to have generated the lowest three noise levels at 1000 RPM. At 1500 RPM, muffler-6, muffler-7 & muffler-11 were found to have generated the lowest three noise levels on Tractor-2. At 2000 RPM on Tractor-2, Muffler-4, muffler-5 & muffler-7 were found to have generated the lowest three noise levels among all other mufflers.

Table 4.8: Noise levels measured under different mufflers at 1000, 1500 & 2000 RPM on Tractor-2 (at 10 m distance)

Sr. No.	Muffler	Mean SPL (dBA) at 1000 RPM	Mean SPL (dBA) at 1500 RPM	Mean SPL (dBA) at 2000 RPM
1.	No-Muffler	67.8	76.8	82.8
2.	Standard Muffler	66.6	70.9	75.8
3.	Muffler-01	65.0	71.6	75.3
4.	Muffler-03	65.5	70.7	75.3

5.	Muffler-04	65.2	70.7	75.0
6.	Muffler-05	64.9	70.7	74.9
7.	Muffler-06	64.9	70.3	75.1
8.	Muffler-07	64.5	70.1	74.8
9.	Muffler-08	65.0	71.4	77.7
10.	Muffler-09	64.7	71.4	77.1
11.	Muffler-10	65.9	72.3	76.9
12.	Muffler-11	64.4	70.5	75.3

Table 4.8 revealed that at 1000 RPM Tractor-2 produced the lowest noise SPL of 64.4 dBA under muffler-11 and second lowest noise SPL of 64.5 dBA as recorded at 10 m distance under muffler-7 among all mufflers. At 1500 RPM Tractor-2 produced the lowest noise SPL of 70.1 dBA under muffler-7 at 10 m distance among all mufflers. At 2000 RPM Tractor-2 produced the lowest noise SPL of 74.8 dBA under muffler-7 at 10 m distance among all mufflers.

Among the mufflers under test, other than standard muffler, muffler-7 has been found most attenuating muffler at all engine speeds under test viz. 1000, 1500 & 2000 RPM. On basis of the results depicted in Table 4.7 & 4.8, **muffler-4 & muffler-7** were selected for Tractor-2 for further detailed trials along with standard muffler.

4.2.2.3 Selection of mufflers for tractor-2

Further averaging of the noise levels found during preliminary tests provided supplementary information for selection of mufflers for Tractor-2. At ear level, minimum average noise level (82.8 dBA) has been found under muffler-4 on Tractor-2. At 10 m distance from the tractor (exhaust noise source), minimum average noise level (69.8 dBA) has been found under muffler-7 on Tractor-2. Hence, muffler-4 & muffler-7 were finally selected for detailed experimentation on Tractor-2.

4.2.3 Selection of Common Muffler for Tractor-1 & Tractor-2

Based on the inferences drawn in earlier sections, muffler-7 has been found a common noise attenuating device on Tractor-1 (Mini Tractor) and Tractor-2 both. Therefore, muffler-7 has been selected as common muffler for mounting on Tractor-1 & Tractor-2 both for further detailed noise level comparison with standard muffler mounting.

4.2.4 Selection and Coding of Mufflers for Detailed Noise Level (SPL) Test

On basis of the results of noise level test conducted for different mufflers as discussed under section 4.2.1 & 4.2.2, three mufflers, two for each one tractor, were selected for detailed measurement and analysis of the noise levels generated at variable places and at variable engine speed of tractors. Standard muffler was incorporated as control for comparison of the performance of newly designed mufflers. The standard muffler, muffler-3, muffler-4 & muffler-7 were respectively coded as muffler-S, muffler-A, muffler-B & muffler-C. The selected mufflers viz. muffler-A, muffler-B & muffler-C were further experimented for in-depth analysis of noise attenuation capability of the selected mufflers at given places of noise level measurement.

For the sake of applying appropriate statistical design, muffler mouting was considered as main treatment and engine speed of tractor was treated as sub plot treatment. Five engine speed levels were 1000, 1250, 1500, 1750 & 2000 RPM. The results were analyzed with application of two way ANOVA and by use of Split Plot Design (SPD) method for each of the tractor under test.

4.3 CONSTRUCTIONAL PARAMETERS OF SELECTED MUFFLERS

The outer dimensions of the muffler were however kept uniform, the variable construction parameters were measured and recorded (Table 4.9). The internal configurations of the muffler-A, B & C are presented in Fig. 4.22, 4.23 & 4.24 respectively.

Table 4.9: Constructional parameters of newly fabricated mufflers

Particulars	Muffler-A	Muffler-B	Muffler-C
Length of casing	40.6 cm	40.6 cm	40.6 cm
Diameter of casing (out side)	8.85 cm	8.85 cm	8.85 cm
Diameter of casing (in side)	8.25 cm	8.25 cm	8.25 cm
No. of split / partition	2	2	1
Diameter of outer pipe (out side)	4.65 cm	4.65 cm	4.65 cm
Diameter of outer pipe (in side)	4.35 cm	4.35 cm	4.35 cm
Dia. of primary perforated pipe	4.65 cm	4.65 cm	4.65 cm
Diameter of secondary perforated pipe (if any)	-	3.15 cm	4.65 cm
Number of primary perforations	28 Nos.	28 Nos.	28 Nos.
Size of perforations	6 mm	6 mm	6 mm
Materials of construction	M.S.	M.S.	M.S.
Thickness of M.S. pipe (casing)	2 mm	2 mm	2 mm
Thickness of M.S. pipe (outer)	1.5 mm	1.5 mm	1.5 mm

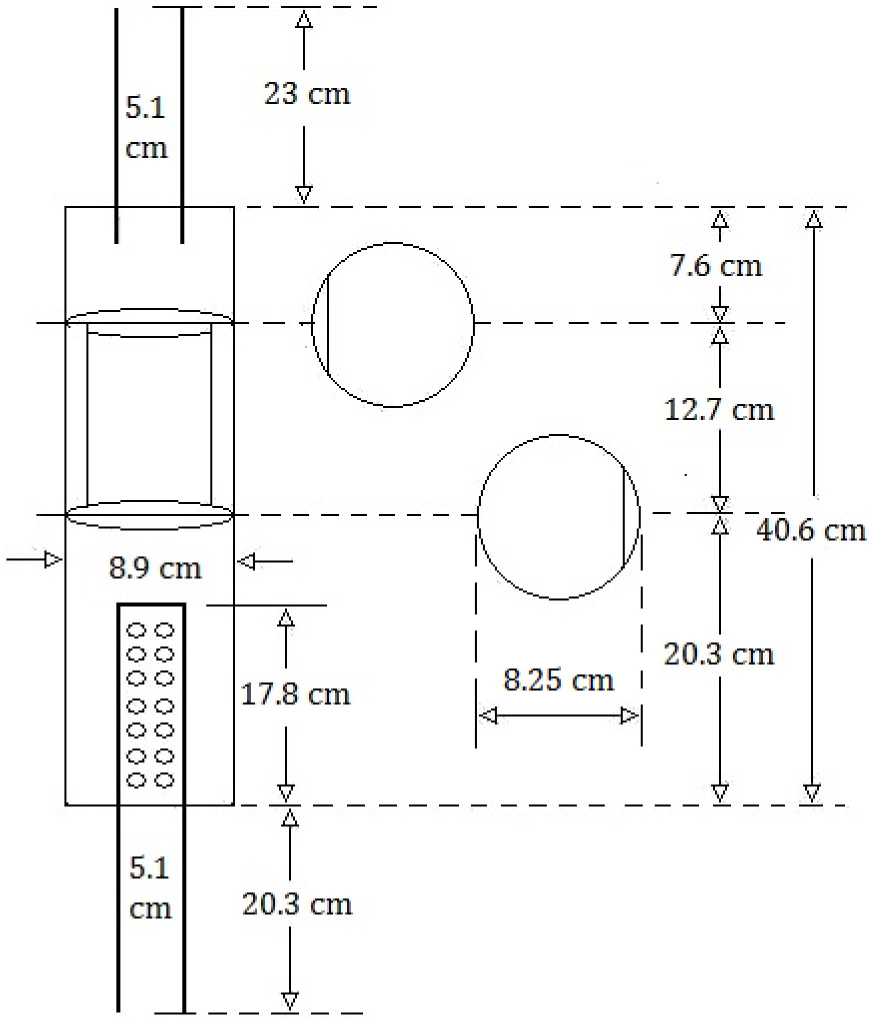


Fig. 4.22: Internal configuration of Muffler-A

Muffler-A, B & C were made up of similar shape (circular cross section) equal sizes. Length & diameter of resonating chamber, diameter of outer and perforated pipes, number of primary perforatins, size of perforations, materials of construction etc. were uniform. However, the secondary perforated pipes placed in Muffler-B & Muffler-C were replaced by two perforated plates fixed at opposite to one another. Exhaust gases entering at one side moved laterally towards another perforated plate and escaped again into the upper direction for further exit.

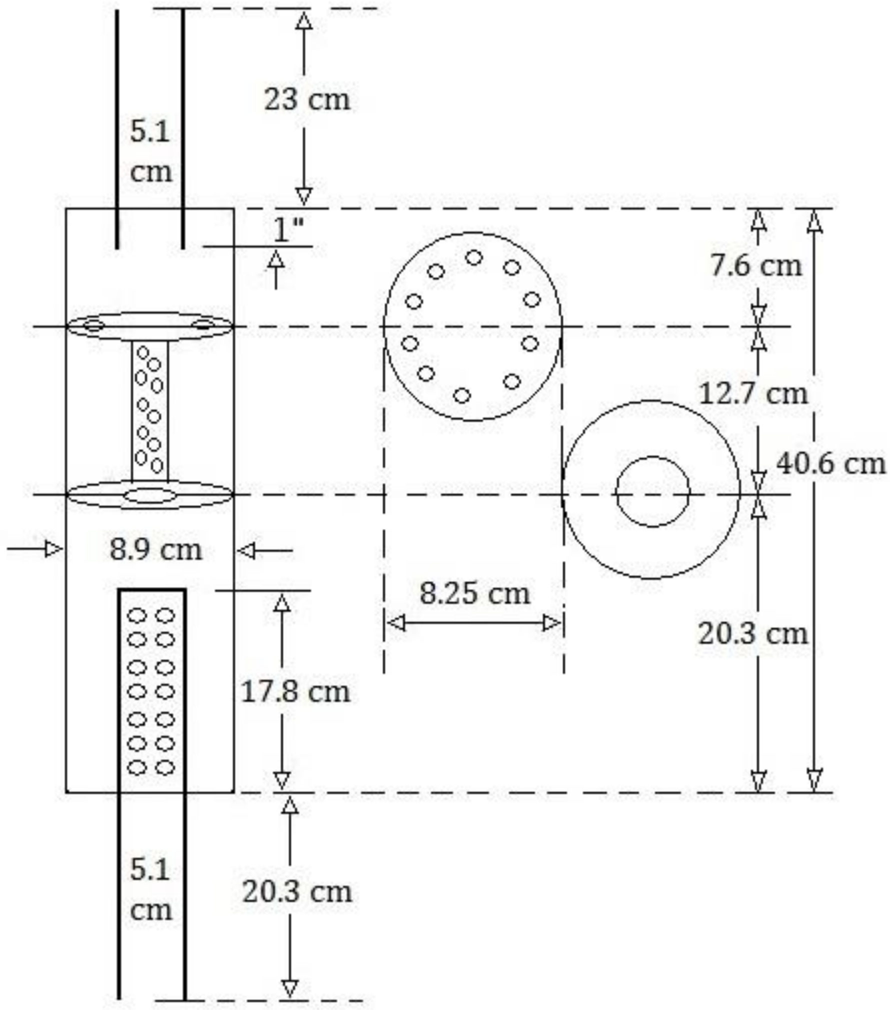


Fig. 4.23: Internal configuration of Muffler-B

At outer side, muffler-B was made up of similar shape (circular) & equal size as that of muffler-A & C both. Length & diameter of resonating chamber, diameter of outer and perforated pipes, number of primary perforatins, size of perforations, materials of construction etc. were uniform. The secondary perforated pipe of smaller size (diameter) was between two splitters as shown in the figure. Exhaust gases entering at lower into the secondary perforated pipe again diverted laterally circular side walls of resonating chamber (referred as outer casing in the Table --) and collided & reflected and were further pushed towards exit through perforations made on the upper side splitter.

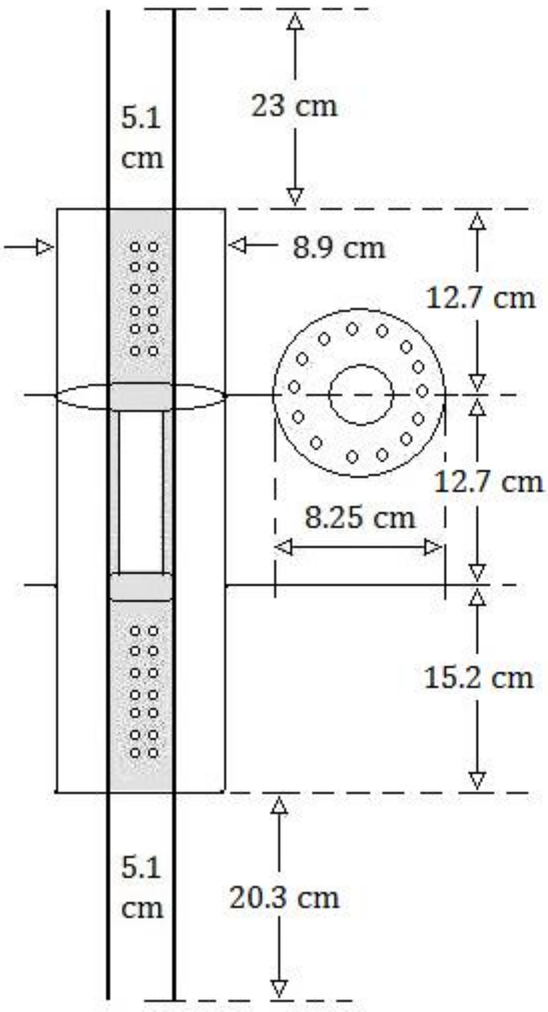


Fig. 4.24: Internal configuration of Muffler-C

At outer side, muffler-C was also made up of similar shape (circular) & equal size as that of muffler-A & B. Length & diameter of resonating chamber, diameter of outer and perforated pipes, number of primary perforatins, size of perforations, materials of construction etc. were uniform. The secondary perforated pipe was part of primary perforated pipe itself and had equal size & number of perforations as that of primary perforations. Only one splitter with perforations on its circular perophery was placed near secondary perforated pipe which rather than diverting them inside lead the exhaust gases towards exit. Thus only one lateral diversion of the exhaust gas and thus that of sound waves took place once only during expansion in the resonating chamber.

Length of circularly cross-sectional casing (resonating chamber) of the muffler was kept 40 cm with outer & inner diameter of 8.85 & 8.25 cm respectively. The thickness of M.S. pipe used for resonating chamber was 2 mm. Diameter of primary perforated pipe was also uniform (4.65 cm). Number of primary perforations were 28 in each muffler under test. Size of perforations were 6 mm in size (diameter).

4.4 INFLUENCE OF MUFFLER DESIGN ALTERATION & ENGINE SPEED ON NOISE LEVELS OF TRACTOR-1 AND TRACTOR-2

The Split-Plot Design was used to statistically analyze the influence of muffler alterations and different engine speeds on the noise levels generated by Tractor-1 (Mini Tractor) and Tractor-2. Muffler types were treated as main treatments with different engine speed levels as sub treatments. For Tractor-1, three mufflers viz. M1, M2 and M3 respectively referred to (i) Muffler-S, (ii) Muffler-A and (iii) Muffler-C. For Tractor-2, three mufflers viz. M1, M2 and M3 respectively referred to (i) Muffler-S, (ii) Muffler-B and (iii) Muffler-C. The engine speed levels S1, S2, S3, S4 and S5 respectively represented tractor engine speeds of 1000, 1250, 1500, 1750 and 2000 RPM.

4.4.1 Effect of Muffler Design Alteration & Engine Speed on Noise Levels Recorded at Operator's Ear Level

ANOVA table for noise level observations at ear level on Tractor-1 and Tractor-2 are presented in Table 4.10 & Table 4.11 respectively. Application of Split-Plot Design to the noise levels recorded at ear level under specified muffler conditions & engine speeds revealed useful information as tabulated under Table 4.12 for Tractor-1 & Tractor-2 both.

Since calculated value of F (Table 4.10) is greater than table value of F at 5% level of significance (α=0.05) for effect of muffler, effect of speed and effect of interaction between muffler & speed, F-ratio is regarded as significant and difference in noise levels at operator's ear level of Tractor-1 is significant at 5% level of significance.

Table 4.10: ANOVA Table for noise levels recorded at ear level (Tractor-1)

Source	D F	S S	M S	F Cal	F Tab 5%	S Em.±	CD at 5%	TEST
Replication	2	0.194	0.0969	0.000	0.000	0.000	NS	**-**
Main	2	0.150	0.075	12.036	3.400	0.020	0.080	*****
Error(a)	4	0.025	0.006		0.100	**C.V. %= 0.10**		
Sub	4	332.441	83.110	3730.638	2.780	0.050	0.145	*****
Main X Sub	8	2.068	0.259	11.604	2.360	0.086	0.252	*****
Error(b)	24	0.535	0.022		0.180	**C.V. %= 0.18**		
TOTAL	44	335.412						

Table 4.11: ANOVA Table for noise levels recorded at ear level (Tractor-2)

Source	**D F**	**S S**	**M S**	**F Cal**	**F Tab 5%**	**S Em.±**	**CD at 5%**	**TEST**
Replication	2	0.336	0.168	0.000	0.000		NS	**-**
Main	2	1.708	0.854	10.675	3.400	0.073	0.287	*****
Error(a)	4	0.32	0.080		0.330	**C.V. %= 0.33**		
Sub	4	622.826	155.706	1093.530	2.780	0.126	0.367	*****
Main X Sub	8	3.001	0.375	2.634	2.360	0.218	0.636	*****
Error(b)	24	3.417	0.14239		0.450	**C.V. %= 0.45**		
TOTAL	44	631.608						

Table 4.11 displays that calculated value of F is greater than table value of F at 5% level of significance (α=0.05) for muffler, speed and interaction between muffler & speed, F-ratio is regarded as significant in each case and differences in noise levels at operator's ear level of Tractor-2 due to the individual and combined (interacted) effect of muffler & speed are all treated as significant at 5% level of significance.

Table 4.12: Noise levels recorded at ear level under different mufflers at different engine speeds (Tractor-1 & Tractor-2)

Treatment	**Noise Level (dBA) on Tractor-1 (Mini Tractor)**	**Noise Level (dBA) on Tractor-2**
MAIN		
M-1	83.09	84.90
M-2	83.04	84.52
M-3	82.95	84.46
S.Em.±	0.02	0.073
C.D.at 5%	0.08	0.287
C.V. %	0.10	0.33
SUB		
S1	78.58	79.26
S2	81.74	82.38
S3	83.32	84.30
S4	85.21	87.26
S5	86.29	89.94

S.Em.± C.D.at 5% C.V. %	0.05 0.145 0.18	0.126 0.367 0.45
Main X Sub		
S.Em.± C.D.at 5%	0.086 0.252	0.218 0.636

Mean significant difference (MSD) for effect of main treatment (muffler) was found 0.08 dBA, hence from Table 4.12, it can be concluded that at ear level on Tractor-1 (mini tractor), the mean noise level observed under muffler-C i.e. 82.95 dBA was significantly lower (by 0.14 dBA) than that recorded under muffler-S (83.09 dBA) but was not significantly different when compared with noise level obtained under muffler-A i.e. 83.04 dBA (lower by 0.05 dBA than that of muffler-S). Further the difference between noise levels of muffler-C & muffler-A was also found significant (0.09 dBA). The noise levels observed under different engine speeds revealed significant increment in SPL (greater than 0.15 dBA) at every level of increase in the speed.

Similarly, mean significant difference (MSD) for effect of main treatment (muffler) at ear level on Tractor-2 was found 0.29 dBA, hence, the noise levels observed under muffler-B & muffler-C viz. 84.52 & 84.46 dBA respectively lower by 0.38 & 0.44 dBA, both were significantly at low level than that recorded under muffler-S i.e. 84.90 dBA. However, the difference between the noise levels of muffler-B & muffler-C (0.06 dBA) was insignificant. The noise levels observed under different engine speeds revealed significant increment in SPL (greater than 0.37 dBA) at every level of increase in the speed.

4.4.2 Effect of Muffler Design Alteration & Engine Speed on Noise Levels Recorded at 10 m Distance

ANOVA table for noise level observations at 10 m distance on Tractor-1 and Tractor-2 are presented in Table 4.13 & Table 4.14 respectively. Application of Split-Plot Design to the noise levels recorded at 10 m distance under specified muffler conditions & engine speeds revealed useful information as tabulated under Table 4.15 for Tractor-1 & Tractor-2.

Since calculated value of F (Table 4.13) is greater than table value of F at 5% level of significance (α=0.05) for effect of muffler, effect of speed and effect of interaction between muffler & speed, F-ratio is regarded as significant and difference in noise levels at 10 m distance away from Tractor-1 is significant at 5% level of significance.

Table 4.14 displays that calculated value of F is greater than table value of F at 5% level of significance (α=0.05) for muffler, speed and interaction between muffler & speed, F-ratio is regarded as significant in each case and differences in noise levels recorded at 10 m distance from Tractor-2 due to the individual and combined (interacted) effect of muffler & speed are all treated as significant at 5% level of significance.

Table 4.13: ANOVA Table for noise levels recorded at 10 m distance away from Tractor-1

Source	D F	S S	M S	F Cal	F Tab 5%	S Em.±	CD at 5%	TEST
Replication	2	0.048	0.024	0.000	0.000	0.000	NS	-
Main	2	4.312	2.156	41.82	3.400	0.059	0.230	*
Error(a)	4	0.206	0.052		0.340	**C.V. %= 0.34**		
Sub	4	264.140	66.035	1416.722	2.780	0.072	0.210	*
Main X Sub	8	2.345	0.293	6.290	2.360	0.125	0.364	*
Error(b)	24	1.119	0.047		0.320	**C.V. %= 0.32**		
TOTAL	44	272.171						

Table 4.14: ANOVA Table for noise levels recorded at 10 m distance away from Tractor-2

Source	D F	S S	M S	F Cal	F Tab 5%	S Em.±	CD at 5%	TEST
Replication	2	0.145	0.073	0.000	0.000	0.000	NS	**-**
Main	2	8.929	4.465	393.941	3.400	0.027	0.108	*****
Error(a)	4	0.045	0.011		0.150	**C.V. %= 0.15**		
Sub	4	501.276	125.319	2941.000	2.780	0.069	0.201	*****
Main X Sub	8	2.893	0.362	8.486	2.360	0.119	0.348	*****
Error(b)	24	1.023	0.043		0.290	**C.V. %= 0.29**		
TOTAL	44	514.312						

Table 4.15: Noise levels recorded at 10 m distance from Tractor-1 and Tractor-2 under different mufflers at different engine speeds

Treatment	Noise Level (dBA) on Tractor-1 (Mini Tractor)	Noise Level (dBA) on Tractor-2
MAIN		
M-1	68.09	72.61
M-2	67.44	71.53
M-3	67.43	71.90
S.Em.±	0.29	0.027
C.D.at 5%	0.230	0.108
C.V. %	0.34	0.15
SUB		
S1	63.71	66.98
S2	66.46	69.79
S3	68.02	72.46
S4	69.41	74.43
S5	70.68	76.41
S.Em.±	0.072	0.069
C.D.at 5%	0.210	0.201
C.V. %	0.32	0.29

Main X Sub		
S.Em.±	0.125	0.119
C.D.at 5%	0.36	0.35

Mean significant difference (MSD) for effect of main treatment (muffler) was found 0.23 dBA, hence from Table 4.15, it can be concluded that at 10 m distance on Tractor-1 (mini tractor), the mean noise levels observed under muffler-A & muffler-C i.e. 67.44 & 67.43 dBA respectively were significantly lower (by 0.65 & 0.66 dBA respectively) than that recorded under muffler-S (68.09 dBA). Further the difference between noise levels of muffler-C & muffler-A was insignificant (0.01 dBA). The noise levels observed under different engine speeds revealed significant increment in SPL (greater than 0.21 dBA) at every level of increase in the speed.

Similarly, mean significant difference (MSD) for effect of main treatment (muffler) at 10 m distance on Tractor-2 was found 0.11 dBA (Table 4.15), hence, the noise levels observed at 10 m distance under muffler-B & muffler-C viz. 71.53 & 71.90 dBA were lower by 1.08 & 0.71 dBA respectively, both having significantly lower level than that recorded under muffler-S i.e. 72.61 dBA. Further, the difference between the noise levels of muffler-B & muffler-C (0.37 dBA) was also found significant as difference between their respective noise levels was found 0.37 dBA which was higher than the critical difference (C.D.) viz. 0.11 dBA. The noise levels observed under different engine speeds revealed significant increment in SPL (greater than 0.20 dBA) at every level of increase in the speed.

4.4.3 Effect of Muffler Design Alteration & Engine Speed on Noise Levels Recorded at 30 m Distance

ANOVA table for noise level observations at 30 m distance on Tractor-1 and Tractor-2 are presented in Table 4.16 & Table 4.17 respectively. Application of Split-Plot Design to the noise levels recorded at 30 m distance under specified muffler conditions & engine speeds revealed useful information as tabulated under Table 4.18 for Tractor-1 & Tractor-2.

Table 4.16: ANOVA Table for noise levels recorded at 30 m distance away from Tractor-1

Source	**D F**	**S S**	**M S**	**F Cal**	**F Tab 5%**	**S Em.±**	**CD at 5%**	**TEST**
Replication	2	0.041	0.0207	0.000	0.000	0.000	NS	**-**
Main	2	2.665	1.333	30.754	3.400	0.054	0.211	*****
Error(a)	4	0.173	0.043		0.350	**C.V. %= 0.35**		
Sub	4	226.911	56.728	1826.655	2.780	0.059	0.171	*****
Main X Sub	8	2.284	0.285	9.191	2.360	0.102	0.297	*****
Error(b)	24	0.745	0.031		0.290	**C.V. %= 0.29**		
TOTAL	44	232.820						

Table 4.17: ANOVA Table for noise levels recorded at 30 m distance away from Tractor-2

Source	**D F**	**S S**	**M S**	**F Cal**	**F Tab 5%**	**S Em.±**	**CD at 5%**	**TEST**
Replication	2	0.092	0.046	0.000	0.000	0.000	NS	**-**
Main	2	0.339	0.170	7.000	3.400	0.040	0.158	*****
Error(a)	4	0.097	0.024		0.250	**C.V. %= 0.25**		
Sub	4	544.468	136.117	6843.872	2.780	0.047	0.137	*****
Main X Sub	8	2.079	0.260	13.064	2.360	0.081	0.238	*****
Error(b)	24	0.477	0.020		0.220	**C.V. %= 0.22**		
TOTAL	44	547.552						

Since calculated value of F (Table 4.16) is greater than table value of F at 5% level of significance (α=0.05) for effect of muffler, effect of speed and effect of interaction between muffler & speed, F-ratio is regarded as significant and difference in noise levels at 30 m distance away from Tractor-1 is significant at 5% level of significance.

In Table 4.17 calculated value of F is greater than table value of F at 5% level of significance (α=0.05) for muffler, speed and interaction between muffler & speed, F-ratio is regarded as significant in each case and differences in noise levels recorded at 30 m distance from Tractor-2 due to the individual and combined (interactive) effect of muffler & speed are all treated as significant at 5% level of significance.

Mean significant difference (MSD) for effect of main treatment (muffler) was found 0.21 dBA, hence from Table 4.18, it can be concluded that at 30 m distance on Tractor-1 (mini tractor), the mean noise levels observed under muffler-A & muffler-C i.e. 60.27 & 59.92 dBA respectively were significantly lower (by 0.24 & 0.59 dBA respectively) than that recorded under muffler-S (60.51 dBA). Further the difference between noise levels of muffler-C & muffler-A was also found significant (0.35 dBA which was greater than C.D. 0.21 dBA). The noise levels observed under different engine speeds revealed significant increment in SPL (greater than 0.17 dBA) at every level of increase in the speed.

Table 4.18: Noise levels recorded at 30 m distance away from Tractor-1 and Tractor-2 under different mufflers at different engine speeds

Treatment	Noise Level (dBA) on Tractor-1 (Mini Tractor)	Noise Level (dBA) on Tractor-2
MAIN		
M1	60.51	62.89
M2	60.27	62.72
M3	59.92	62.70
S.Em.±	0.054	0.040
C.D.at 5%	0.211	0.158
C.V. %	0.350	0.250
SUB		
S1	56.53	57.66
S2	59.02	60.26
S3	60.96	63.24
S4	61.71	65.31
S5	62.94	67.39
S.Em.±	0.059	0.047
C.D.at 5%	0.171	0.137
C.V. %	0.290	0.220
Main X Sub		
S.Em.±	0.102	0.081
C.D.at 5%	0.297	0.238

Similarly, mean significant difference (MSD) for effect of main treatment (muffler) at 30 m distance on Tractor-2 was found 0.16 dBA (Table 4.18), hence, the noise levels observed at 30 m distance under muffler-B & muffler-C viz. 62.72 & 62.70 dBA were lower by 0.17 & 0.19 dBA respectively, both having significantly lower level than that recorded under muffler-S i.e. 62.89 dBA. But, the difference between the noise levels of muffler-B & muffler-C (0.02 dBA) was found insignificant. The noise levels observed under different engine speeds revealed significant increment in SPL (greater than 0.14 dBA) at every level of increase in the speed.

4.5 RELATIVE NOISE ATTENUATION PERFORMANCE OF SELECTED MUFFLERS ON TRACTOR-1 (MINI TRACTOR) AND TRACTOR-2

4.5.1 Noise Attenuation Performance of Selected Mufflers on Tractor-1 (Mini Tractor)

4.5.1.1 Noise attenuation in decibels by selected mufflers on tractor-1 (mini tractor)

The sound pressure levels were recorded in the units of dB(A) under three different muffler conditions at specified engine speeds at EL, 10 m & 30 m distance away from the tractor. The data provided useful information on noise attenuability of different mufflers and the noise levels generated at particular places of measurement. The changes in decibels caused by muffler type and location of measurement are summarized in the following table (Table 4.19).

Table 4.19: Noise attenuation produced by different mufflers in dBA and percent (%) on Tractor-1 (mini tractor)

Location of Measurement	No Muffler	Muffler-S		Muffler-A		Muffler-C	
	Average SPL (dBA)	Average SPL (dBA)	Change in SPL (dBA)	Average SPL (dBA)	Change in SPL (dBA)	Average SPL (dBA)	Change in SPL (dBA)
EL	85.7	83.1	2.6 (3.0%)	83.0	2.7 (3.2%)	82.9	2.8 (3.3%)
10 m	69.4	68.1	1.3 (1.9%)	67.4	2.0 (2.9%)	67.4	2.0 (2.9%)
30 m	62.0	60.5	1.5 (2.4%)	60.3	1.7 (2.7%)	59.9	2.1 (3.4%)

Mean SPLs (dBA) obtained under varied engine speeds by selected muffler installations on Tractor-1 at ear level under field condition revealed lowest mean noise level generation (82.9 dBA) under muffler-C. Mean SPLs (dBA) obtained under varied engine speeds by selected muffler installations on Tractor-1 at 10 m distance under field condition revealed lowest mean noise level generation (67.4 dBA) under muffler-A & C. Mean SPLs (dBA) obtained under varied engine speeds by selected muffler installations on Tractor-1 at 30 m distance away from the tractor revealed lowest mean noise level generation (59.9 dBA) under muffler-C.

At ear level on Tractor-1, the muffler-S, muffler-A and muffler-C caused reduction of the quantum of 2.6, 2.7 and 2.8 dBA leading to noise attenuation of 3.0, 3.2 and 3.3 percent respectively in respect of noise level generated without mounting of muffler i.e. 85.7 dBA at ear level. Similarly at 10 m distance away from the tractor-1, the average SPL without use of muffler being 69.4 dBA, muffler-S, A and C caused reduction of 1.3, 2.0 and 2.0 dBA respectively with noise attenuation of 1.9, 2.9 and

2.9 % respectively in respect of noise level generated at 10 m away without mounting any muffler on tractor-1. At 30 m distance from the tractor, muffler-S, muffler-A and muffler-C caused reduction in SPL (dBA) to the tune of 1.5, 1.7 and 2.1 dBA leading to noise attenuability of 2.4, 2.7 and 3.4 percent respectively in respect of 62.0 dBA that was calculated average noise level at 30 m distance without use of the muffler on tractor-1. The results are graphically represented in Fig. 4.25.

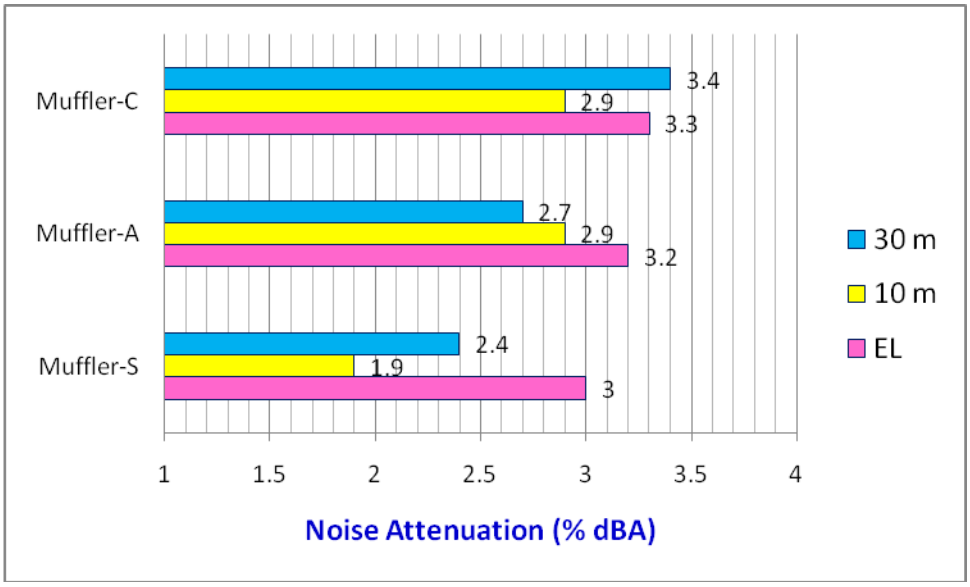


Fig. 4.25: Comparative noise attenuation (in percent dBA) obtained by different mufflers on Tractor-1 (mini tractor)

Fig. 4.37 revealed the following outcomes. At ear level, maximum noise attenuation (3.3%) could be obtained by muffler-C. At 10 m distance, maximum noise attenuation (2.9%) could be obtained by muffler-A & muffler-C. At 30 m distance, maximum noise attenuation (3.4%) could be obtained by muffler-C. Hence, muffler-C came up as the most effective noise attenuation device which could be fabricated by making changes into the internal configuration of the reactive mufflers of equal size & shape.

4.5.1.2 Noise attenuation in µPa by selected mufflers on tractor-1 (mini tractor)

The mean SPL obtained under each location (EL, 10 m, 30 m) under different muffler installations in the field condition were converted into equivalent sound pressures in the unit of micro pascals. The data provides useful information on noise attenuability of different mufflers and the sound pressure of noise levels in micro-pascal generated at particular places of measurement. The changes in SPL in mico-pascal (µPa) values caused by muffler type and location of measurement are summarized in the following table (Table 4.20).

At ear level on Tractor-1, the muffler-S, muffler-A and muffler-C caused reduction of the amount of 99726.1, 102997.4 and 106231.2 µPa leading to noise attenuation of 25.9, 26.7 and 27.6 percent respectively in respect of noise level generated without mounting of muffler i.e. 385504.9 µPa at ear level. At 10 m distance away from the Tractor-1, the average SPL without use of muffler being 59024.2 µPa, muffler-S, A and C caused reduction of 8204.7, 12139.6 and 12139.6 µPa respectively with noise attenuation of 13.9, 20.6 and 20.6 % respectively in respect of noise level generated at 10 m away without mounting any muffler on tractor-1. At 30 m distance from the tractor, muffler-S, muffler-A and muffler-C caused reduction in SPL (µPa) to the tune of 3993.4, 4475.7 and 5407.4 µPa leading to noise attenuability of 15.9, 17.8 and 21.5 percent respectively in respect of 25178.5 µPa that was calculated average noise level at 30 m distance without use of the muffler on tractor-1. The results are graphically represented in Fig. 4.26.

Table 4.20: Noise attenuation produced by different mufflers in micro-pascal (µPa) and percent (%) on Tractor-1 (mini tractor)

Location of Measure-ment	No Muffler	Muffler-S		Muffler-A		Muffler-C	
	Average SPL (µPa)	Average SPL (µPa)	Change in SPL (µPa)	Average SPL (µPa)	Change in SPL (µPa)	Average SPL (µPa)	Change in SPL (µPa)
EL	385504.9	285778.8	99726.1 (25.9%)	282507.5	102997.4 (26.7%)	279273.7	106231.2 (27.6%)
10 m	59024.2	50819.5	8204.7 (13.9%)	46884.6	12139.6 (20.6%)	46884.6	12139.6 (20.6%)
30 m	25178.5	21185.1	3993.4 (15.9%)	20702.8	4475.7 (17.8%)	19771.1	5407.4 (21.5%)

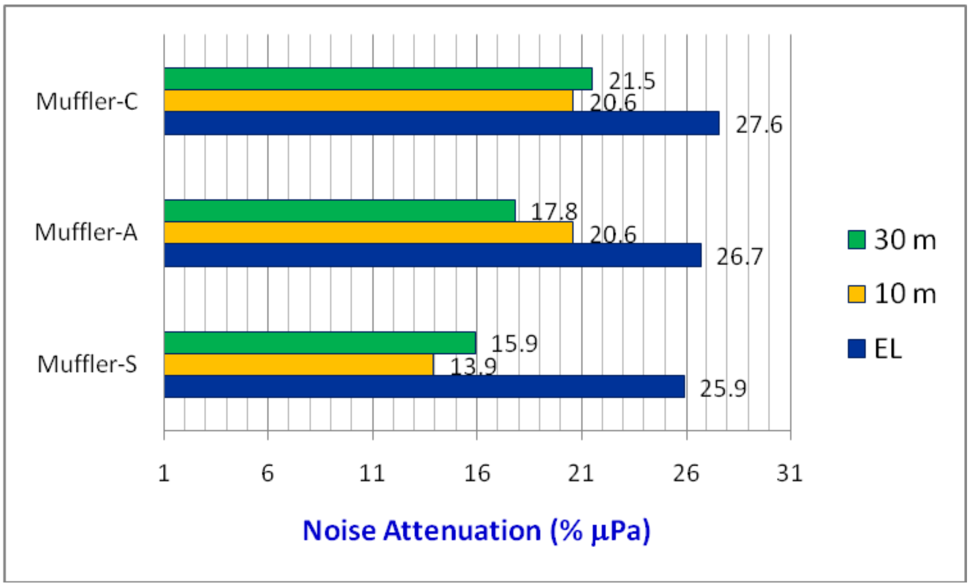


Fig. 4.26: Comparative noise attenuation (in % µPa) obtained by different mufflers on Tractor-1 (mini tractor)

Fig. 4.26 revealed the following outcomes. At ear level, maximum noise attenuation (27.6%) could be obtained by muffler-C. At 10 m distance, maximum noise attenuation (20.6%) could be obtained by muffler-A & muffler-C which were found at par in noise attenuation performance. At 30 m distance, maximum noise attenuation (21.5%) could be obtained by muffler-C. Hence, muffler-C came up as the most effective noise attenuation device which could be fabricated by making changes into the internal configuration of the reactive mufflers of equal size & shape.

4.5.2 Noise Attenuation Performance of Selected Mufflers on Tractor-2

4.5.2.1 Noise attenuation in decibels by selected mufflers on tractor-2

The sound pressure levels were recorded in the units of dB(A) under three different muffler conditions at specified engine speeds at EL, 10 m & 30 m distance away from the tractor. Like Tractor-1, data provided useful information on noise attenuability of different mufflers and the noise levels generated at particular places of measurement. The changes in decibels caused by muffler mounting and location of measurement are summarized in the following table (Table 4.21).

Table 4.21: Noise attenuation produced by different mufflers in dBA and percent (%) on Tractor-2

Muffler	No Muffler	Muffler-S		Muffler-B		Muffler-C	
Place	Average SPL (dBA)	Average SPL (dBA)	Change in SPL (dBA)	Average SPL (dBA)	Change in SPL (dBA)	Average SPL (dBA)	Change in SPL (dBA)
EL	90.0	84.9	5.1 (5.7%)	84.5	5.5 (6.1%)	84.5	5.5 (6.1%)
10 m	75.5	72.6	2.9 (3.8%)	71.5	4.0 (5.3%)	71.9	3.6 (4.8%)
30 m	65.9	62.9	3.0 (4.6%)	62.7	3.2 (4.9%)	62.7	3.2 (4.9%)

Mean SPLs (dBA) obtained under varied engine speeds by selected muffler installations on Tractor-2 at ear level under field condition revealed lowest mean noise level generation (84.5 dBA) under muffler-B & C. Mean SPLs (dBA) obtained under varied engine speeds by selected muffler installations on Tractor-2 at 10 m distance under field condition revealed lowest mean noise level generation (71.5 dBA) under muffler-B. Mean SPLs (dBA) obtained under varied engine speeds by selected muffler installations on Tractor-2 at 30 m distance away from the tractor revealed lowest mean noise level generation (62.7 dBA) under muffler-B & C.

At ear level on Tractor-2, the muffler-S, muffler-B and muffler-C caused reduction of the quantum of 5.1, 5.5 and 5.5 dBA leading to noise attenuation of 5.7, 6.1 and 6.1 percent respectively in respect of noise level generated without mounting of muffler i.e. 90.0 dBA at ear level. Similarly at 10 m distance away from the tractor-1, the average SPL without use of muffler being 75.5 dBA, muffler-S, B and C caused reduction of 2.9, 4.0 and 3.6 dBA respectively with noise attenuation of 3.8, 5.3 and

4.8 % respectively in respect of noise level generated at 10 m away without mounting any muffler on tractor-1. At 30 m distance from the tractor, muffler-S, muffler-B and muffler-C caused reduction in SPL (dBA) to the tune of 3.0, 3.2 and 3.2 dBA leading to noise attenuability of 4.6, 4.9 and 4.9 respectively in respect of 65.9 dBA that was calculated average noise level at 30 m distance without use of the muffler on tractor-1. The results are graphically represented in Fig. 4.27.

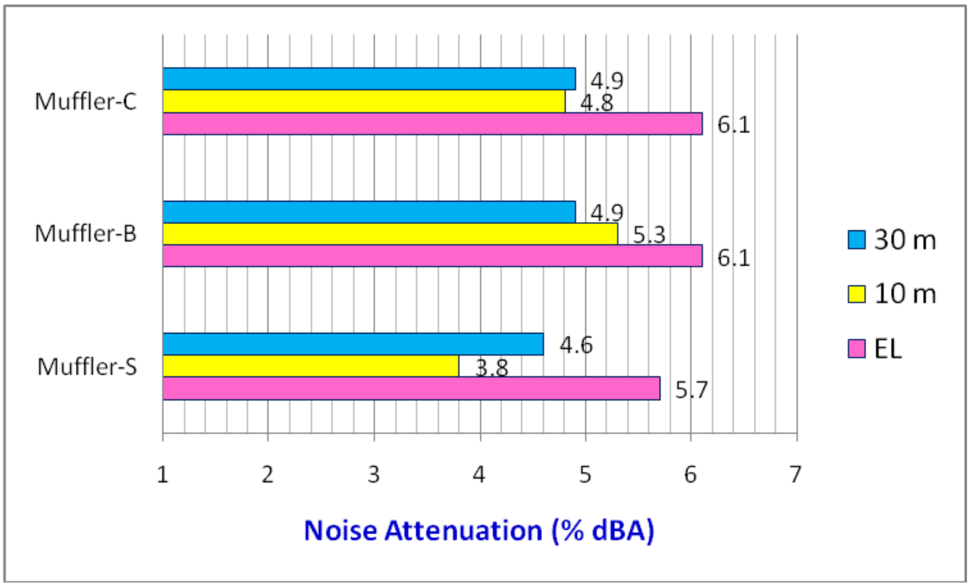


Fig. 4.27: Comparative noise attenuation (in percent dBA) obtained by different mufflers on Tractor-2

Fig. 4.27 revealed the following outcomes. At ear level, maximum noise attenuation (6.1%) could be obtained by muffler-B & muffler-C both. At 10 m distance, maximum noise attenuation (5.3%) could be obtained by muffler-B. At 30 m distance, maximum noise attenuation (3.4%) could be obtained by muffler-C. Hence, muffler-B & muffler-C both were found almost equally effective noise attenuation devices which could be fabricated by making changes into the internal configuration of the reactive mufflers of equal size & shape.

Fig. 4.27 reveals that equal amount of noise attenuation on Tractor-2 was recorded by both muffler-B & muffler-C at ear level (6.1%) and at 30 m distance (4.9%) which were higher than that by the standard muffler (muffler-S) viz. 5.7 & 4.6 at ear level & at 30 m distance respectively. At 10 m distance, noise attenuation achieved by muffler-S, muffler-B & muffler-C were 3.8, 5.3 & 4.8 respectively.

4.5.2.2 Noise attenuation in µPa by selected mufflers on tractor-2

The mean SPL obtained on Tractor-2 under each location (EL, 10 m, 30 m) under different muffler installations in the field condition were coverted into equivalent sound pressure in micro pascal (µPa) unit. The data provided useful information on noise attenuability of different mufflers and the sound pressure of noise levels in micro-pascal measured at particular places of measurement. The changes in SPL mico-pascal (µPa) values caused by muffler mounting and location of measurement are summarized in the following table (Table 4.22).

On Tractor-2, average SPL in µPa at ear level without mounting of mufffler has been found 632455.5 µPa, the muffler-S, muffler-B and muffler-C caused reduction of the amount of 280870.8, 296694.7 and 296694.7 µPa leading to noise attenuation of 44.4, 46.9 and 46.9 percent respectively in respect of noise level generated without mounting of muffler i.e. 632455.5 µPa at ear level. Similarly at 10 m distance away from the tractor-2, the average SPL without use of muffler being 119132.4 µPa, muffler-S, A and C caused reduction of 33816.5, 43964.9 and 40422.4 µPa respectively with noise attenuation of 28.4, 36.9 and 33.9 % respectively in respect of noise level generated at 10 m away without mounting any muffler on tractor-2. At 30 m distance from the tractor, muffler-S, muffler-A and muffler-C caused reduction in SPL (µPa) to the tune of 11521.1, 12156.8 and 12156.8 µPa leading to noise attenuability of 29.2, 30.8 and 30.8 percent respectively in respect of 39448.5 µPa that was calculated average noise level at 30 m distance without use of the muffler on tractor-1. The results are graphically represented in Fig. 4.28.

Table 4.22: Noise attenuation produced by different mufflers in micro-pascal (µPa) and percent (%) on Tractor-2

Muffler	No Muffler	Muffler-S		Muffler-B		Muffler-C	
Place	Average SPL (µPa)	Average SPL (µPa)	Change in SPL (µPa)	Average SPL (µPa)	Change in SPL (µPa)	Average SPL (µPa)	Change in SPL (µPa)
EL	632455.5	351584.7	280870.8 (44.4%)	335760.8	296694.7 (46.9%)	335760.8	296694.7 (46.9%)
10 m	119132.4	85315.9	33816.5 (28.4%)	75167.5	43964.9 (36.9%)	78710.0	40422.4 (33.9%)
30 m	39448.5	27927.4	11521.1 (29.2%)	27291.7	12156.8 (30.8%)	27291.7	12156.8 (30.8%)

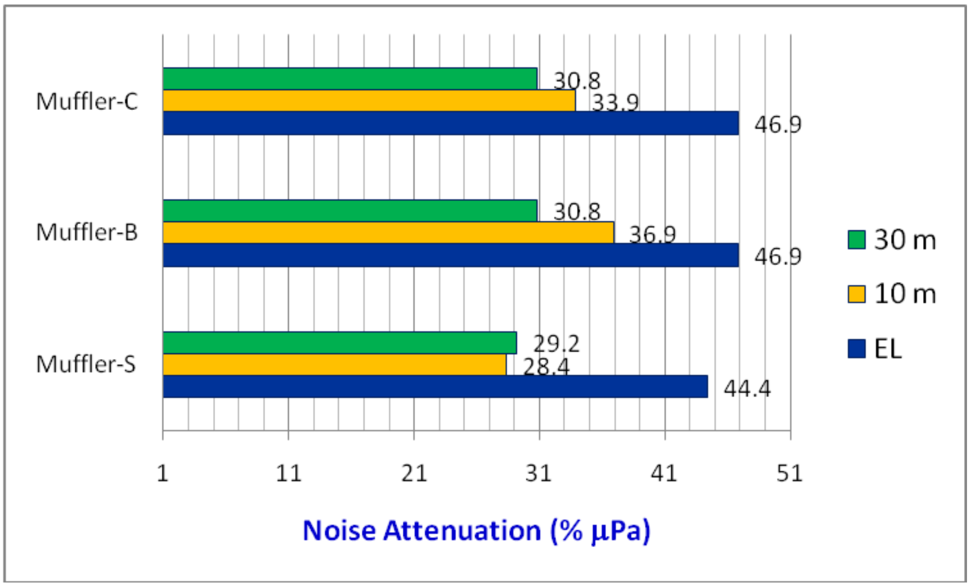


Fig. 4.28: Comparative noise attenuation (in µPa) obtained by different mufflers on Tractor-2

Fig. 4.28 revealed the following outcomes. At ear level, maximum noise attenuation (46.9%) could be obtained by muffler-B & muffler-C both. At 10 m distance, maximum noise attenuation (36.9%) could be obtained by muffler-B. At 30 m distance, maximum noise attenuation (30.8%) could be obtained by muffler-B & muffler-C both. Hence, muffler-B & muffler-C both were considered as equally effective noise attenuation devices which could be fabricated by making changes into the internal configuration of the reactive mufflers of equal size & shape.

4.6 AMPLITUDE LEVELS OF TRACTOR NOISE FREQUENCIES

The amplitude levels of the frequencies of sound of exhaust noise were estimated from the graphs generated with the help of suitable softwares. The graphs produced through the *Spectrumview* presented the frequency spectrum analyzed and obtained from periodical sound level observations over every 500 mili seconds by inputting the .wav files. The graphs were obtained for three muffler conditions selected from those which were laid out under the experiment namely (i) No-muffler mounting (M-1), (ii) Muffler-S, standard muffler as mounted by company (M-2) & (iii) Muffler-C, Common muffler used on both tractors under test (M-3).

The peak frequencies at the interval of 0.5 seconds were tabulated by processing the sound data of each muffler for Tractor-1 and Tractor-2 under different engine speed conditions i.e. 1000, 1250, 1500, 1750 and 2000 RPMs. The sound frequency spectrum ranged from 0 to 24000 Hz frequency range that included the human hearing range i.e. from 20 to 20000 Hz. The randomly selected graphical views of the frequency distribution in form of frequency versus amplitude at different engine speeds obtained through processing the .wav formats of sound clips by *Spectrumview* application are presented for above stated three muffler conditions. The sound clips recorded at ear level and at 10 m distance away from the tractor are processed.

The spectogram of the noise audio could be created with the assistance of *Spek* application. The *Spek* is an acousic spectrum analyzer software which provided the graphs consisting of the combination of different frequencies (kHz) and intensities (dBs) during the entire period of sound level observations. The relative frequency-amplitude characteristics of different exhaust mufflers under test for Tractor-1 and Tractor-2 are interpretted and discussed in the following sections with the help of both kinds of software applications. The spectrograms are interpretted visually to estimate the decibel levels among eight frequency classes i.e. 0.0-2.5, 2.5-5.0, 5.0-7.5, 7.5-10.0, 10.0-12.5, 12.5-15.0, 15.0-17.5 & 17.5-20.0 kHz. Each decibel levels were then converted into respective amplitude ratio values and consequently the percent amplitudes of each frequency range were counted to estimate the presence of different frequencies of tractor noise at particular engine speed and at particular location of noise recording.

4.6.1 Frequency Spectrum, Peak Frequencies and Spectogram of Noise on Tractor-1 (Mini Tractor)

The frequency spectra are obtained by inputting wave file to Audio Spectrum Analyzer program. Audio Spectrum Analyzer has variable displays, Fast Fourier Transform (FFT) display, variable sample rates (8000 Hz, 11025 Hz, 22050 Hz, and 44100 Hz), variable transform sizes (1k, 2k, 4k, and 8k), adjustable upper and lower limits, continuous, averaged, and peak hold, variable markers, etc. A sample of the form display is presented in the following figure (Fig. 4.29).

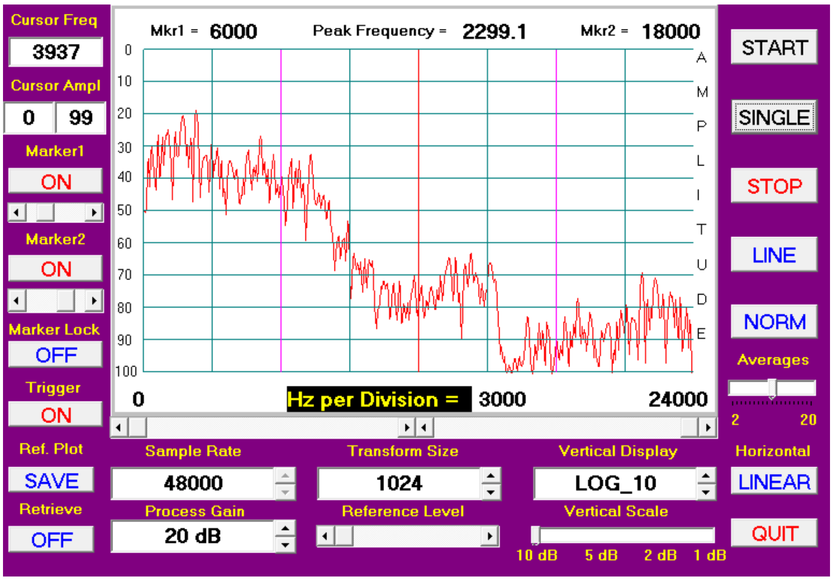


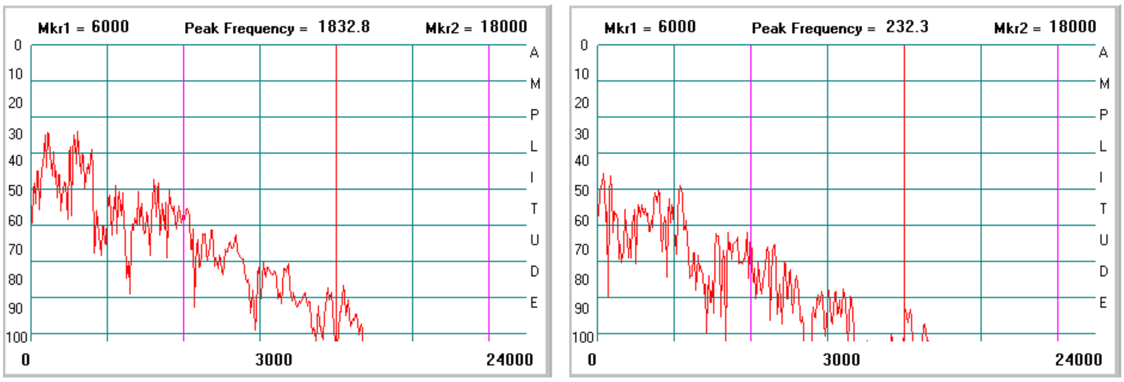
Fig. 4.29: Form display of the output obtained by Audio Spectrum Analyzer

4.6.1.1 Frequency spectrum of noise on tractor-1 (mini tractor)

4.6.1.1.1 Frequency spectrum of noise under no muffler on tractor-1 (mini tractor)

Frequency spectrum generated by the Spectrumview provided the specific frequency which has highest value of amplitude as peak frequency. Accordingly, for each muffler mounting and each speed level, the peak frequency observations were recorded and later analyzed for investigating the effect of muffler mounting on the sound frequencies emanated out of it passing through the varying kinds of internal reactive muffler configurations as experimented. Further, sound frequency observations recorded at two places viz. ear level & 10 m distance were analyzed.

Sample views of the display of frequency spectrum obtained by Spectrumview after input of .wav files are shown in the following figures (Fig. 4.30 to Fig. 4.34). The spectra displayed were taken over the interval of 0.5 seconds of the sound file. Peak frequencies were observed & tabulated for same interval of time.

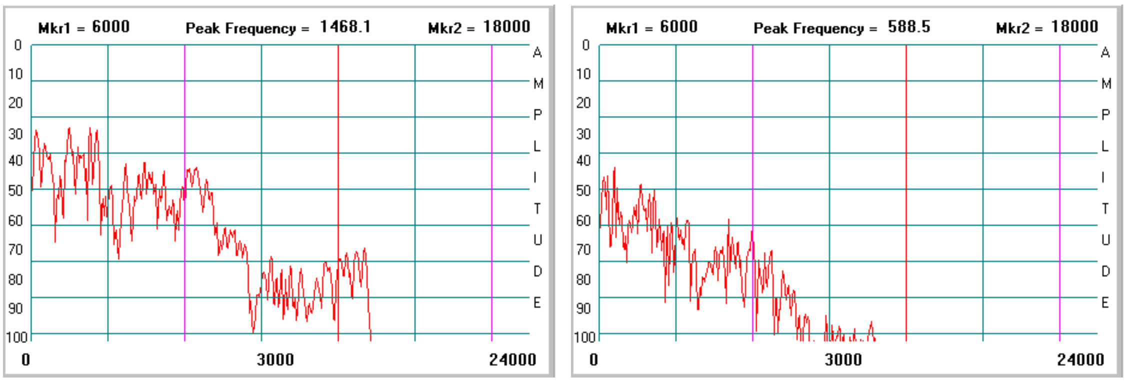


(a) (b)

Fig. 4.30: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-1 at 1000 RPM under no muffler

(a) at ear level, and

(b) at 10 m distance

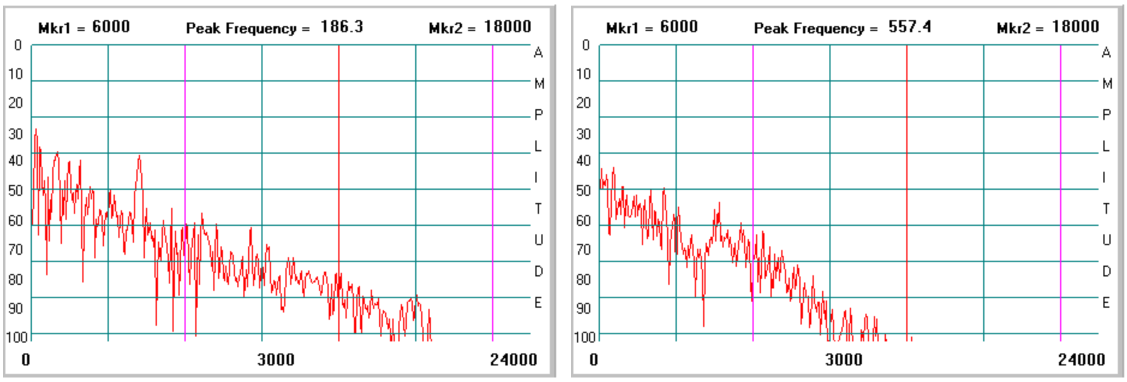


(a) (b)

Fig. 4.31: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-1 at 1250 RPM under no muffler

(a) at ear level, and

(b) at 10 m distance

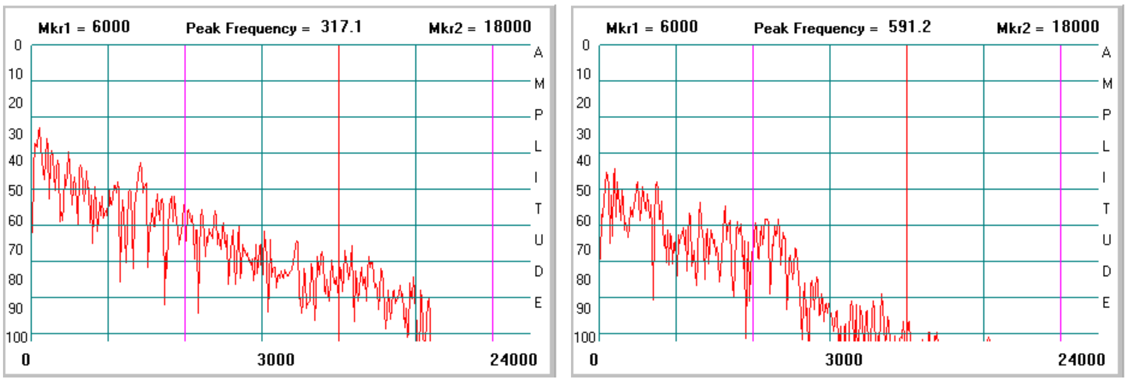


(a) (b)

Fig. 4.32: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-1 at 1500 RPM under no muffler

(a) at ear level, and

(b) at 10 m distance

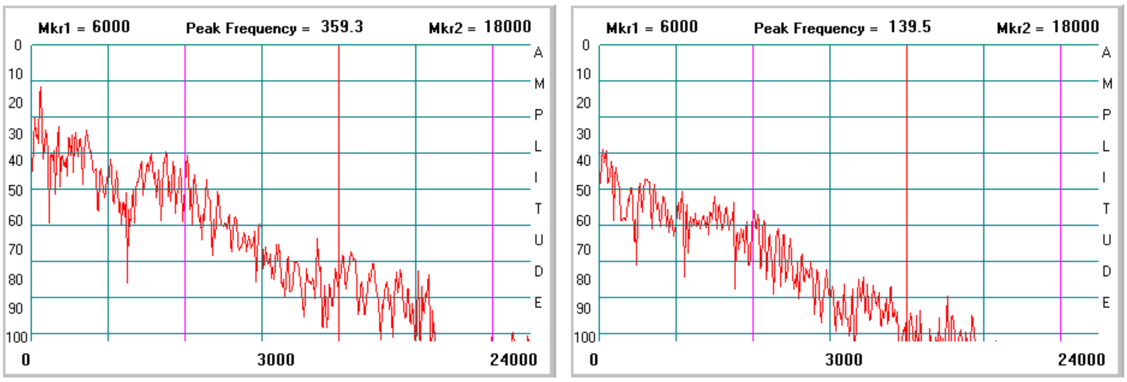


(a) (b)

Fig. 4.33: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-1 at 1750 RPM under no muffler

(a) at ear level, and

(b) at 10 m distance



(a) (b)

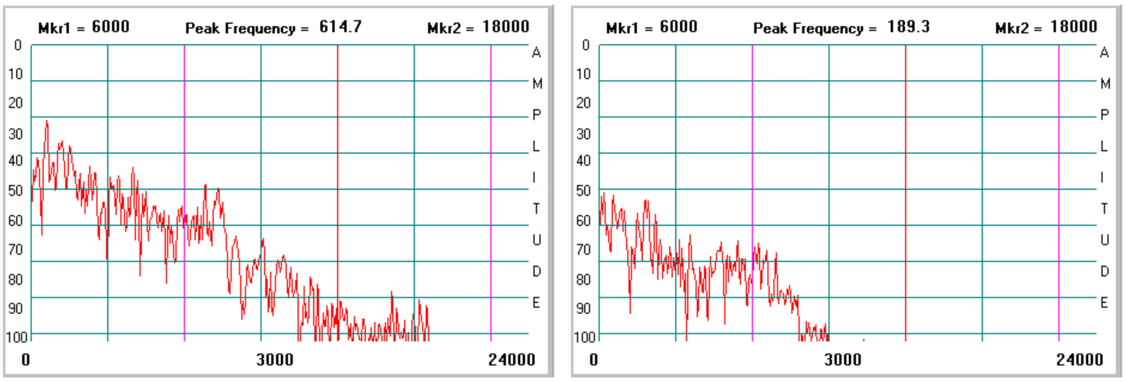
Fig. 4.34: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-1 at 2000 RPM under no muffler

(a) at ear level, and

(b) at 10 m distance

4.6.1.1.2 Frequency spectrum of noise under standard muffler on tractor-1 (mini tractor)

Sample views of the display of frequency spectrum obtained at ear level & 10 m distance noise recordings are shown in the following figures (Fig. 4.35 to Fig. 4.39). The spectra displayed were taken over the interval of 0.5 seconds of the sound file. Peak frequencies were observed & tabulated for same interval of time.

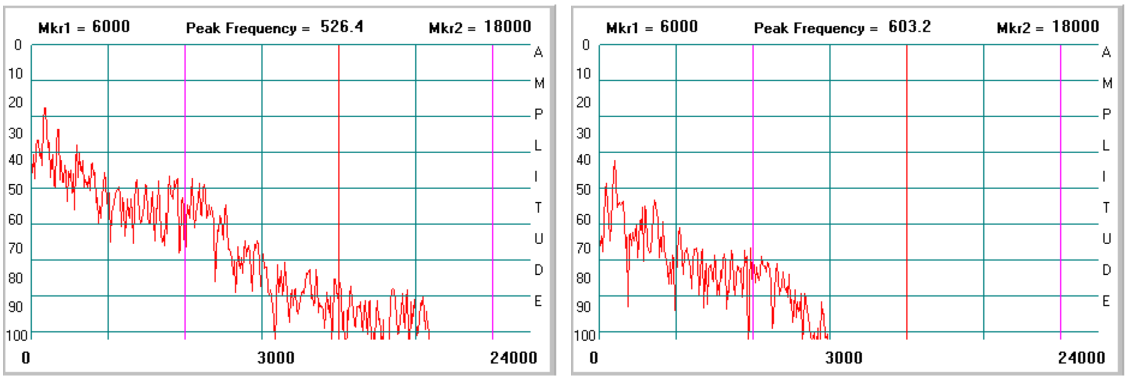


(a) (b)

Fig. 4.35: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-1 at 1000 RPM under standard muffler

(a) at ear level, and

(b) at 10 m distance

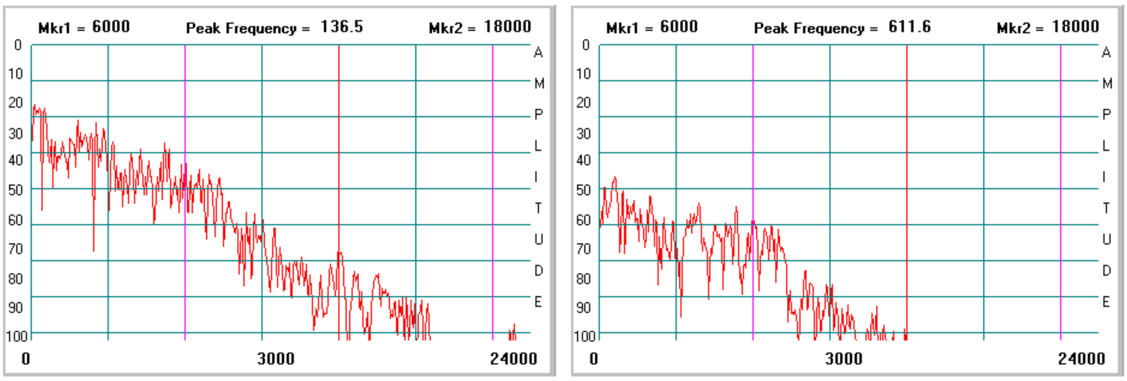


(a) (b)

Fig. 4.36: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-1 at 1250 RPM under standard muffler

(a) at ear level, and

(b) at 10 m distance

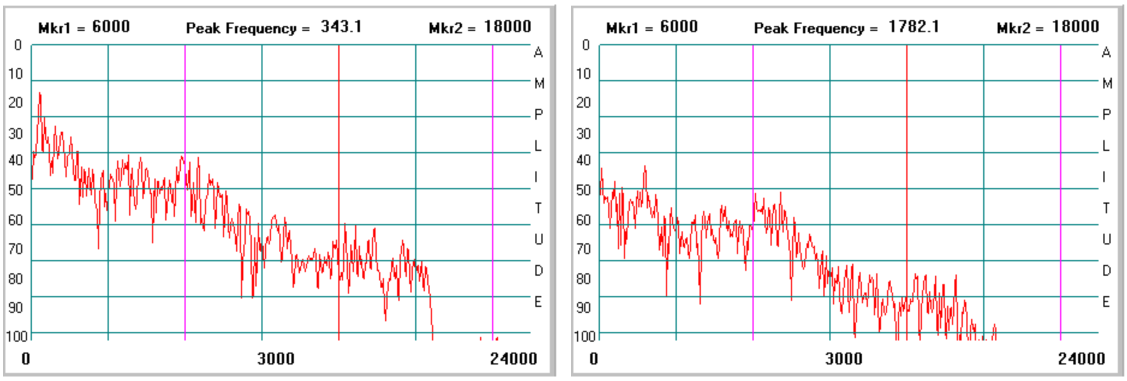


(a) (b)

Fig. 4.37: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-1 at 1500 RPM under standard muffler

(a) at ear level, and

(b) at 10 m distance

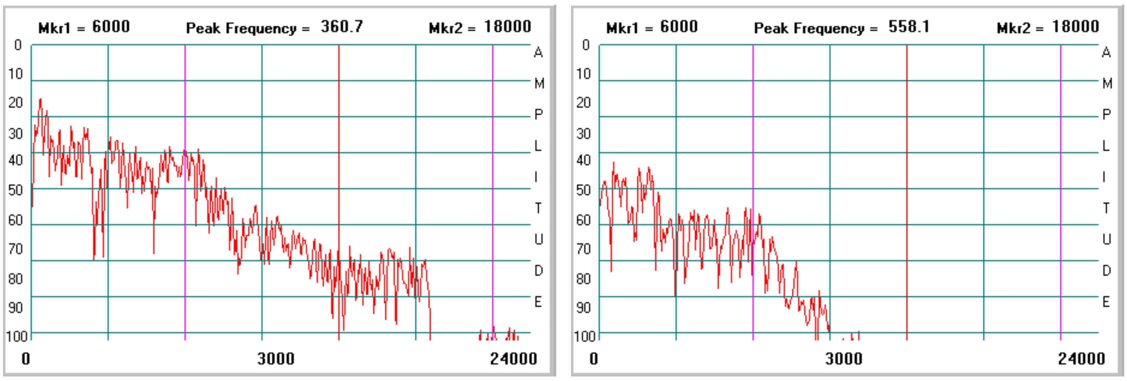


(a) (b)

Fig. 4.38: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-1 at 1750 RPM under standard muffler

(a) at ear level, and

(b) at 10 m distance



(a) (b)

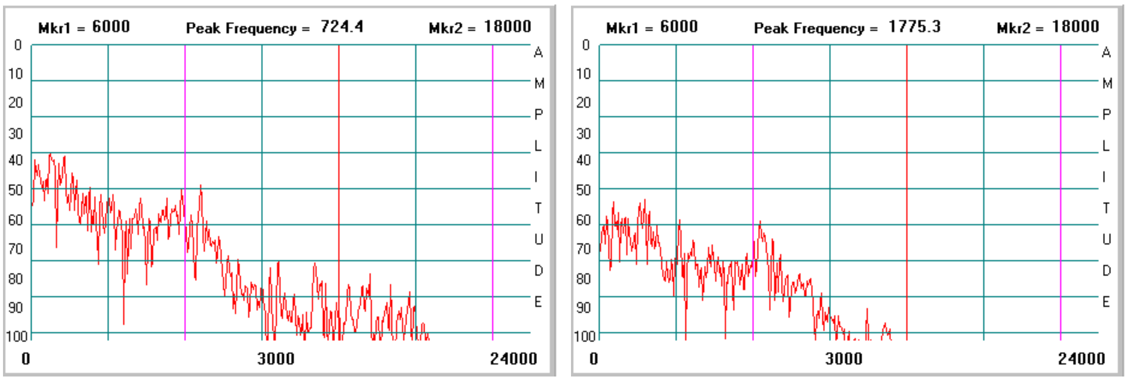
Fig. 4.39: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-1 at 2000 RPM under standard muffler

(a) at ear level, and

(b) at 10 m distance

4.6.1.1.3 Frequency spectrum of noise under muffler-C on tractor-1 (mini tractor)

Sample views of the display of frequency spectrum obtained at ear level & 10 m distance noise recordings are shown in the following figures (Fig. 4.40 to Fig. 4.44). The spectra displayed were taken over the interval of 0.5 seconds of the sound file. Peak frequencies were observed & tabulated for same interval of time.

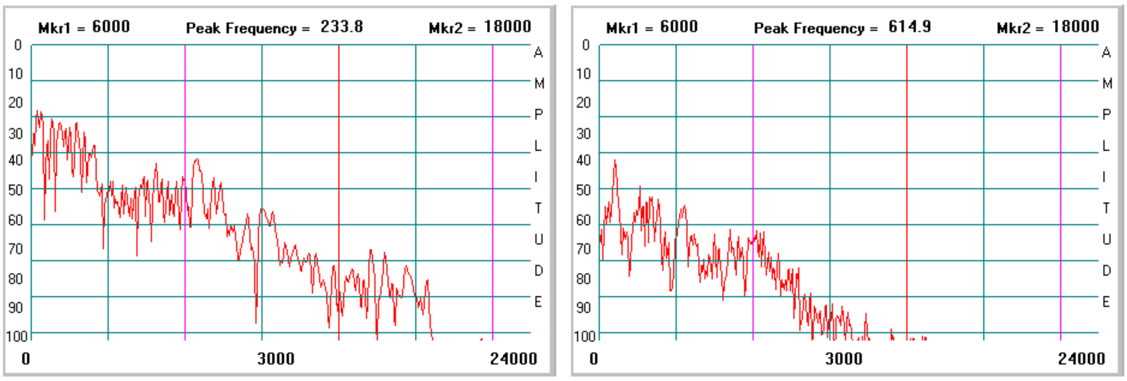


(a) (b)

Fig. 4.40: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-1 at 1000 RPM under muffler-C

(a) at ear level, and

(b) at 10 m distance

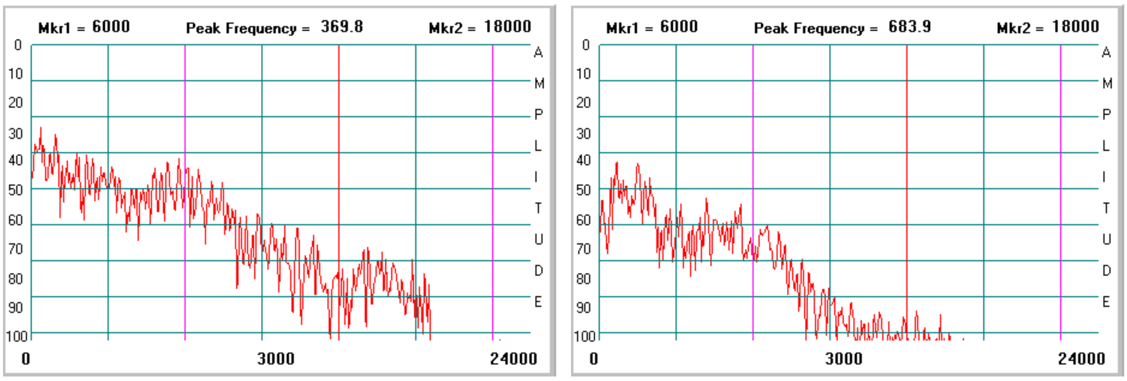


(a) (b)

Fig. 4.41: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-1 at 1250 RPM under muffler-C

(a) at ear level, and

(b) at 10 m distance

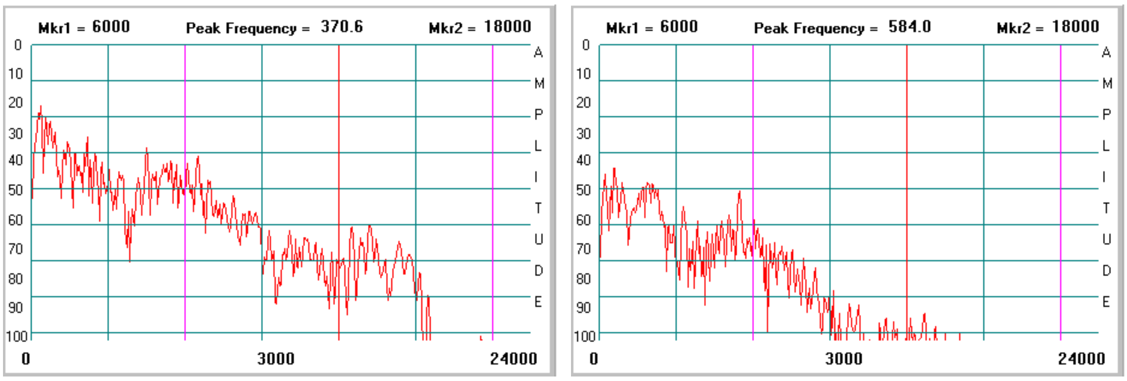


(a) (b)

Fig. 4.42: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-1 at 1500 RPM under muffler-C

(a) at ear level, and

(b) at 10 m distance

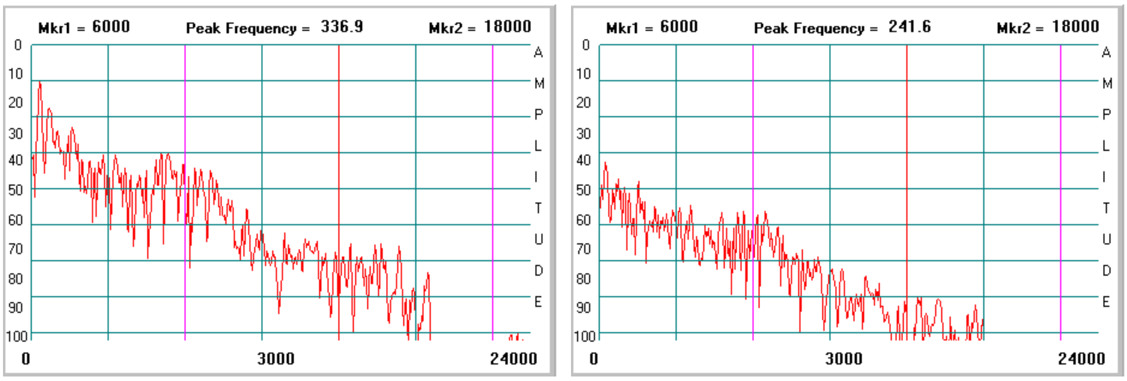


(a) (b)

Fig. 4.43: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-1 at 1750 RPM under muffler-C

(a) at ear level, and

(b) at 10 m distance



(a) (b)

Fig. 4.44: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-1 at 2000 RPM under muffler-C

(a) at ear level, and

(b) at 10 m distance

4.6.1.2 Peak frequencies of noise on tractor-1

4.6.1.2.1 Peak frequencies of noise recorded at ear level of tractor-1

A comparison of mean values of peak frequencies observed at ear level under three muffler mountings at different engine speeds on Tractor-1 (mini tractor) are tabulated (Table 4.23).

Table 4.23: Mean values of peak frequencies observed at ear level at different engine speeds on Tractor-1 (mini tractor)

Muffler Type	**Engine Speed (RPM)**					**Mean**
	1000	**1250**	**1500**	**1750**	**2000**	
No Muffler	762.5	597.4	537.3	650.0	383.6	586.2
Standard Muffler	741.3	870.7	779.2	647.1	470.7	701.8
Muffler-C	638.0	522.1	602.0	500.4	448.0	542.1

At ear level observations on Tractor-1 (mini tractor), Muffler-C exhibited lower peak frequencies in comparison to that observed under standard muffler at all engine speeds experimented i.e. 1000 RPM, 1250 RPM, 1500 RPM, 1750 RPM and 2000 RPM.

The minimum and maximum peak frequencies observed during the sample test of noise level measurements at ear level and at 10 m distance away from tractor on Tractor-1 under no-muffler, standard muffler and muffler-C are presented in the following tables (Table 4.24) along with their mean, mean deviation, standard deviation and coefficient of variation (%).

Table 4.24: Minimum, maximum, mean, median, mean deviation, standard deviation and coefficient of variation (%) under different muffler installations on Tractor-1 at ear level

Muffler Installation	Peak Frequency, Hz						Coefficient of Variation (%)
	Maximum	Minimum	Mean	Median	Mean Deviation	Standard Deviation	
No Muffler	1131.5	174.5	586.2	544.1	203.4	244.8	41.8
Standard Muffler	1256.6	241.3	701.8	699.8	187.8	234.5	33.4
Muffler-C	898.1	386.2	542.1	520.7	79.8	104.4	19.3

The lowest mean (542.1 Hz) and maximum (898.1 Hz) values of averaged peak frequencies was found under muffler-C at ear level on Tractor-1 (mini tractor). The maximum value of coefficient of variation (C.V. in %) was observed under no muffler mounting. Minimum standard deviation (104.4 Hz) was observed under muffler-C mounting.

Fig. 4.45 depicts peak frequency observations made under all mufflers in ear level noise (SPL) observations on tractor-1. Peak frequency observations obtained under the mounting of muffler-C were minimum in comparison to that obtained under other mufflers.

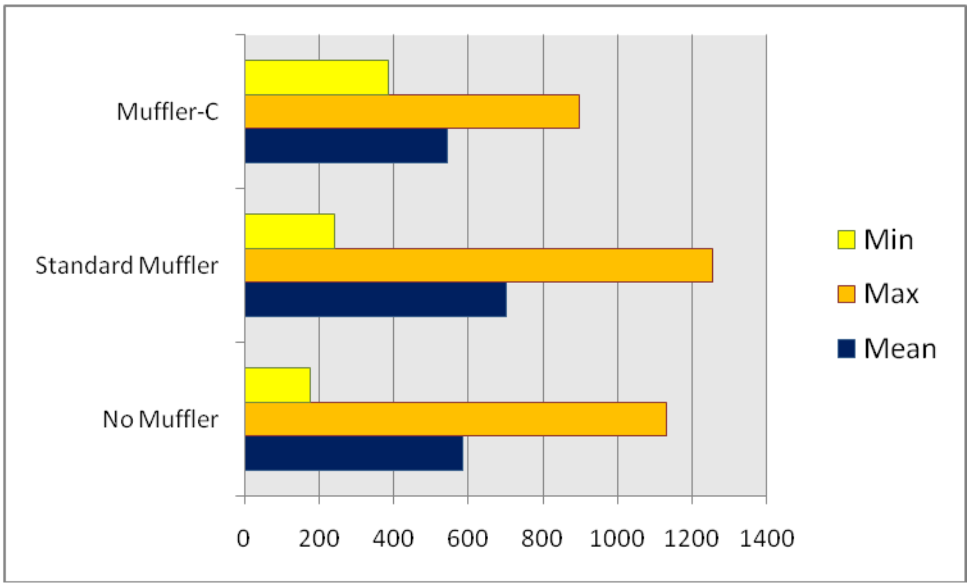


Fig. 4.45: Minimum, maximum and mean level of peak frequencies of the noise recorded at ear level on Tractor-1 under different muffler installations

4.6.1.2.2 Peak frequencies of noise recorded at 10 m distance from tractor-1

A comparison of mean values of peak frequencies observed at 10 m distance under three muffler mountings at different engine speeds on Tractor-1 (mini tractor) are tabulated (Table 4.25).

Table 4.25: Mean values of peak frequencies (Hz) observed at 10 m distance from tractor at different engine speeds on Tractor-1 (mini tractor)

Muffler Type	**Engine Speed (RPM)**					**Mean (Hz)**
	1000	**1250**	**1500**	**1750**	**2000**	
No Muffler	420.4	403.6	389.7	679.9	239.7	426.7
Standard Muffler	882.7	820.0	863.6	627.1	442.3	727.1
Muffler-C	574.6	432.0	798.3	680.9	419.7	581.1

At 10 m distance observations on Tractor-1 (mini tractor), Muffler-C exhibited lower peak frequencies in comparison to that observed under standard muffler at four engine speeds out of five experimental treatments viz. 1000 RPM, 1250 RPM, 1500 RPM and 2000 RPM (except 1750 RPM). The analysis of mean peak frequency observations of tractor noise recorded at 10 m distance away on Tractor-1 revealed lower mean peak frequency occurrences under muffler-C (581.1 Hz) than that obtained under standard muffler (727.1 Hz). The standard deviation and C.V. (%) for standard muffler and muffler-C were found 216.2 & 204.9 Hz and 29.7 & 35.3 percent respectively for Tractor-1.

Table 4.26: Minimum, maximum, mean, median, mean deviation, standard deviation and coefficient of variation (%) under different muffler installations on Tractor-1 at 10 m distance

Muffler Installation	Peak Frequency, RPM						Coefficient of Variation (%)
	Maximum	Minimum	Mean	Median	Mean Deviation	Standard Deviation	
No Muffler	808.6	201.1	426.7	399.5	103.6	130.6	30.6
Standard Muffler	1332.2	419.8	727.1	687.3	176.9	216.2	29.7
Muffler-C	1219.9	295.6	581.1	515.4	166.0	204.9	35.3

The mean of peak frequency observations obtained under standard muffler (muffler-S) (727.1 Hz) was higher than that observed undr muffler-C (581.1 Hz). The standard deviation and C.V. (%) for muffler-S and muffler-C were found 216.2 & 204.9 Hz and 29.7 & 35.3 percent respectively for Tractor-1.

Fig. 4.46 depicts peak frequency observations made under all mufflers in the noise (SPL) observations recorded at 10 m distance on tractor-1. Peak frequency observations obtained under the mounting of muffler-C were lesser in comparison to that obtained under muffler-S.

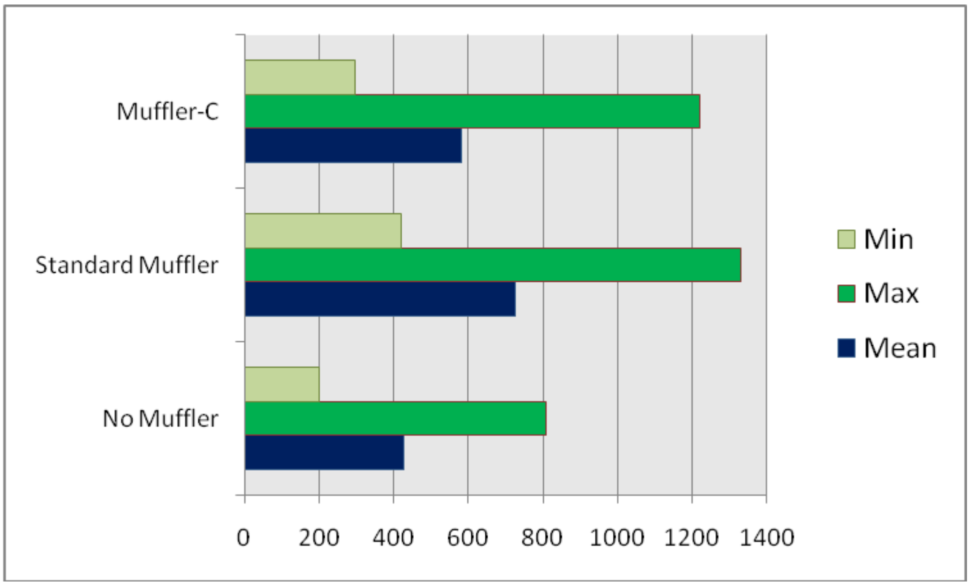


Fig. 4.46: Minimum, maximum and mean level of peak frequencies of the noise recorded at 10 m distance away on Tractor-1 under different muffler installations

4.6.1.2.3 Comparison of peak frequencies of noise recorded at ear level & at 10 m distance from tractor-1

The graphical display (Fig. 4.53 and Fig. 4.54) and the tabulated information (Table 4.48 and 4.49) of the mean, maximum and minimum peak frequency levels obtained in the noise clips recorded at ear level and at 10 m distance away under Tractor-1 showed several specific and notable differences which are tabulated below (Table 4.27).

Table 4.27: Comparison of mean peak frequency, standard deviation and coefficient of variation observed in the noise (sound clips) recorded at ear level and at 10 m distance from the Tractor-1

Parameter	Ear Level	10 m Away
Mean peak frequency (Hz)	Lower average peak frequency (542.1 Hz) is observed under muffler-C.	Lower average peak frequency (581.1 Hz) is observed under muffler-C mounting.
Standard Deviation, s (Hz)	The standard deviation (s) for standard muffler and muffler-C were found 234.5 & 104.4 Hz respectively.	The standard deviation (s) for standard muffler and muffler-C were found 216.2 & 204.9 Hz respectively.
Coefficient of Variation (%)	C.V. (%) for standard muffler and muffler-C were found 33.4 & 19.3 percent respectively.	C.V. (%) for standard muffler and muffler-C were found 29.7 & 35.3 percent respectively.

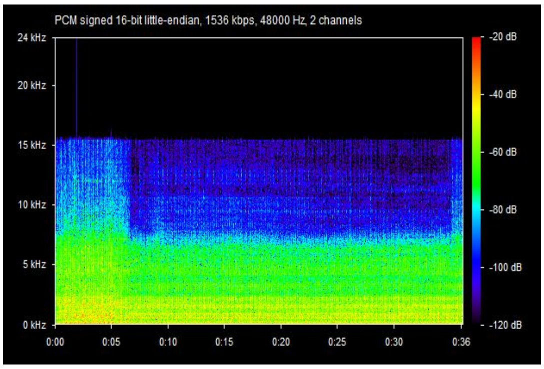
4.6.1.3 Spectrograms of noise on tractor-1 (mini tractor)

4.6.1.3.1 Spectrograms of noise under no muffler mounting on tractor-1

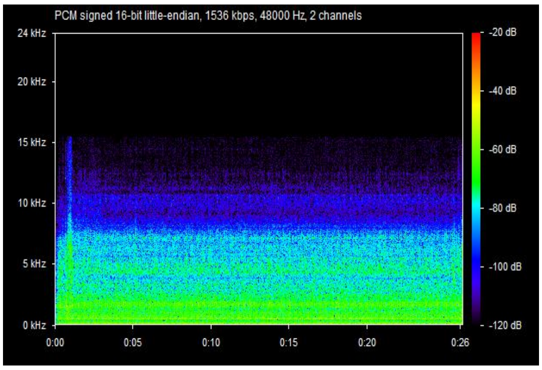
The spectrogram of the noise clips recorded with the help of a uniform device on tractor-1 without mounting any exhaust muffler are generated with the help of an acoustic spectrum analyzer namely Spek at different engine speeds are presented in following figures. (Fig. 4.47 to Fig. 4.51). For this, noise clips recorded at two places viz. ear level & 10 m distance were analyzed.

The spectogram or true spectrum are visually analuzed to obtain the amplitude levels (dB) of the specific frequency ranges which were than converted into amplitude scale factors (amplitude ratio). Percent contributions of each frequency ranges were obtained. The data on decibel levels and their respective amplitude ratio values and percent amplitudes of different frequency ranges contained in the true spectrum are tabulated and included in the appendices.

Mainly four out of eight frequency ranges under different engine speeds demonstrated varying properties of the noise in terms of their proportional amounts as recorded at two different locations i.e. ear level & 10 m distances.



(a)

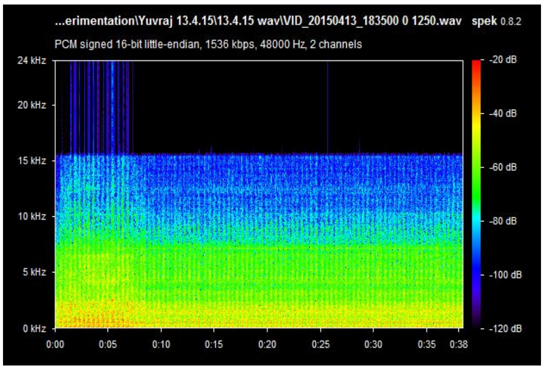


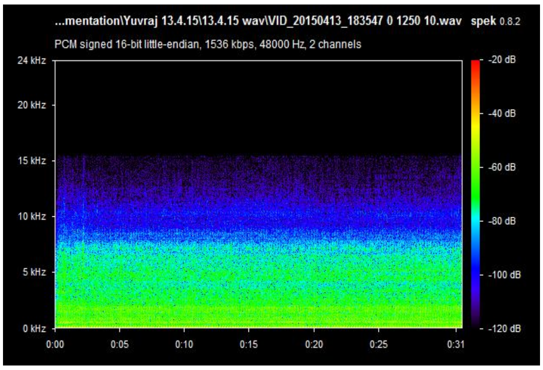
(b)

Fig. 4.47: Spectrogram of noise clips recorded at 1000 RPM under no muffler on Tractor-1

(a) at ear level (EL)

(b) at 10 m distance



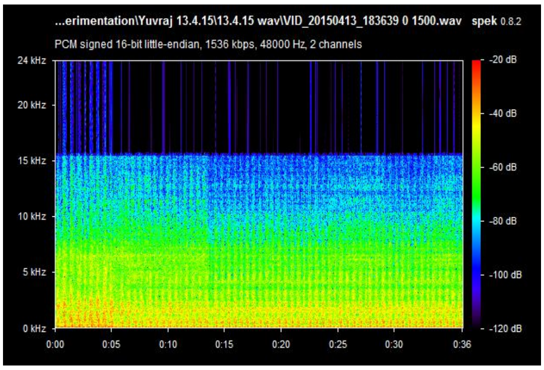


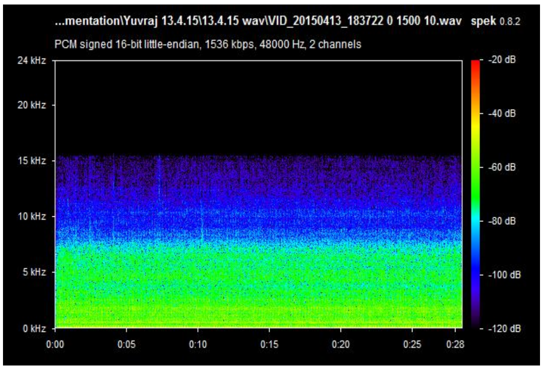
(a) (b)

Fig. 4.48: Spectrogram of noise clips recorded at 1250 RPM under no muffler on Tractor-1

(a) at ear level (EL)

(b) at 10 m distance



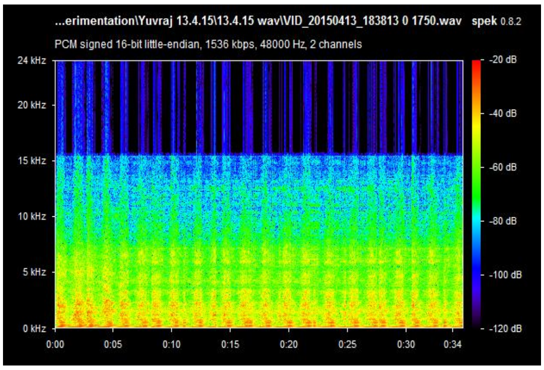


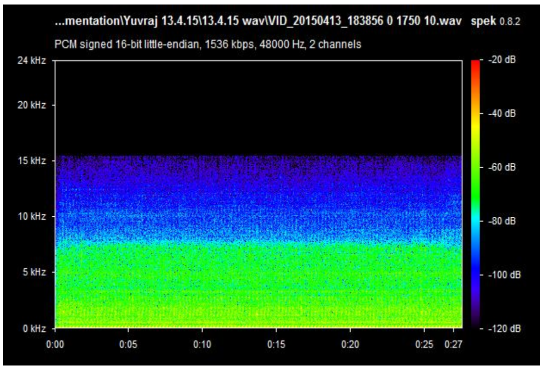
(a) (b)

Fig. 4.49: Spectrogram of noise clips recorded at 1500 RPM under no muffler on Tractor-1

(a) at ear level (EL)

(b) at 10 m distance



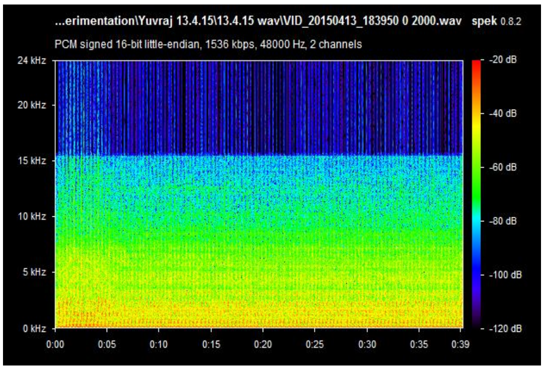


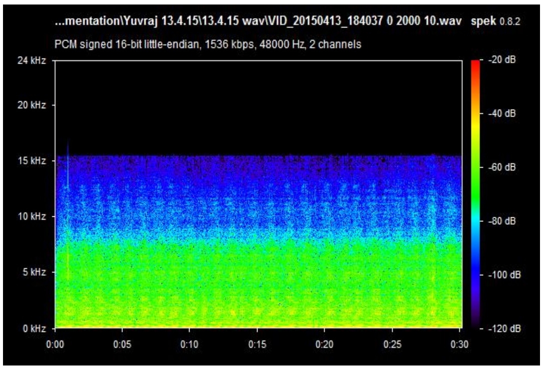
(a) (b)

Fig. 4.50: Spectrogram of noise clips recorded at 1750 RPM under no muffler on Tractor-1

(a) at ear level (EL)

(b) at 10 m distance





(a) (b)

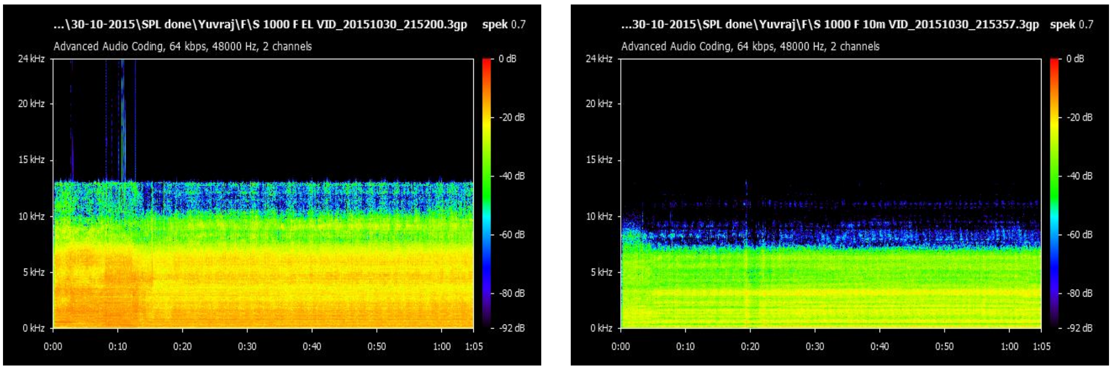
Fig. 4.51: Spectrogram of noise clips recorded at 2000 RPM under no muffler on Tractor-1

(a) at ear level (EL)

(b) at 10 m distance

4.6.1.3.2 Spectrograms of noise under muffler-S on tractor-1

The spectrogram of the noise clips recorded on tractor-1 with standard exhaust muffler mounted are generated with the help of an acoustic spectrum analyzer (Spek) at different engine speeds are presented in Fig. 4.52 to Fig. 4.56. Manually observed decibel levels and their respective amplitude ratio values based on these graphs are presented in the following tables along with percent level of frequencies contributed or composed in the true spectrum.

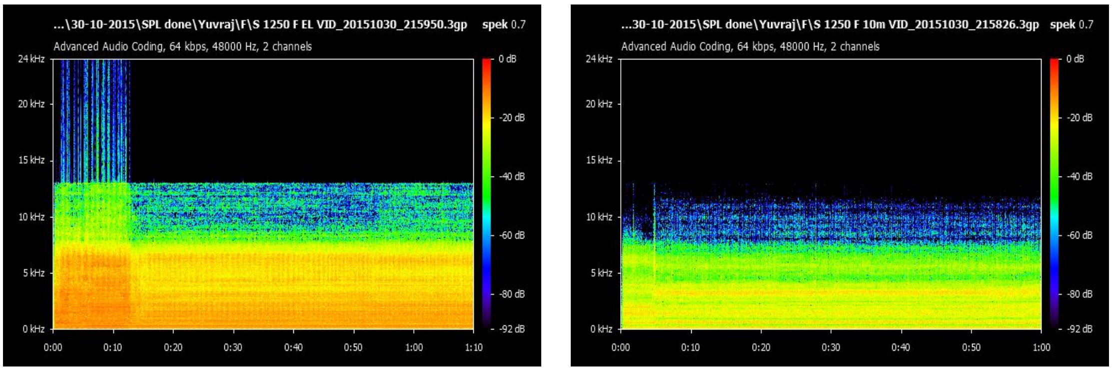


(a) (b)

Fig. 4.52: Spectrogram of noise clips recorded at 1000 RPM under standard muffler on Tractor-1

(a) at ear level (EL)

(b) at 10 m distance

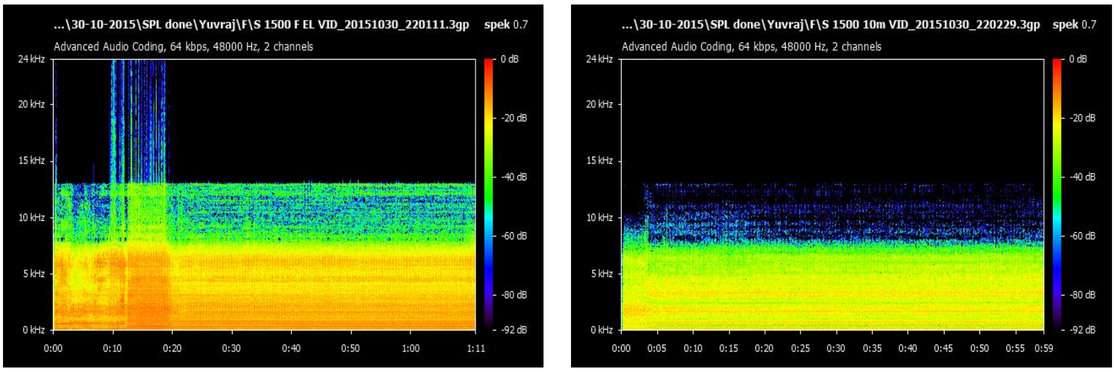


(a) (b)

Fig. 4.53: Spectrogram of noise clips recorded at 1250 RPM under standard muffler on Tractor-1

(a) at ear level (EL)

(b) at 10 m distance

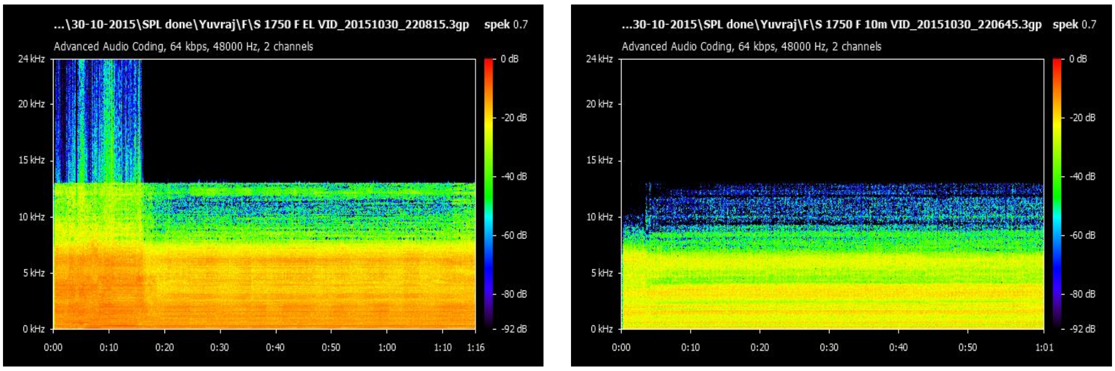


(a) (b)

Fig. 4.54: Spectrogram of noise clips recorded at 1500 RPM under standard muffler on Tractor-1

(a) at ear level (EL)

(b) at 10 m distance

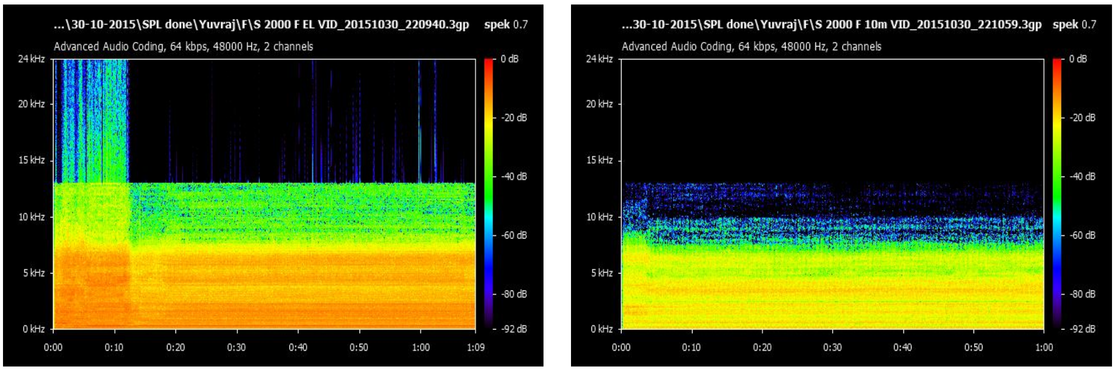


(a) (b)

Fig. 4.55: Spectrogram of noise clips recorded at 1750 RPM under standard muffler on Tractor-1

(a) at ear level (EL)

(b) at 10 m distance



(a) (b)

Fig. 4.56: Spectrogram of noise clips recorded at 2000 RPM under standard muffler on Tractor-1

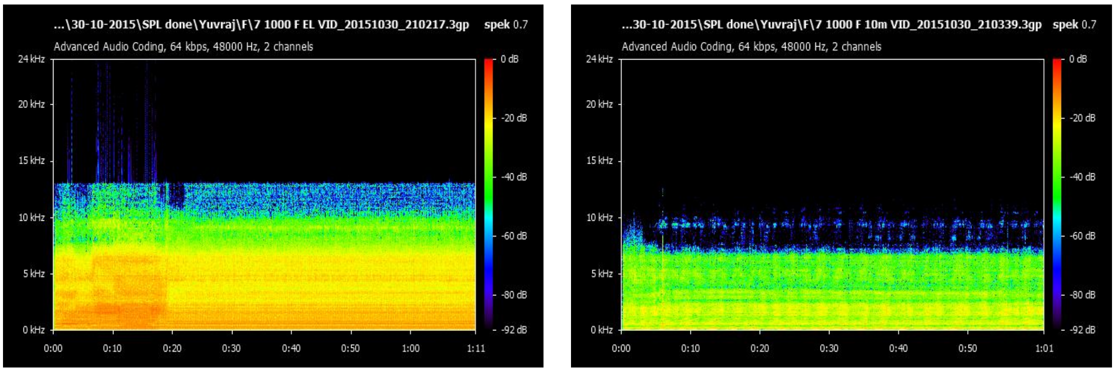
(a) at ear level (EL)

(b) at 10 m distance

Under muffler-S on Tractor-2, eight specified frequency ranges under different engine speeds had different level of percent amplitudes at two locations viz. ear level & 10 m distance. Hence, eight frequency ranges under different engine speeds demonstrated properties of noise in terms of proportional amplitude values of different frequency ranges as recorded at two different locations i.e. ear level (EL) & 10 m distance.

4.6.1.3.3 Spectrograms of noise under muffler-C on tractor-1

The spectrogram of the noise clips recorded with the help of a uniform device on tractor-1 after mounting muffler-C on the exhaust pipe are generated with the help of acoustic spectrum analyzer SPEK at different engine speeds are presented in Fig. 4.57 to Fig. 4.61.

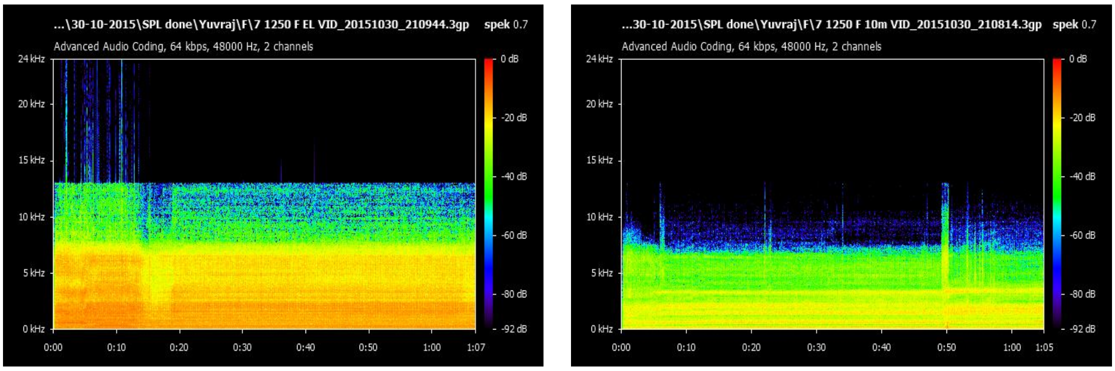


(a) (b)

Fig. 4.57: Spectrogram of noise clips recorded at 1000 RPM under muffler-C on Tractor-1

(a) at ear level (EL)

(b) at 10 m distance

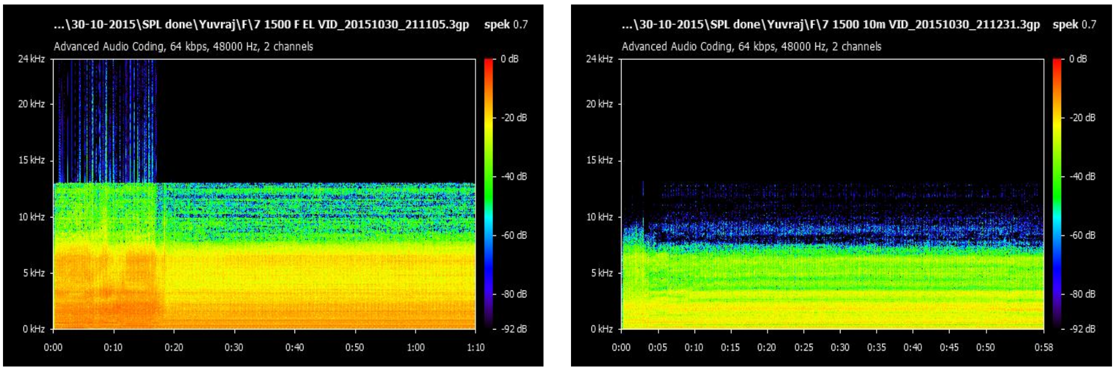


(a) (b)

Fig. 4.58: Spectrogram of noise clips recorded at 1250 RPM under muffler-C on Tractor-1

(a) at ear level (EL)

(b) at 10 m distance

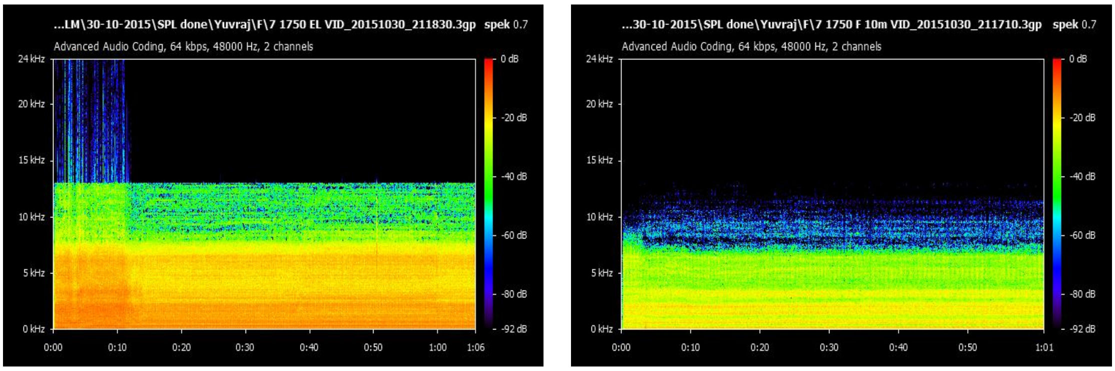


(a) (b)

Fig. 4.59: Spectrogram of noise clips recorded at 1500 RPM under muffler-C on Tractor-1

(a) at ear level (EL)

(b) at 10 m distance

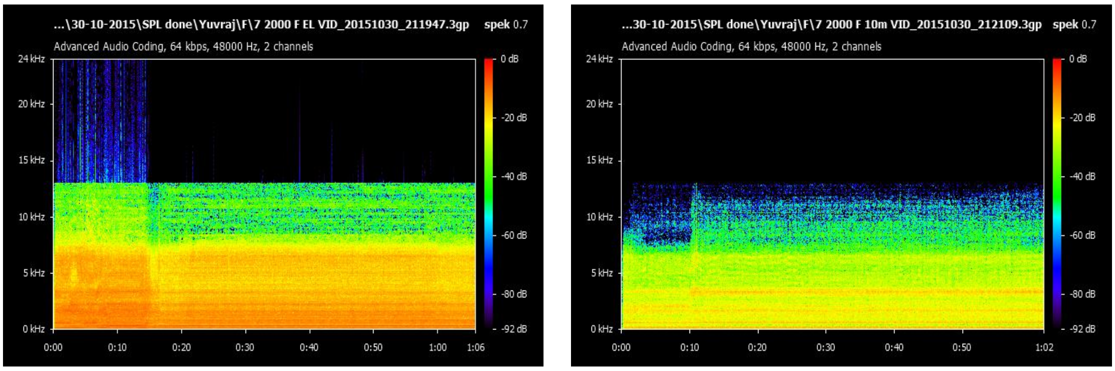


(a) (b)

Fig. 4.60: Spectrogram of noise clips recorded at 1750 RPM under muffler-C on Tractor-1

(a) at ear level (EL)

(b) at 10 m distance



(a) (b)

Fig. 4.61: Spectrogram of noise clips recorded at 2000 RPM under muffler-C on Tractor-1

(a) at ear level (EL)

(b) at 10 m distance

Under muffler-C, eight frequency ranges under different engine speeds demonstrated various amplitude values as recorded at two different locations i.e. ear level (EL) & 10 m distance.

4.6.1.4 Amplitudes of tractor noise frequencies on tractor-1

The proportional amounts in terms of percent amplitudes of the specified frequency ranges recorded under different muffler installations and under different engine speeds at two places are presented in the following tables.

Table 4.28: Percent amplitudes corresponding to different frequency ranges under different mufflers at 1000 RPM on Tractor-1 (mini tractor) at ear level

Frequency Range (kHz)	**No Muffler**	**Standard Muffler**	**Muffler-C**
0.0 – 2.5	53.6	44.5	41.3
2.5 – 5.0	22.6	25.0	13.1
5.0 – 7.5	22.6	25.0	41.3
7.5 – 10.0	0.9	4.5	4.1
10.0 – 12.5	0.2	0.4	0.1
12.5 – 15.0	0.0	0.4	0.0
15.0 – 17.5	0.0	0.0	0.0
17.5 – 20.0	0.0	0.0	0.0

Table 4.29: Percent amplitudes corresponding to different frequency ranges under different mufflers at 1250 RPM on Tractor-1 (mini tractor) at ear level

Frequency Range (kHz)	**No Muffler**	**Standard Muffler**	**Muffler-C**
0.0 – 2.5	39.6	38.6	51.9
2.5 – 5.0	29.7	21.7	21.9
5.0 – 7.5	29.7	38.6	21.9
7.5 – 10.0	0.5	0.7	3.9
10.0 – 12.5	0.5	0.4	0.4
12.5 – 15.0	0.0	0.0	0.0
15.0 – 17.5	0.0	0.0	0.0
17.5 – 20.0	0.0	0.0	0.0

Table 4.30: Percent amplitudes corresponding to different frequency ranges under different mufflers at 1500 RPM on Tractor-1 (mini tractor) at ear level

Frequency Range (kHz)	**No Muffler**	**Standard Muffler**	**Muffler-C**
0.0 – 2.5	44.7	46.9	46.6
2.5 – 5.0	25.1	26.4	26.2
5.0 – 7.5	25.1	26.4	26.2

7.5 – 10.0	2.5	0.3	0.5
10.0 – 12.5	2.5	0.3	0.5
12.5 – 15.0	0.0	0.0	0.0
15.0 – 17.5	0.0	0.0	0.0
17.5 – 20.0	0.0	0.0	0.0

Table 4.31: Percent amplitudes corresponding to different frequency ranges under different mufflers at 1750 RPM on Tractor-1 (mini tractor) at ear level

Frequency Range (kHz)	**No Muffler**	**Standard Muffler**	**Muffler-C**
0.0 – 2.5	39.3	46.9	42.4
2.5 – 5.0	22.1	26.4	13.4
5.0 – 7.5	22.1	26.4	42.4
7.5 – 10.0	12.4	0.3	1.3
10.0 – 12.5	3.9	0.3	0.4
12.5 – 15.0	0.1	0.0	0.0
15.0 – 17.5	0.0	0.0	0.0
17.5 – 20.0	0.0	0.0	0.0

Table 4.32: Percent amplitudes corresponding to different frequency ranges under different mufflers at 2000 RPM on Tractor-1 (mini tractor) at ear level

Frequency Range (kHz)	**No Muffler**	**Standard Muffler**	**Muffler-C**
0.0 – 2.5	43.0	46.1	46.6
2.5 – 5.0	24.2	25.9	26.2
5.0 – 7.5	24.2	25.9	26.2
7.5 – 10.0	4.3	1.5	0.5
10.0 – 12.5	4.3	0.8	0.5
12.5 – 15.0	0.0	0.0	0.0
15.0 – 17.5	0.0	0.0	0.0
17.5 – 20.0	0.0	0.0	0.0

Percent amplitudes corresponding to different frequency ranges under different mufflers at different RPM on Tractor-1 (mini tractor) at ear level (Table 4.28 to Table 4.32) revealed the following outcomes.

(i) At 1000 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (53.6%) were reduced by 9.1 & 12.3 % under standard muffler (44.5%) & muffler-C (41.3%) respectively. Percent amplitudes of 5-7.5 kHz frequencies were found higher (41.3%) under muffler-C.

(ii) At 1250 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (39.6%) were reduced by 1.0% & increased by 12.3% under standard muffler (38.6%) & muffler-C (51.9%) respectively. Percent amplitudes of 5-7.5 kHz frequencies were found higher (38.6%) under standard muffler.

(iii) At 1500 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (44.7%) were increased by 2.2 & 1.9 % under standard muffler (46.9%) & muffler-C (46.6%) respectively. Percent amplitudes of 2.5-5.0 & 5.0-7.5 kHz frequencies increased in little amount under muffler-S & C.

(iv) At 1750 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (39.3%) increased by 7.6 & 3.1 % under standard muffler (46.9%) & muffler-C (42.4%) respectively. Percent amplitudes of 5-7.5 kHz frequencies were found higher (42.4%) under muffler-C.

(v) At 2000 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (43.0%) increased by 3.1 & 3.6 % under standard muffler (46.1%) & muffler-C (46.6%) respectively. Percent amplitudes of 2.5-5.0 & 5.0-7.5 kHz frequencies increased in little amount under muffler-S & C.

Table 4.33: Percent amplitudes corresponding to different frequency ranges under different mufflers at 1000 RPM on Tractor-1 (mini tractor) at 10 m

Frequency Range (kHz)	**No Muffler**	**Standard Muffler**	**Muffler-C**
0.0 – 2.5	83.0	43.3	57.2
2.5 – 5.0	8.3	43.3	32.3
5.0 – 7.5	8.3	13.7	10.2
7.5 – 10.0	0.3	0.4	0.1
10.0 – 12.5	0.0	0.1	0.0
12.5 – 15.0	0.0	0.0	0.0

15.0 – 17.5	0.0	0.0	0.0
17.5 – 20.0	0.0	0.0	0.0

Table 4.34: Percent amplitudes corresponding to different frequency ranges under different mufflers at 1250 RPM on Tractor-1 (mini tractor) at 10 m

Frequency Range (kHz)	**No Muffler**	**Standard Muffler**	**Muffler-C**
0.0 – 2.5	61.2	57.5	53.2
2.5 – 5.0	19.3	32.4	29.8
5.0 – 7.5	19.3	10.2	16.8
7.5 – 10.0	0.0	0.1	0.2
10.0 – 12.5	0.0	0.0	0.1
12.5 – 15.0	0.0	0.0	0.0
15.0 – 17.5	0.0	0.0	0.0
17.5 – 20.0	0.0	0.0	0.0

Table 4.35: Percent amplitudes corresponding to different frequency ranges under different mufflers at 1500 RPM on Tractor-1 (mini tractor) at 10 m

Frequency Range (kHz)	**No Muffler**	**Standard Muffler**	**Muffler-C**

0.0 – 2.5	61.2	43.1	60.2
2.5 – 5.0	19.3	43.1	25.3
5.0 – 7.5	19.3	13.6	14.3
7.5 – 10.0	0.1	0.1	0.1
10.0 – 12.5	0.1	0.0	0.0
12.5 – 15.0	0.0	0.0	0.0
15.0 – 17.5	0.0	0.0	0.0
17.5 – 20.0	0.0	0.0	0.0

Table 4.36: Percent amplitudes corresponding to different frequency ranges under different mufflers at 1750 RPM on Tractor-1 (mini tractor) at 10 m

Frequency Range (kHz)	**No Muffler**	**Standard Muffler**	**Muffler-C**
0.0 – 2.5	43.2	42.6	66.1
2.5 – 5.0	32.4	42.6	20.8
5.0 – 7.5	24.3	13.5	11.8
7.5 – 10.0	0.1	1.3	1.2
10.0 – 12.5	0.0	0.1	0.1
12.5 – 15.0	0.0	0.0	0.0

15.0 – 17.5	0.0	0.0	0.0
17.5 – 20.0	0.0	0.0	0.0

Table 4.37: Percent amplitudes corresponding to different frequency ranges under different mufflers at 2000 RPM on Tractor-1 (mini tractor) at 10 m

Frequency Range (kHz)	**No Muffler**	**Standard Muffler**	**Muffler-C**
0.0 – 2.5	53.1	45.7	42.1
2.5 – 5.0	29.7	45.7	42.1
5.0 – 7.5	16.8	8.1	13.3
7.5 – 10.0	0.3	0.5	2.4
10.0 – 12.5	0.1	0.0	0.1
12.5 – 15.0	0.0	0.0	0.0
15.0 – 17.5	0.0	0.0	0.0
17.5 – 20.0	0.0	0.0	0.0

Percent amplitudes corresponding to different frequency ranges under different mufflers at different RPM on Tractor-1 (mini tractor) at 10 m distance (Table 4.33 to 4.37) revealed the following outcomes.

(i) At 1000 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (83.0%) were reduced by 39.7 & 25.8 % under standard muffler

(43.3%) & muffler-C (57.2%) respectively. Percent amplitudes of 2.5-5.0 kHz frequencies were found higher (43.3%) under muffler-S.

(ii) At 1250 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (61.2%) were reduced by 3.7 & 8.0 % under standard muffler (57.5%) & muffler-C (53.2%) respectively. Percent amplitudes of 2.5-5.0 kHz frequencies were found higher (32.4%) under standard muffler.

(iii) At 1500 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (61.2%) were reduced by 18.1 & 1.0 % under standard muffler (43.1%) & muffler-C (60.2%) respectively. Percent amplitudes of 2.5-5.0 were found higher (43.1%) under standard muffler.

(iv) At 1750 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (43.2%) decreased by 0.6% & increased by 22.9% under standard muffler (42.6%) & muffler-C (66.1%) respectively. Percent amplitudes of 2.5-5.0 kHz frequencies were found higher (42.6%) under muffler-S.

(v) At 2000 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (53.1%) reduced by 7.4 & 11.0 % under standard muffler (45.7%) & muffler-C (42.1%) respectively. Percent amplitudes of 2.5-5.0 kHz frequencies found higher under standard muffler (45.7%) and muffler-C (42.1%).

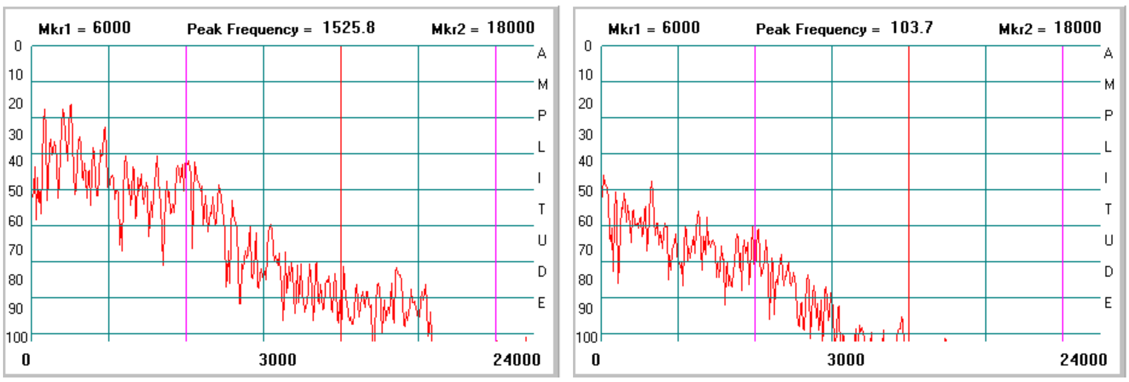
4.6.2 Frequency Spectrum, Peak Frequencies and Spectrogram of Noise on Tractor-2

4.6.2.1 Frequency spectrum of noise on tractor-2

The graphs are obtained by input to Audio Spectrum Analyzer from wave file. Audio Spectrum Analyzer has variable displays, Fast Fourier Transform (FFT) display, variable sample rates (8000 Hz, 11025 Hz, 22050 Hz, and 44100 Hz), variable transform sizes (1k, 2k, 4k, and 8k), adjustable upper and lower limits, continuous, averaged, and peak hold, selectable foreground and backgrounds, variable markers, etc. Sound frequency observations recorded at two places viz. ear level & 10 m distance were analyzed.

4.6.2.1.1 Frequency spectrum of noise under no muffler on tractor-2

Frequency spectrum generated by the Spectrumview provided the specific frequency which has highest value of amplitude as peak frequency. Accordingly, for each muffler mounting and each speed level, the peak frequency observations were recorded and later analyzed for investigating the effect of muffler mounting on the sound frequencies emanated out of it passing through the varying kinds of internal reactive muffler configurations as experimented. Further, sound frequency observations recorded at two places viz. ear level & 10 m distance were analyzed. Frequency spectrum are presnted in the following figures (Fig. 4.62 to Fig. 4.66).

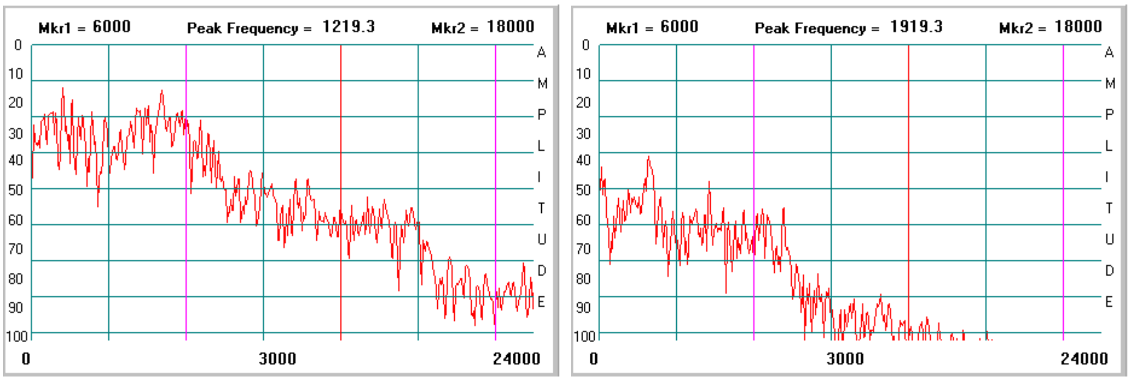


(a) (b)

Fig. 4.62: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-2 at 1000 RPM under no muffler

(a) at ear level, and

(b) at 10 m distance

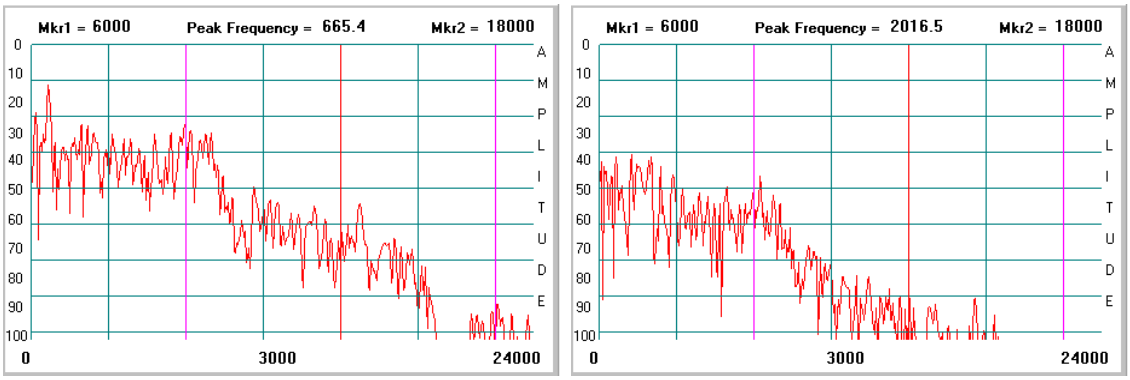


(a) (b)

Fig. 4.63: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-2 at 1250 RPM under no muffler

(a) at ear level, and

(b) at 10 m distance

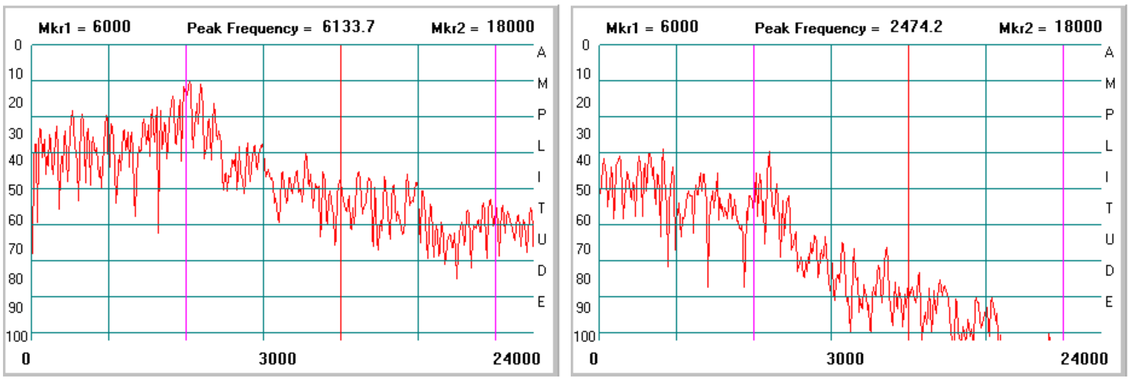


(a) (b)

Fig. 4.64: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-2 at 1500 RPM under no muffler

(a) at ear level, and

(b) at 10 m distance

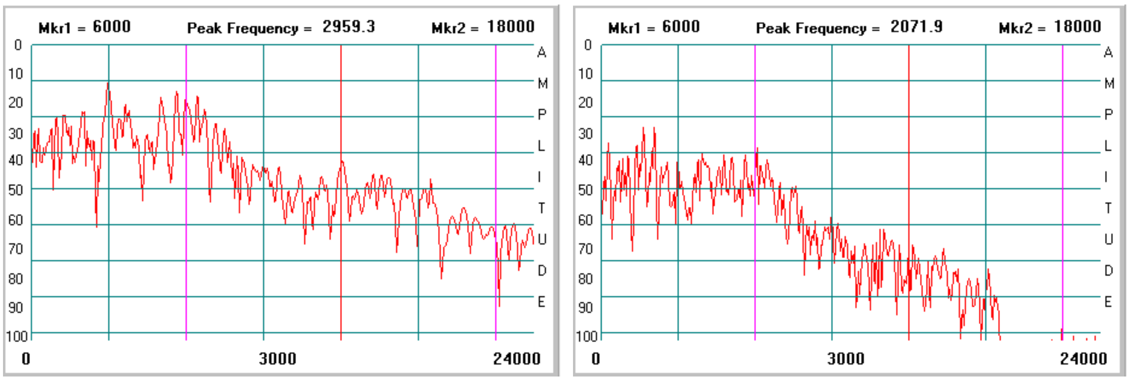


(a) (b)

Fig. 4.65: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-2 at 1750 RPM under no muffler

(a) at ear level, and

(b) at 10 m distance



(a) (b)

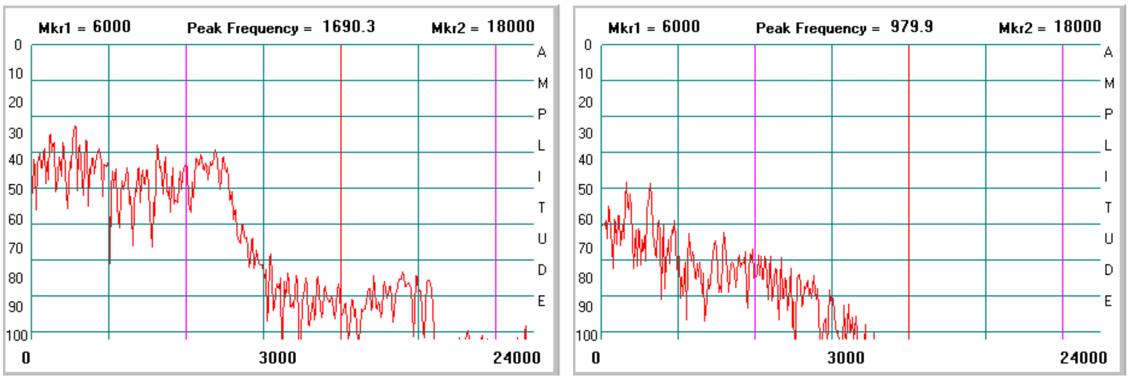
Fig. 4.66: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-2 at 2000 RPM under no muffler

(a) at ear level, and

(b) at 10 m distance

4.6.2.1.2 Frequency spectrum of noise under muffler-S on tractor-2

Sample views of the display of frequency spectrum obtained at ear level & 10 m distance noise recordings are shown in the following figures (Fig. 4.67 to Fig. 4.71). The spectra displayed were taken over the interval of 0.5 seconds of the sound file. Peak frequencies were observed & tabulated for same interval of time.

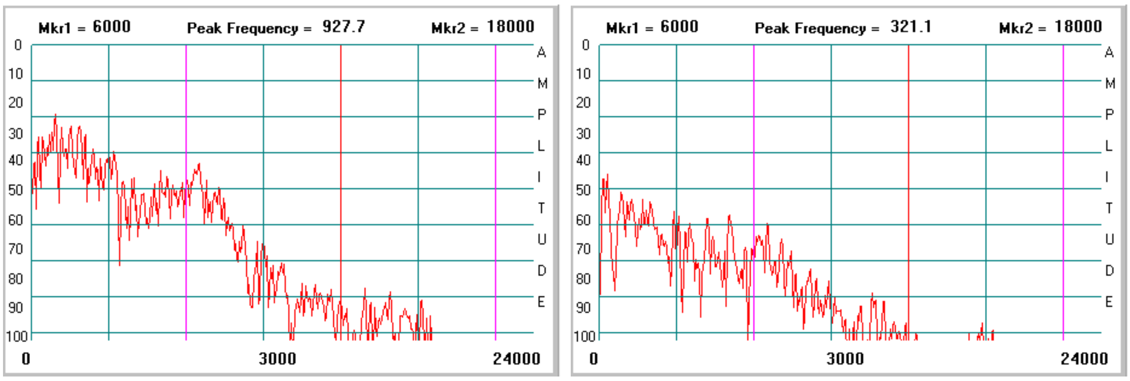


(a) (b)

Fig. 4.67: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-2 at 1000 RPM under standard muffler

(a) at ear level, and

(b) at 10 m distance

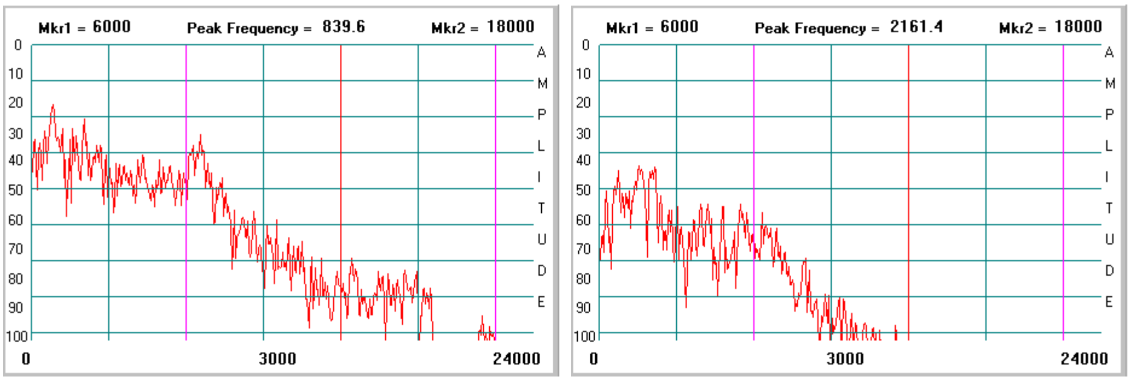


(a) (b)

Fig. 4.68: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-2 at 1250 RPM under standard muffler

(a) at ear level, and

(b) at 10 m distance

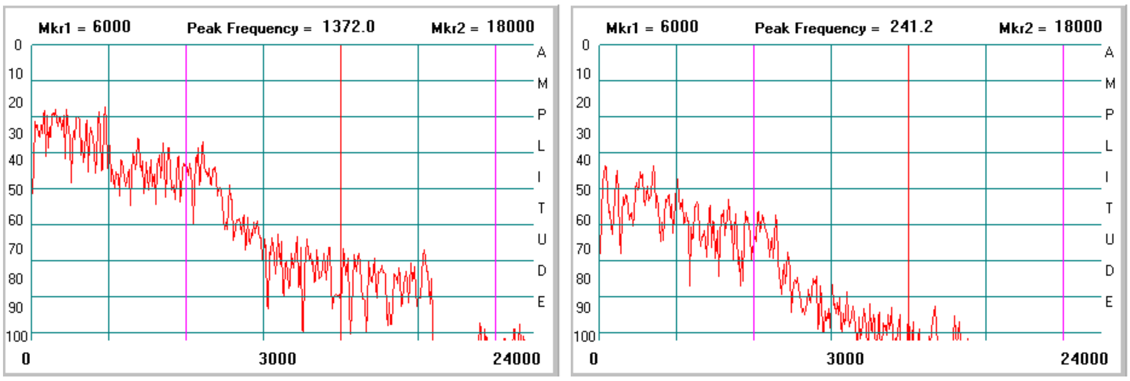


(a) (b)

Fig. 4.69: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-2 at 1500 RPM under standard muffler

(a) at ear level, and

(b) at 10 m distance

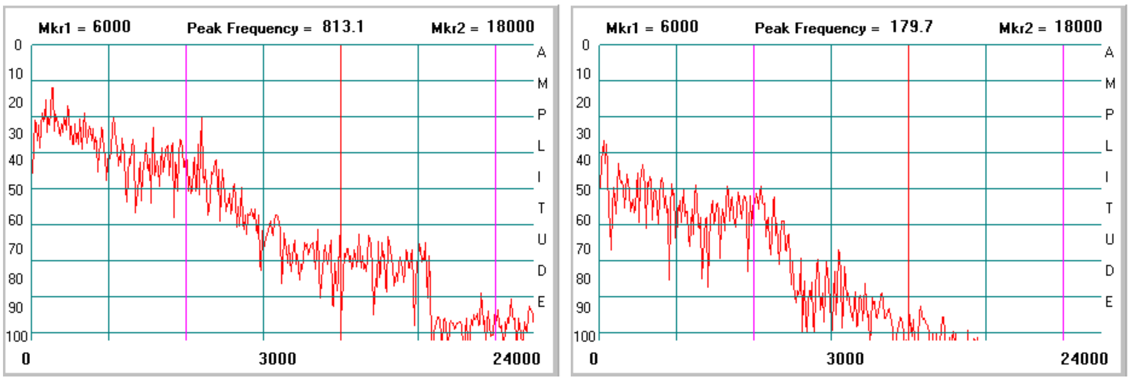


(a) (b)

Fig. 4.70: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-2 at 1750 RPM under standard muffler

(a) at ear level, and

(b) at 10 m distance



(a) (b)

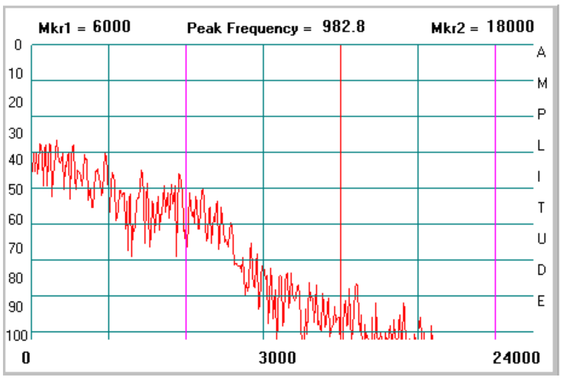
Fig. 4.71: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-2 at 2000 RPM under standard muffler

(a) at ear level, and

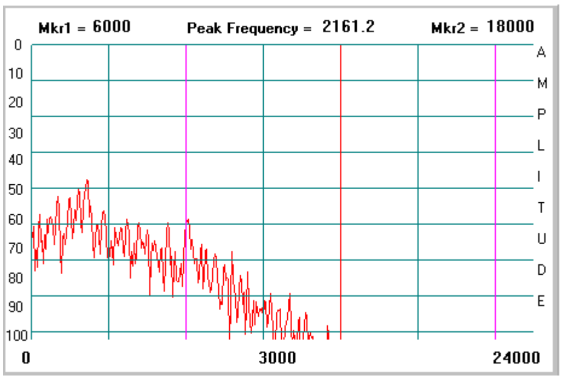
(b) at 10 m distance

4.6.2.1.3 Frequency spectrum of noise under muffler-C on tractor-2

Sample views of the display of frequency spectrum obtained at ear level & 10 m distance noise recordings are shown in the following figures (Fig. 4.72 to Fig. 4.76). The spectra displayed were taken over the interval of 0.5 seconds of the sound file. Peak frequencies were observed & tabulated for same interval of time.



(a)

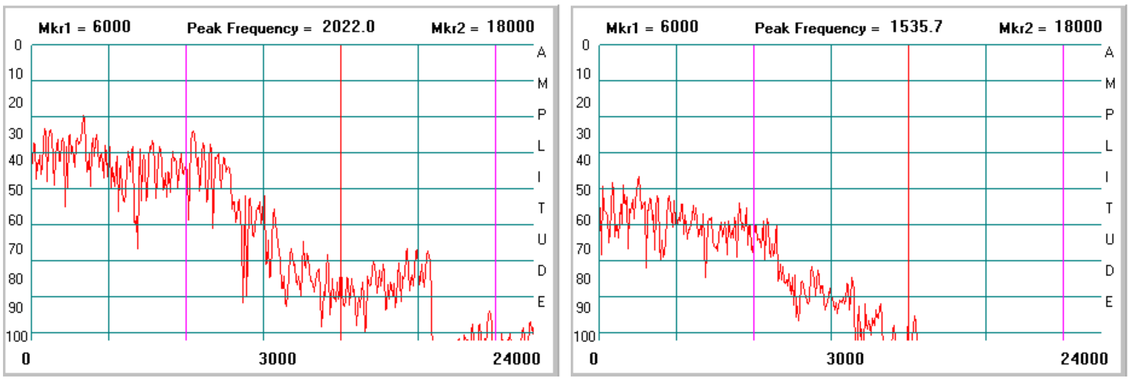


(b)

Fig. 4.72: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-2 at 1000 RPM under muffler-C

(a) at ear level, and

(b) at 10 m distance

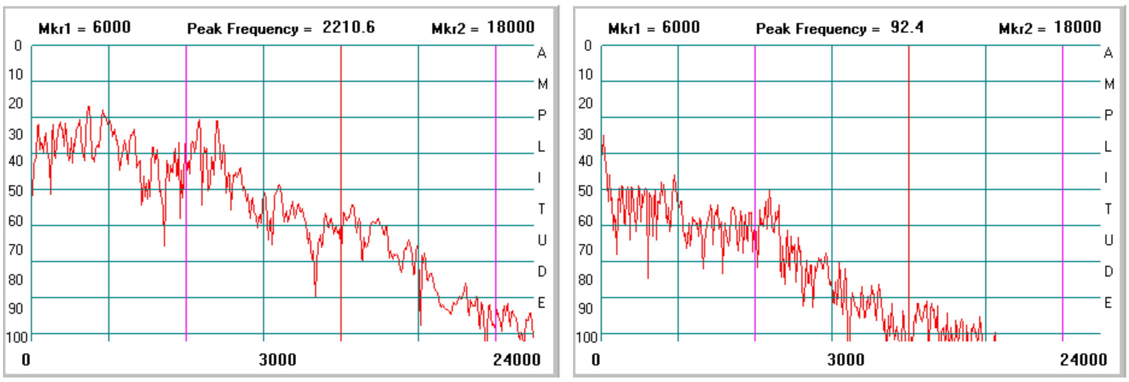


(a) (b)

Fig. 4.73: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-2 at 1250 RPM under muffler-C

(a) at ear level, and

(b) at 10 m distance

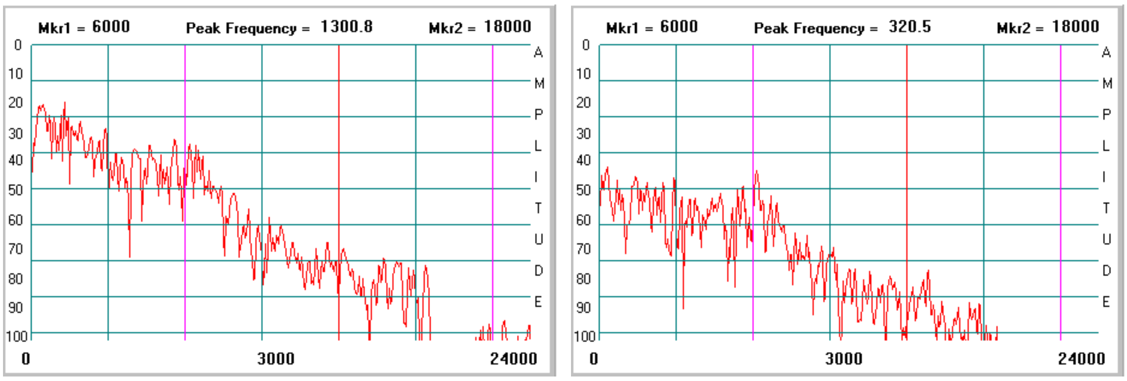


(a) (b)

Fig. 4.74: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-2 at 1500 RPM under muffler-C

(a) at ear level, and

(b) at 10 m distance

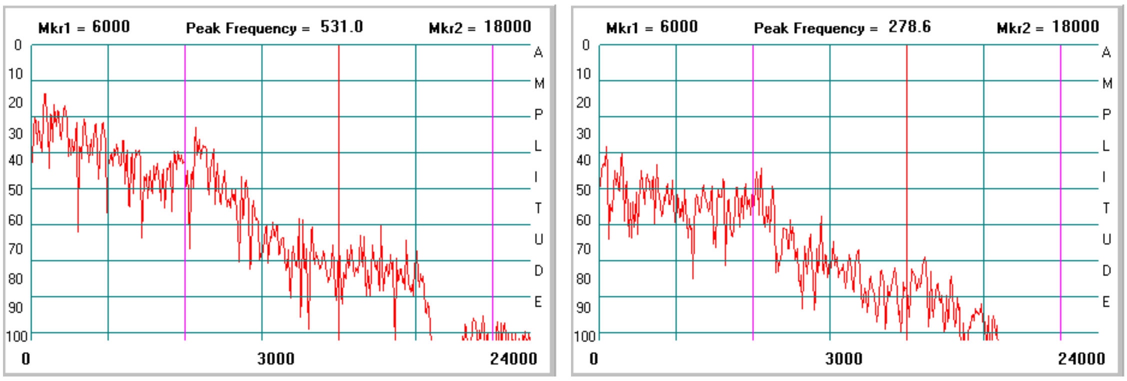


(a) (b)

Fig. 4.75: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-2 at 1750 RPM under muffler-C

(a) at ear level, and

(b) at 10 m distance



(a) (b)

Fig. 4.76: Frequency spectrum of the tractor noise generated by audio spectrum analyzer for Tractor-2 at 2000 RPM under muffler-C

(a) at ear level, and

(b) at 10 m distance

4.6.2.2 Peak frequencies of noise on tractor-2

4.6.2.2.1 Peak frequencies of noise recorded at ear level of tractor-2

A comparison of mean values of peak frequencies observed at ear level under three muffler mountings at different engine speeds on Tractor-2 are tabulated (Table 4.38).

Table 4.38: Mean values of peak frequencies observed at ear level at different engine speeds on Tractor-2

Muffler Type	**Engine Speed (RPM)**					**Mean**
	1000	**1250**	**1500**	**1750**	**2000**	
No Muffler	1087.7	1232.3	1433.5	1679.7	1986.6	1484.0
Standard Muffler	1079	1191.9	1083.9	874.18	628.86	971.6
Muffler-C	1126	1293.6	1371.5	877.09	907.3	1115.1

At ear level observations on Tractor-2, standard muffler and no muffler mounting respectively exhibited lowest and highest peak frequencies in comparison to that observed under muffler-C which exhibited moderate peak frequency levels at all engine speeds experimented i.e. 1000 RPM, 1250 RPM, 1500 RPM, 1750 RPM and 2000 RPM.

The minimum and maximum peak frequencies observed during the sample noise test at ear level and at 10 m distance away from tractor on Tractor-2 under no-muffler, standard muffler and muffler-C are presented in the following tables (Table 4.39) along with their mean, mean deviation, standard deviation and coefficient of variation (%).

Table 4.39: Minimum, maximum, mean, median, mean deviation, standard deviation and coefficient of variation (%) under different muffler installations on Tractor-2 at ear level

Muffler Installation	Peak Frequency, Hz						Coefficient of Variation (%)
	Maximum	Minimum	Mean	Median	Mean Deviation	Standard Deviation	
No Muffler	1950.6	1129.2	1484.0	1469.1	175.7	220.3	14.8
Standard Muffler	1336.5	640.1	971.6	981.6	131.6	162.7	16.7
Muffler-C	1495.1	783.2	1115.1	1103.7	121.4	158.3	14.2

The mean values of averaged peak frequencies observed in noise recorded on Tractor-2 at ear level were found 1484.0 Hz, 971.6 Hz and 1115.1 Hz under no muffler, standard muffler and muffler-C respectively. The values of mean deviation and standard deviation of ear level peak frequencies under muffler-C were found 121.4 & 158.3 Hz respectively which were minimum among three muffler mountings under test on Tractor-2. The value of coefficient of variation (CV) of peak frequencies observed under muffler-C was found 14.2% which was also minimum than that found under remaining muffler mountings as stated in Table 4.80 at above.

Fig. 4.77 depicts peak frequency observations made under all mufflers in the noise (SPL) observations recorded at operator's ear level on tractor-2. Peak frequency observations obtained under the mounting of muffler-C were higher in comparison to muffler-S but were found lesser in comparison to that obtained under no muffler mounting.

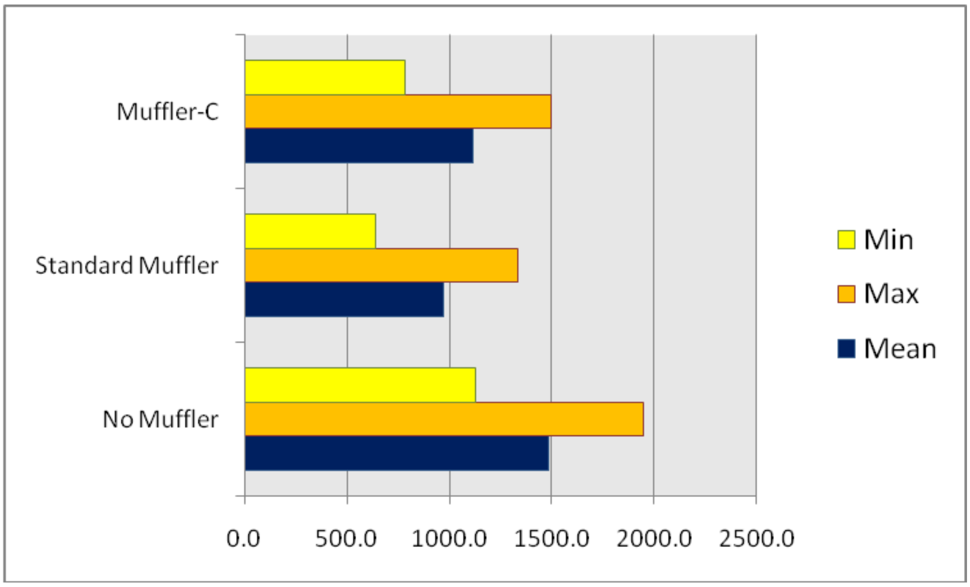


Fig. 4.77: Minimum, maximum and mean peak frequency values of the noise recorded at ear level on Tractor-2 under different muffler installations

4.6.2.2.2 Peak frequencies of noise recorded at 10 m distance from tractor-2

A comparison of mean values of peak frequencies observed at 10 m distance under three muffler mountings at different engine speeds on Tractor-2 are tabulated (Table 4.40).

Table 4.40: Mean values of peak frequencies observed at 10 m distance from tractor at different engine speeds on Tractor-2

Muffler Type	**Engine Speed (RPM)**					**Mean RPM**
	1000	**1250**	**1500**	**1750**	**2000**	
No Muffler	923.22	1273.8	1899.9	1754.3	1774.4	1525.1
Standard Muffler	1230.6	1260.1	1193	645.12	374.09	940.6
Muffler-C	744.13	630.98	810.24	498.45	347.64	606.3

At 10 m distance observations on Tractor-2, Muffler-C exhibited lowest individual & mean of peak frequencies obtained at different engine speeds viz. 1000 RPM, 1250 RPM, 1500 RPM, 1750 RPM and 2000 RPM in comparison to that observed under standard and no muffler mountings at all engine speeds experimental treatments.

Table 4.41: Minimum, maximum, mean, median, mean deviation, standard deviation and coefficient of variation (%) under different muffler installations on Tractor-2 at 10 m distance

Muffler Installation	Peak Frequency, RPM						Coefficient of Variation (%)
	Maximum	Minimum	Mean	Median	Mean Deviation	Standard Deviation	
No Muffler	2049.5	1020.2	1525.1	1526.8	192.3	251.4	16.5
Standard Muffler	1416.9	502.3	940.6	926.5	132.2	183.0	19.5
Muffler-C	1391.5	248.0	606.3	592.3	166.5	220.1	36.3

The lowest mean (606.3 Hz) and median (592.3 Hz) values of peak frequencies (averaged over five different engine speeds) were found under muffler-C mounting at 10 m distance observations on Tractor-2. However, the mean deviation and standard deviation were observed minimum under standard muffler mounting on Tractor-2 among three.

Fig. 4.78 depicts peak frequency observations made under all mufflers in the noise (SPL) observations recorded at 10 m distance on tractor-2. Peak frequency observations obtained under the mounting of muffler-C were lesser in comparison to that obtained under muffler-S & no-muffler mounting.

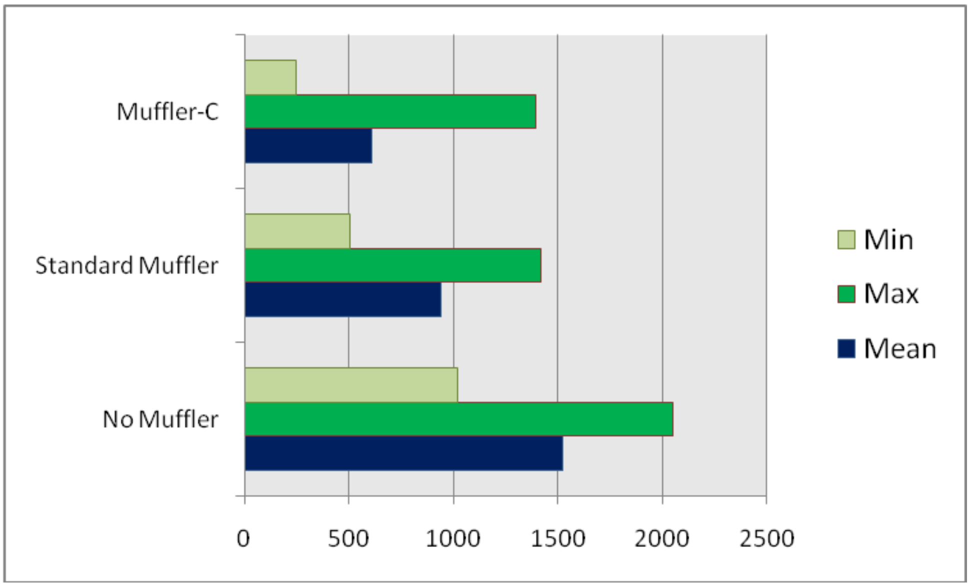


Fig. 4.78: Minimum, maximum and mean peak frequency values of the noise recorded at 10 m distance on Tractor-2 under different muffler installations

4.6.2.2.3 Comparison of peak frequencies of noise recorded at ear level & at 10 m distance from tractor-2

The graphical display (Fig. 4.104 and Fig. 4.105) and the tabulated information (Table 4.81 and 4.82) of the mean, maximum and minimum peak frequency levels obtained in the noise clips recorded at ear level and at 10 m distance away on Tractor-2 showed several specific and notable differences which are tabulated below (Table 4.42).

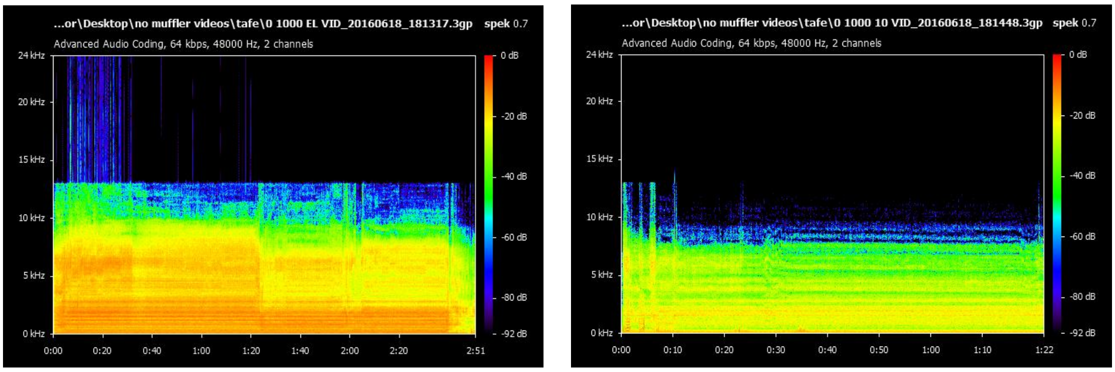
Table 4.42: Comparison of mean peak frequency, standard deviation and coefficient of variation observed in the noise (sound clips) recorded at ear level and at 10 m distance from Tractor-2

Parameter	Ear Level	10 m Away
Mean peak frequency (Hz)	Lower average peak frequency (971.6 Hz) is observed under standard muffler.	Lower average peak frequency (606.3 Hz) is observed under muffler-C mounting.
Standard Deviation, s (Hz)	The standard deviation (s) for standard muffler and muffler-C were found 162.7 & 158.3 Hz respectively.	The standard deviation (s) for standard muffler and muffler-C were found 183.0 & 220.1 Hz respectively.
Coefficient of Variation (%)	C.V. (%) for standard muffler and muffler-C were found 16.7 & 14.2 percent respectively.	C.V. (%) for standard muffler and muffler-C were found 19.5 & 36.3 percent respectively.

4.6.2.3 Spectrograms of noise on tractor-2

4.6.2.3.1 Spectrograms of noise under no muffler on tractor-2

The noise clip recorded with the help of a uniform device on tractor-2 without mounting any exhaust muffler is processed to generate the spectrogram by using an acoustic spectrum analyzer SPEK at different engine speeds which are presented in Fig. 4.79 to Fig. 4.83. Noise clips recorded at two places viz. ear level & 10 m distance were analyzed. The data on decibel levels and their respective amplitude ratio values and percent amplitudes of different frequency ranges contained in the true spectrum are tabulated and included in the appendices.

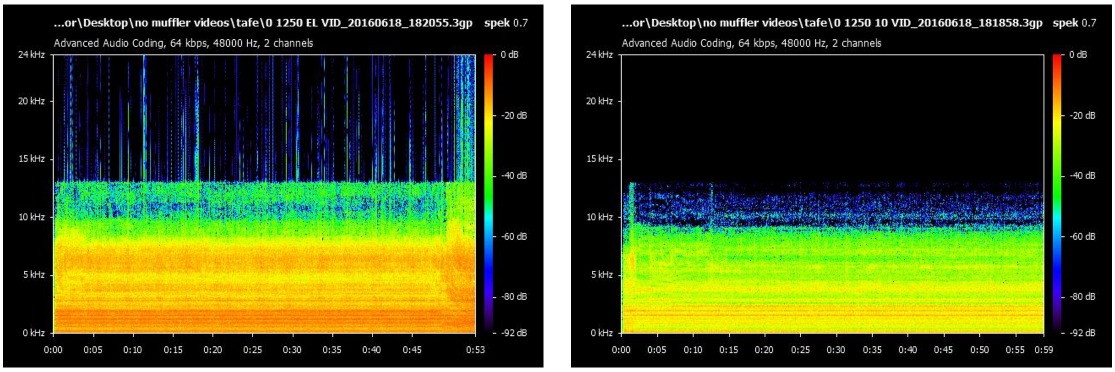


(a) (b)

Fig. 4.79: Spectrogram of noise clips recorded at 1000 RPM under no muffler on Tractor-2

(a) at ear level (EL)

(b) at 10 m distance

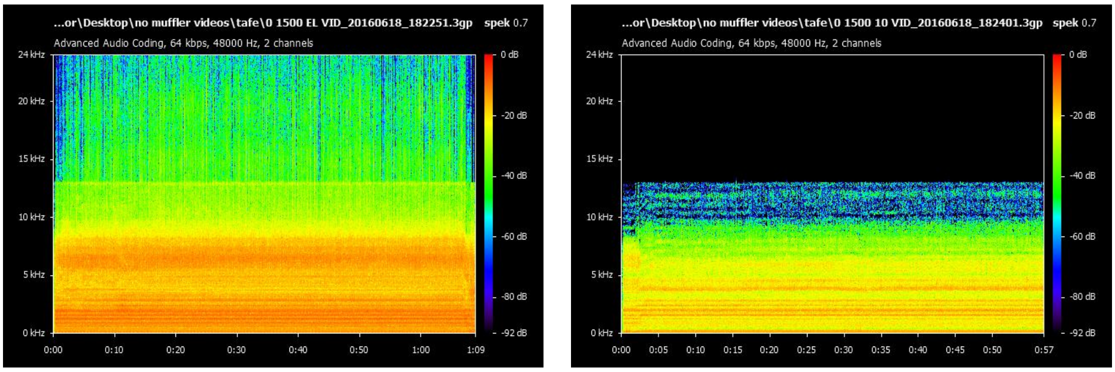


(a) (b)

Fig. 4.80: Spectrogram of noise clips recorded at 1250 RPM under no muffler on Tractor-2

(a) at ear level (EL)

(b) at 10 m distance

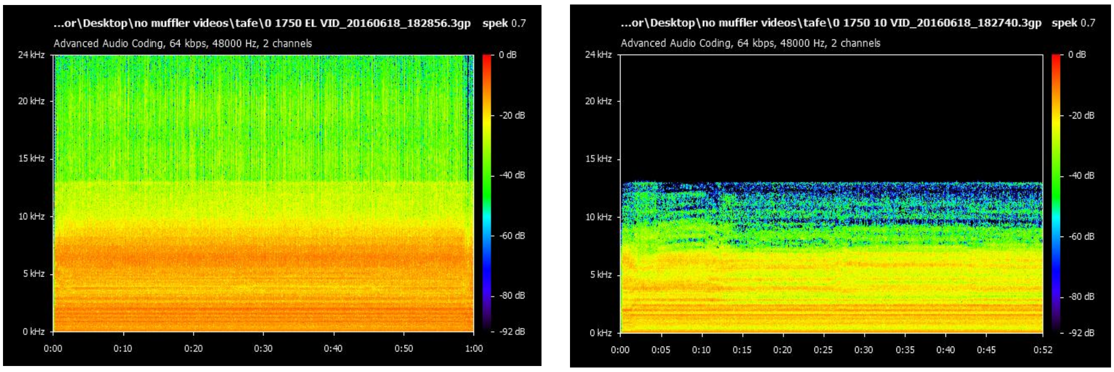


(a) (b)

Fig. 4.81: Spectrogram of noise clips recorded at 1500 RPM under no muffler on Tractor-2

(a) at ear level (EL)

(b) at 10 m distance

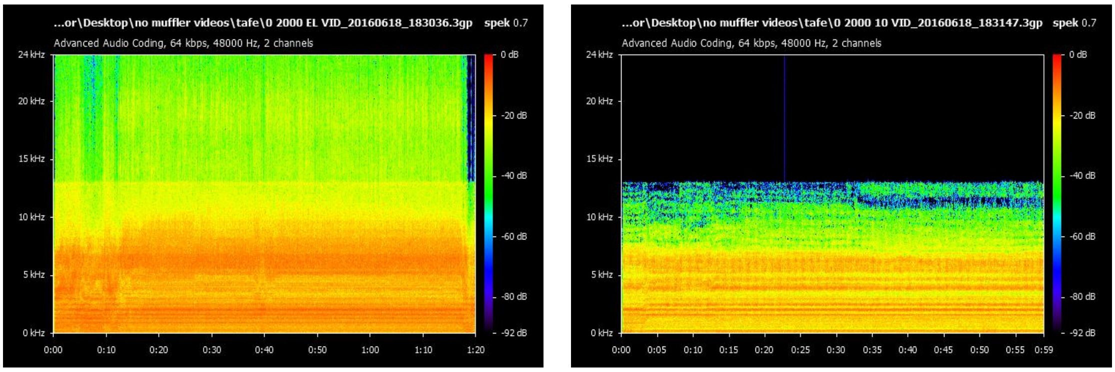


(a) (b)

Fig. 4.82: Spectrogram of noise clips recorded at 1750 RPM under no muffler on Tractor-2

(a) at ear level (EL)

(b) at 10 m distance



(a) (b)

Fig. 4.83: Spectrogram of noise clips recorded at 2000 RPM under no muffler on Tractor-2

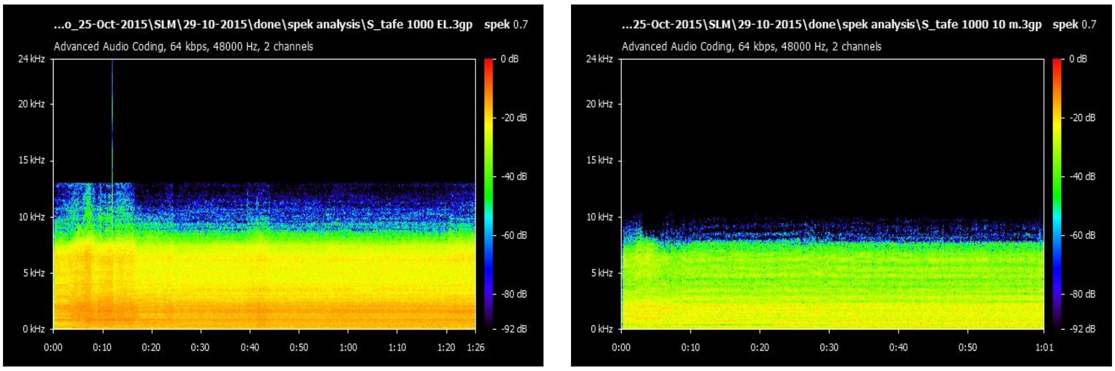
(a) at ear level (EL)

(b) at 10 m distance

Under no muffler, mainly four out of eight frequency ranges under different engine speeds demonstrated various amplitude percent levels as recorded at two different locations i.e. ear level and 10 m distance.

4.6.2.3.2 Spectrograms of noise under muffler-S on tractor-2

The noise clips were processed to generate the spectrogram which are presented in Fig. 4.84 to Fig. 4.88. The data on decibel levels and their respective amplitude ratio values and percent amplitudes of different frequency ranges contained in the true spectrum are tabulated and included in the appendices.

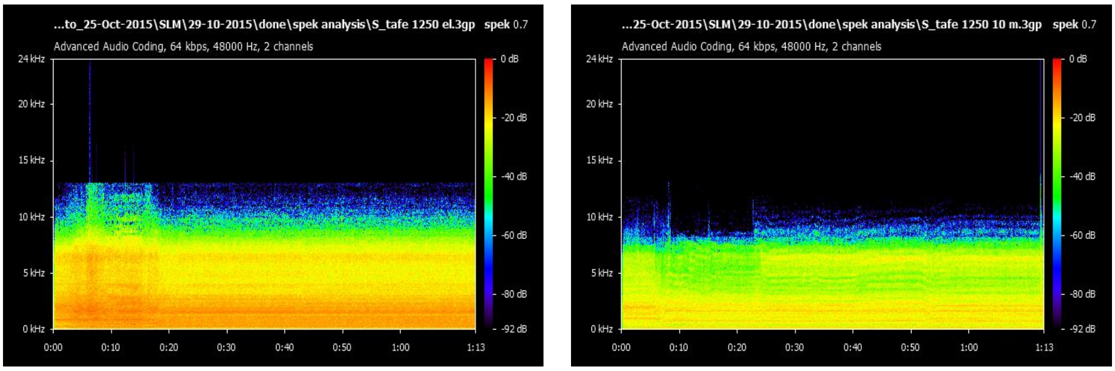


(a) (b)

Fig. 4.84: Spectrogram of noise clips recorded at 1000 RPM under standard muffler on Tractor-2

(a) at ear level (EL)

(b) at 10 m distance

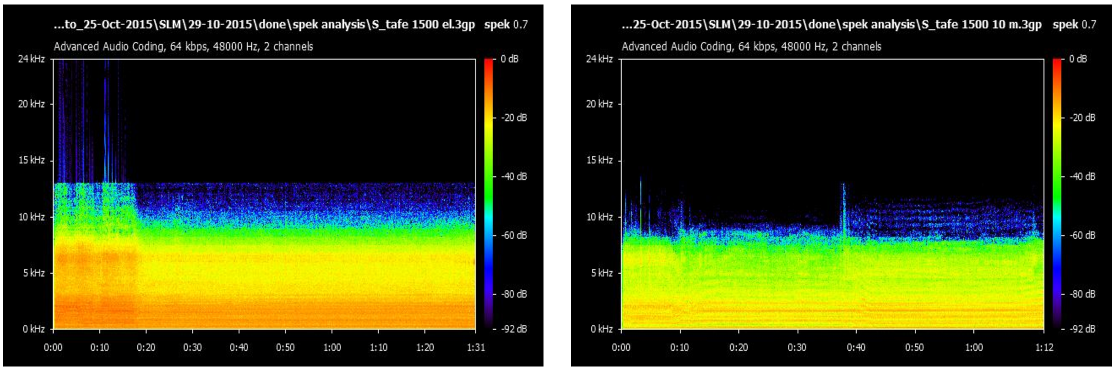


(a) (b)

Fig. 4.85: Spectrogram of noise clips recorded at 1250 RPM under standard muffler on Tractor-2

(a) at ear level (EL)

(b) at 10 m distance

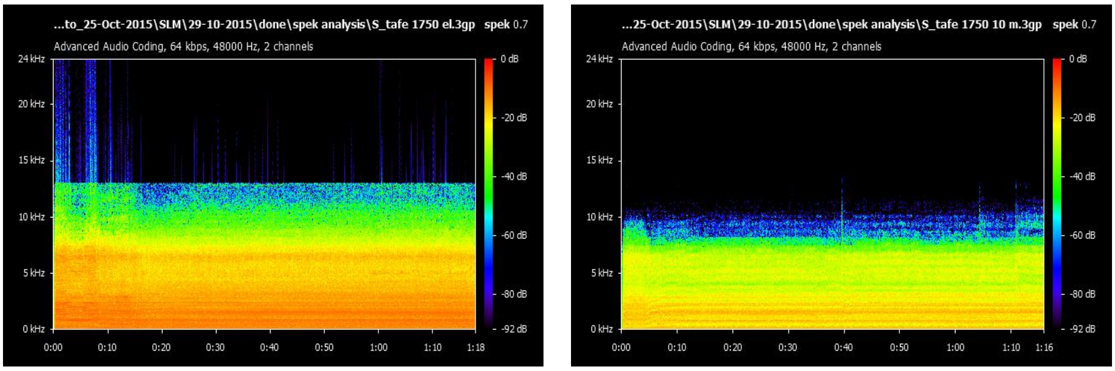


(a) (b)

Fig. 4.86: Spectrogram of noise clips recorded at 1500 RPM under standard muffler on Tractor-2

(a) at ear level (EL)

(b) at 10 m distance

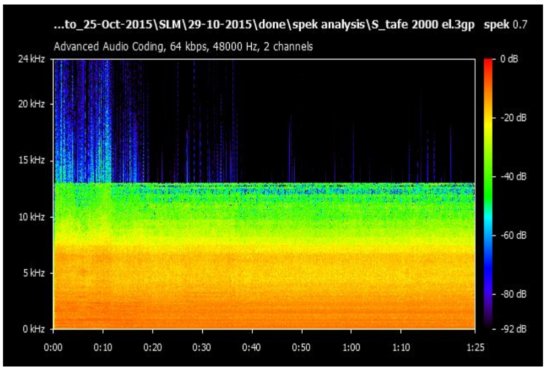


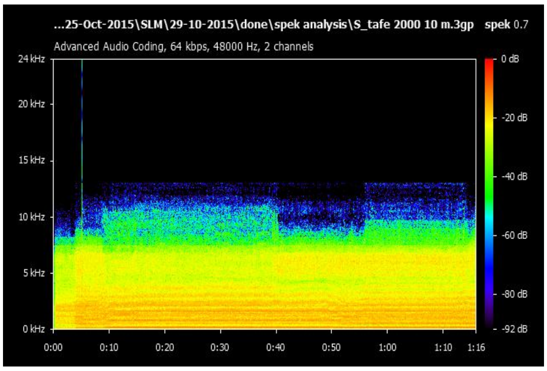
(a) (b)

Fig. 4.87: Spectrogram of noise clips recorded at 1750 RPM under standard muffler on Tractor-2

(a) at ear level (EL)

(b) at 10 m distance





(a) (b)

Fig. 4.88: Spectrogram of noise clips recorded at 2000 RPM under standard muffler on Tractor-2

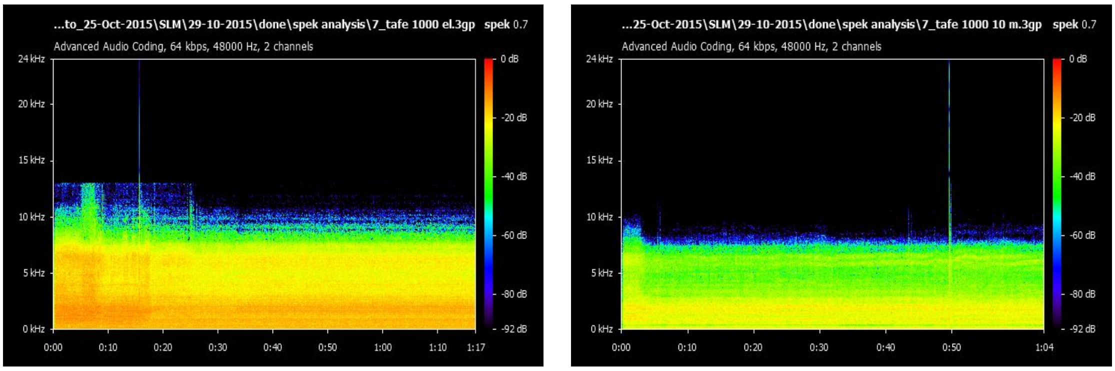
(a) at ear level (EL)

(b) at 10 m distance

Under muffler-S, mainly four out of eight frequency ranges under different engine speeds demonstrated various amplitude percent levels as recorded at two different locations i.e. ear level & 10 m distance.

4.6.2.3.3 Spectrograms of noise under muffler-C on tractor-2

The noise clip recorded with the help of a uniform device on tractor-2 after mounting muffler-C on tractor exhaust pipe is processed to generate the spectrogram by using a spectrum analyzer called SPEK at different engine speeds which are presented in Fig. 4.89 to Fig. 4.93.

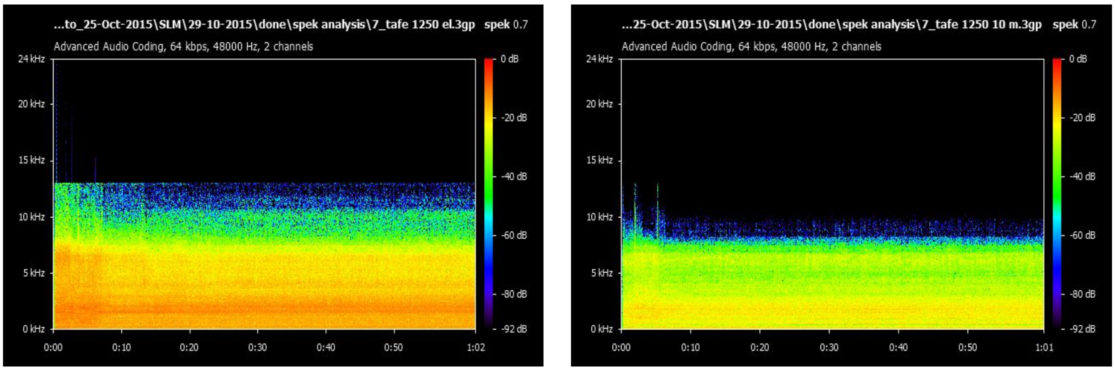


(a) (b)

Fig. 4.89: Spectrogram of noise clips recorded at 1000 RPM under muffler-C on Tractor-2

(a) at ear level (EL)

(b) at 10 m distance

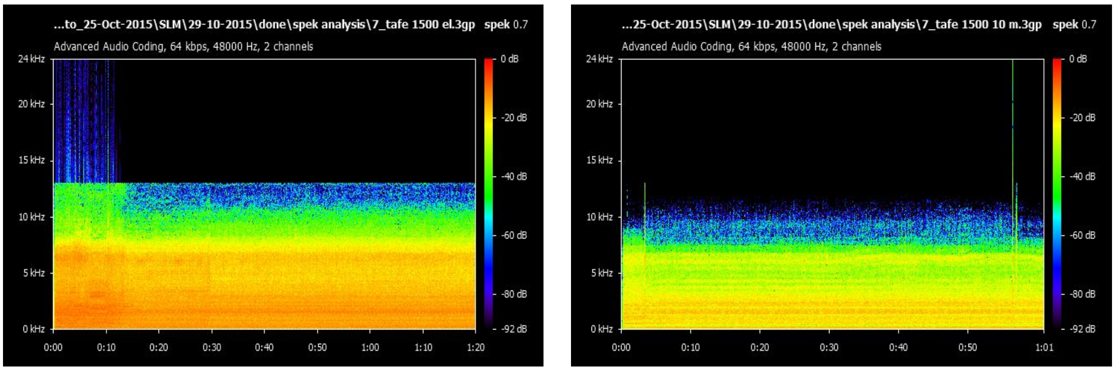


(a) (b)

Fig. 4.90: Spectrogram of noise clips recorded at 1250 RPM under muffler-C on Tractor-2

(a) at ear level (EL)

(b) at 10 m distance

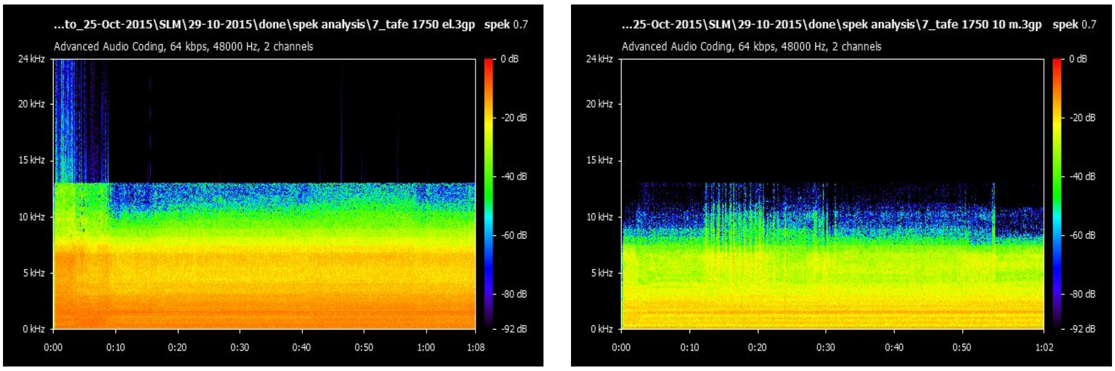


(a) (b)

Fig. 4.91: Spectrogram of noise clips recorded at 1500 RPM under muffler-C on Tractor-2

(a) at ear level (EL)

(b) at 10 m distance

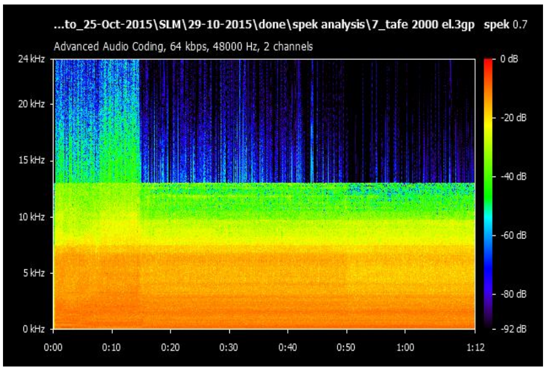


(a) (b)

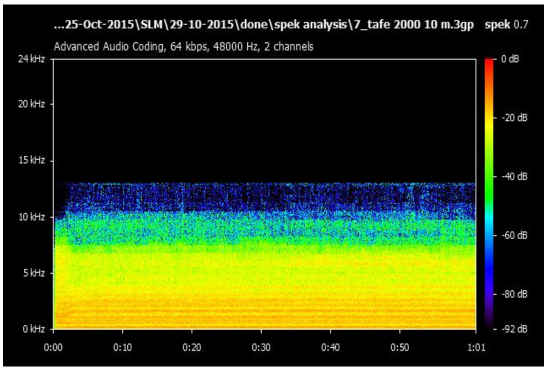
Fig. 4.92: Spectrogram of noise clips recorded at 1750 RPM under muffler-C on Tractor-2

(a) at ear level (EL)

(b) at 10 m distance



(a)



(b)

Fig. 4.93: Spectrogram of noise clips recorded at 2000 RPM under muffler-C on Tractor-2

(a) at ear level (EL)

(b) at 10 m distance

Under muffler-C on tractor-2, eight specified frequency ranges under different engine speeds has different level of percent amplitudes at two locations viz. ear level & 10 m distance.

4.6.2.4 Amplitudes of tractor noise frequencies on tractor-2

Manually observed decibel levels and their respective amplitude ratio values of certain frequency ranges based on these graphs are presented in the following tables along with their respective percent level of amplitudes. Mainly four out of eight frequency ranges under different engine speeds demonstrated varying properties of the noise in terms of their proportional amounts as recorded at two different locations viz. ear level & 10 m distance under different muffler conditions.

The proportional amounts in terms of percent amplitudes of the specified frequency ranges recorded under different muffler installations and under different engine speeds at two places are presented in the following tables (Table 4.43 to Table 4.52).

Table 4.43: Percent amplitudes corresponding to different frequency ranges under different mufflers at 1000 RPM on Tractor-2 at ear level

Frequency Range (kHz)	No Muffler	Standard Muffler	Muffler-C
0.0 – 2.5	43.3	50.5	41.2
2.5 – 5.0	24.3	28.4	30.9
5.0 – 7.5	24.3	15.9	27.5
7.5 – 10.0	7.7	5.1	0.4
10.0 – 12.5	0.4	0.1	0
12.5 – 15.0	0.0	0.0	0
15.0 – 17.5	0.0	0.0	0
17.5 – 20.0	0.0	0.0	0

Table 4.44: Percent amplitudes corresponding to different frequency ranges under different mufflers at 1250 RPM on Tractor-2 at ear level

Frequency Range (kHz)	No Muffler	Standard Muffler	Muffler-C
0.0 – 2.5	44.3	44.9	39.8
2.5 – 5.0	18.7	25.3	29.9
5.0 – 7.5	33.3	25.3	29.9

7.5 – 10.0	3.3	4.5	0.4
10.0 – 12.5	0.3	0.1	0
12.5 – 15.0	0.0	0.0	0
15.0 – 17.5	0.0	0.0	0
17.5 – 20.0	0.0	0.0	0

Table 4.45: Percent amplitudes corresponding to different frequency ranges under different mufflers at 1500 RPM on Tractor-2 at ear level

Frequency Range (kHz)	**No Muffler**	**Standard Muffler**	**Muffler-C**
0.0 – 2.5	33.0	44.9	39.3
2.5 – 5.0	18.6	25.3	29.5
5.0 – 7.5	33.0	25.3	29.5
7.5 – 10.0	10.4	4.5	1.2
10.0 – 12.5	3.3	0.0	0.4
12.5 – 15.0	1.0	0.0	0
15.0 – 17.5	0.3	0.0	0
17.5 – 20.0	0.3	0.0	0

Table 4.46: Percent amplitudes corresponding to different frequency ranges under different mufflers at 1750 RPM on Tractor-2 at ear level

Frequency Range (kHz)	No Muffler	Standard Muffler	Muffler-C
0.0 – 2.5	26.8	38.3	38.3
2.5 – 5.0	20.2	28.7	28.7
5.0 – 7.5	26.8	28.7	28.7
7.5 – 10.0	20.2	3.8	3.8
10.0 – 12.5	3.6	0.4	0.4
12.5 – 15.0	1.1	0.0	0
15.0 – 17.5	0.6	0.0	0
17.5 – 20.0	0.6	0.0	0

Table 4.47: Percent amplitudes corresponding to different frequency ranges under different mufflers at 2000 RPM on Tractor-2 at ear level

Frequency Range (kHz)	No Muffler	Standard Muffler	Muffler-C
0.0 – 2.5	33.5	38.3	35.1
2.5 – 5.0	10.6	28.7	26.3
5.0 – 7.5	33.5	28.7	26.3

7.5 – 10.0	10.6	3.8	11.1
10.0 – 12.5	4.5	0.4	1.1
12.5 – 15.0	1.9	0.0	0
15.0 – 17.5	1.9	0.0	0
17.5 – 20.0	3.4	0.0	0

Percent amplitudes corresponding to different frequency ranges under different mufflers at different RPM on Tractor-2 at ear level (Table 4.43 to Table 4.47) revealed the following outcomes.

(i) At 1000 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (43.3%) were increased by 7.2% & reduced by 2.1% under standard muffler (50.5%) & muffler-C (41.2%) respectively. Percent amplitudes of 2.5-5.0 kHz frequencies were found higher (30.9%) under muffler-C.

(ii) At 1250 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (44.3%) were increased by 0.6% & reduced by 4.5% under standard muffler (44.9%) & muffler-C (39.8%) respectively. Percent amplitudes of 5-7.5 kHz frequencies were found higher (33.3%) under no muffler mounting.

(iii) At 1500 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (33.0%) were increased by 11.9 & 6.3 % under standard muffler (44.9%) & muffler-C (39.3%) respectively. Percent amplitudes of 5.0-7.5 kHz frequencies found higher (33.0%) under no muffler mounting.

(iv) At 1750 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (26.8%) increased by 11.5% under standard muffler & muffler-C both (38.3%) respectively. Percent amplitudes of 5-7.5 kHz frequencies were found higher (26.8%) under no muffler. Further, 7.5-10.0 frequencies appeared in significant amplitude levels (20.2%) under no muffler.

(v) At 2000 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (33.5%) increased by 4.8 & 1.6 % under standard muffler (38.3%) & muffler-C (35.1%) respectively. Percent amplitudes of 5.0-7.5 kHz frequencies found higher (33.5%) under no muffler. Further, 7.5-10.0 kHz frequencies appeared 10.6, 3.8 & 11.1% amount of percent amplitudes under no muffler, muffler-S & muffler-C respectively.

Table 4.48: Percent amplitudes corresponding to different frequency ranges under different mufflers at 1000 RPM on Tractor-2 at 10 m

Frequency Range (kHz)	**No Muffler**	**Standard Muffler**	**Muffler-C**
0.0 – 2.5	56.5	61.2	61.1
2.5 – 5.0	23.7	19.4	19.3
5.0 – 7.5	17.9	19.3	19.3
7.5 – 10.0	1.8	0.1	0.2
10.0 – 12.5	0.0	0.0	0
12.5 – 15.0	0.0	0.0	0
15.0 – 17.5	0.0	0.0	0
17.5 – 20.0	0.0	0.0	0

Table 4.49: Percent amplitudes corresponding to different frequency ranges under different mufflers at 1250 RPM on Tractor-2 at 10 m

Frequency Range (kHz)	**No Muffler**	**Standard Muffler**	**Muffler-C**
0.0 – 2.5	50.6	60.6	47
2.5 – 5.0	28.3	19.1	26.3
5.0 – 7.5	16.0	19.1	26.3
7.5 – 10.0	5.1	1.1	0.3
10.0 – 12.5	0.1	0.1	0
12.5 – 15.0	0.0	0.0	0
15.0 – 17.5	0.0	0.0	0
17.5 – 20.0	0.0	0.0	0

Table 4.50: Percent amplitudes corresponding to different frequency ranges under different mufflers at 1500 RPM on Tractor-2 at 10 m

Frequency Range (kHz)	**No Muffler**	**Standard Muffler**	**Muffler-C**
0.0 – 2.5	35.8	57.0	49.4
2.5 – 5.0	35.8	21.4	24.7
5.0 – 7.5	20.1	21.4	24.7

7.5 – 10.0	6.4	0.1	1.2
10.0 – 12.5	2.0	0.0	0
12.5 – 15.0	0.0	0.0	0
15.0 – 17.5	0.0	0.0	0
17.5 – 20.0	0.0	0.0	0

Table 4.51: Percent amplitudes corresponding to different frequency ranges under different mufflers at 1750 RPM on Tractor-2 at 10 m

Frequency Range (kHz)	**No Muffler**	**Standard Muffler**	**Muffler-C**
0.0 – 2.5	39.1	54.1	39.3
2.5 – 5.0	29.3	22.8	29.5
5.0 – 7.5	29.3	22.8	29.5
7.5 – 10.0	1.7	0.3	1.6
10.0 – 12.5	0.5	0.0	0
12.5 – 15.0	0.0	0.0	0
15.0 – 17.5	0.0	0.0	0
17.5 – 20.0	0.0	0.0	0

Table 4.52: Percent amplitudes corresponding to different frequency ranges under different mufflers at 2000 RPM on Tractor-2 at 10 m

Frequency Range (kHz)	No Muffler	Standard Muffler	Muffler-C
0.0 – 2.5	27.8	48.9	39.6
2.5 – 5.0	27.8	20.7	29.7
5.0 – 7.5	37.1	27.6	29.7
7.5 – 10.0	6.6	2.8	0.9
10.0 – 12.5	0.7	0.0	0
12.5 – 15.0	0.0	0.0	0
15.0 – 17.5	0.0	0.0	0
17.5 – 20.0	0.0	0.0	0

Percent amplitudes corresponding to different frequency ranges under different mufflers at different RPM on Tractor-2 at 10 m distance (Table 4.48 to 4.52) revealed the following outcomes.

(i) At 1000 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (56.5%) were increased by 4.7 & 4.6 % under standard muffler (61.2%) & muffler-C (61.1%) respectively. Percent amplitudes of 2.5-5.0 kHz frequencies were found little higher (23.7%) under no muffler.

(ii) At 1250 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (50.6%) were increased by 10.0% & reduced by 3.6% under standard muffler (60.6%) & muffler-C (47.0%) respectively. Percent amplitudes of 2.5-5.0 kHz frequencies were found little higher (28.3%) under no muffler.

(iii) At 1500 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (35.8%) were increased by 21.2 & 13.6 % under standard muffler (57.0%) & muffler-C (49.4%) respectively. Percent amplitudes of 2.5-5.0 were found higher (35.8%) under no muffler.

(iv) At 1750 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (39.1%) increased by 15 & 0.2% under standard muffler (54.1%) & muffler-C (39.3%) respectively.

(v) At 2000 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (27.8%) increased by 21.1 & 11.8 % under standard muffler (48.9%) & muffler-C (39.6%) respectively. Percent amplitudes of 5.0-7.5 kHz frequencies found in highest amount of percent amplitudes under no muffler (37.1%). Frequencies 7.5-10.0 kHz also appeared under no muffler mounting (6.6%).

Chapter-5

SUMMARY AND CONCLUSIONS

Under the process of mechanization of Indian agriculture, tractor has remained at fore-front among all mechanical equipments being used on farm. With becoming agricultural mechanization a common part of life, society has been facing both positive and negative outcomes or effects arised out of that. Noisy environment has been one of those threats which have emerged out of modern life styles in urban and rural areas with higher and lesser intensities respectively. Tractors dominate rural areas most. While ploughing or harvesting in fields or transporting on roads, tractors operate for long hours and generate high level of noises that make an impact on the operators and the neighbourhood. It has now been established that exceeded noise levels cause negative impacts resulting into the mental tiredness and lesser working efficiency. Noise exceeding the certain limits can even cause permanent damage to hearing ability of human beings.

Tractor noise is composed of mainly two kinds of noises (i) noise due to machinery motions & vibrations and (ii) noise created during fuel combustion due to the repeating explosions taking place into the cylinders that is delivered out through exhaust that is termed as exhaust noise. The study is mainly aimed at investigating the performance of exhaust mufflers influenced by alteration in the design of internal configuration. The experimental details and important outcomes are summarized in the following sections (section 5.1 to 5.12) and major conclusions are cited in section 5.13.

5.1 VIBRATION LEVEL MEASUREMENTS

Lutron make vibration meter Model VB-8201 was utilized for measurement of vibration levels in velocity (mm/s). The measurements were made in RMS values. The X-axis vibrations were measured in the forward direction of motion, while Y & Z–axis measurements are made in lateral direction (perpendicular to the direction of motion) & vertical direction respectively. The vibration levels were observed on Tractor-1 and Tractor-2 at different engine speeds on different surfaces of tractor / tractor components viz. tractor bonnet, front axle and foot rest. The vibration measurements were made velocity (mm/s) and acceleration (m/s^2). Tests were conducted at three different engine speeds (1000, 1500 & 2000 RPM) of the tractor. Experience has shown that the overall RMS value of vibration velocity gives the better indication of a vibration's severity (Anonymous 1982). A probable explanation is that a given velocity level corresponds to a given energy level so that vibration at low and high frequencies are equally weighted from a vibration energy point of view.

Most modern vibration meters are equipped to measure all three parameters viz. displacement, velocity and acceleration. Because acceleration measurements are weighted towards high frequency vibration components, these parameters tend to be used where the frequency range of interest covers high frequencies. Mechanical systems tend to have much of their vibration energy contained in the relatively narrow frequency range between 10 Hz to 1000 Hz but measurements are often made up to say 10 kHz because there are often interesting vibration components at these higher frequencies.

5.2 MINI TRACTOR VIBRATIONS

The vibration analysis conducted on mini sized tractor (Tractor-1) revealed that normally vibration velocities and accelerations both increased with increase in the engine speed of the tractor in stationery mode. This was true for engine speed rise from 1000 RPM to 1500 RPM for front axle and bonnet surface vibrations with certain exception in the foot rest vibrations. But inverse relationship was observed many a times during engine speed rise from 1500 RPM to 2000 RPM. Vibration velocity at 1500 RPM on front axle of tractor-1 were 136.4 mm/s in longitudinal (X) direction, 44.2 mm/s in lateral (Y) direction and 101.2 mm/s in vertical (Z) direction which reduced to 121.5 mm/s, 27.7 mm/s and 90.2 mm/s respectively when engine speed was increased to 2000 RPM (see Table 4.3). Similarly, bonnet vibration velocities were 68.4, 66.6 and 68.9 mm/s in X, Y and Z directions respectively at 1500 RPM which reduced to 55.1, 43.8 and 50.6 mm/s respectively when tractor engine was operated at 2000 RPM. However it was noticeable that foot rest vibration velocities increased sharply with increase in the engine speed from 1500 to 2000 RPM. Though longitudinal (X) and vertical (Z) vibration velocities on foot rest reduced during speed rise from 1000 to 1500 RPM (Table 4.3). Also, accelerations (m/s^2) on front axle and bonnet increased with engine speed rise from 1000 to 1500

RPM with some exception in case of foot rest vibrations. During speed rise from 1500 to 2000 RPM, (i) front axle acceleration (m/s^2) reduced from 14.0 m/s^2 at 1500 RPM to 13.3 m/s^2 at 2000 RPM in vertical (Z) direction, (ii) bonnet acceleration (m/s^2) reduced from 23.1 m/s^2 at 1500 RPM to 21.0 m/s^2 at 2000 RPM in longitudinal (X) direction and from 22.4 m/s^2 at 1500 RPM to 18.6 m/s^2 at 2000 RPM in lateral (Y) direction. Foot rest accelerations, during engine speed increase from 1500 to 2000 RPM range, sharply increased with increase in speed.

The vibration characteristics of Tractor-1 (mini tractor) in terms of velocity and acceleration are summarized in the following table (Table 5.1).

Table 5.1: Vibration characteristics of Tractor-1 (Mini Tractor)

Particulars	**Velocity Character**	**Acceleration Character**
Rise in engine speed from 1000 to 1500 RPM	Front axle and bonnet vibrations increased in X, Y & Z directions. Foot rest vibration increased in Y direction. Foot rest vibrations decreased in X & Z directions.	Front axle annd bonnet vibrations increased in X, Y & Z directions. Foot rest vibration increased in Y direction. Foot rest vibrations decreased in X & Z directions.
Rise in engine speed from 1500 to 2000 RPM	Front axle and bonnet vibrations decreased in X, Y & Z directions. Foot rest vibrations increased in X, Y & Z	Front axle vibration decreased in Z direction and increased in X & Y directions. Bonnet vbrations decreased in X & Y directions and

	directions. Foot rest vibration increased in X, Y & Z direction.	increased in Z direction. Foot rest vibration increased in X, Y & Z direction.
Maximum vibration level in X direction	136.4 mm/s on front axle at 1500 RPM	23.5 m/s^2 on front axle at 2000 RPM
Maximum vibration level in Y direction	71.5 mm/s on foot rest at 2000 RPM	22.4 m/s^2 on bonnet at 1500 RPM
Maximum vibration level in Z direction	101.2 mm/s on front axle at 1500 RPM	23.7 m/s^2 on bonnet at 2000 RPM

It could be concluded that maximum velocity level in X & Z directions took place at 1500 RPM on front axle and maximum acceleration level in X & Z directions took place at 2000 RPM on front axle & bonnet respectively. While maximum velocity & acceleration level in Y direction respectively took place at 2000 & 1500 RPM on foot rest & bonnet of the tractors respectively.

5.3 MEDIUM TRACTOR VIBRATIONS

The vibration analysis conducted on medium sized tractor (Tractor-2) revealed that normally vibration velocities and accelerations both increased with increase in the engine speed of the tractor in stationery mode. This was quite true for engine speed rise from 1000 RPM to 1500 RPM for front axle, bonnet surface and foot rest surface vibrations with no exceptions in any case. However, during engine speed rise from 1500 RPM to 2000 RPM, vibration velocities increased with increase in the engine speed in each direction and on each part but acceleration values had certain exceptions viz. front axle acceleration in longitudinal (X) and vertical (Z) direction reduced from 9.9 and 21.0 m/s^2 at 1500 RPM to 9.7 and 18.5 m/s^2 at 2000 RPM respectively.

The vibration characteristics of Tractor-2 in terms of velocity and acceleration are summarized in the following table (Table 5.2).

Table 5.2: Vibration characteristics of Tractor-2

Particulars	**Velocity Character**	**Acceleration Character**
Rise in engine speed from 1000 to 1500 RPM	Front axle, bonnet & foot rest vibration levels increased in X, Y & Z directions.	Front axle, bonnet & foot rest vibration levels increased in X, Y & Z directions.
Rise in engine speed from 1500 to 2000 RPM	Front axle, bonnet & foot rest vibration levels increased in X, Y & Z directions.	Vibration levels increased with increase in engine speed on front axle, bonnet & foot rest vibrations with following exception. Vibration acceleration reduced with rise in engine speed on front axle in X (longitudinal) & Z (vertical) directions.
Maximum vibration level in X direction	81.8 mm/s on bonnet at 2000 RPM	32.4 m/s^2 on bonnet at 2000 RPM
Maximum vibration level in Y direction	89.3 mm/s on front axle at 2000 RPM	20.6 m/s^2 on front axle & foot rest at 2000 RPM
Maximum vibration level in Z direction	82.3 mm/s on front axle at 2000 RPM	21.8 m/s^2 on bonnet at 2000 RPM

Thus, maximum accelerations in X, Y & Z directions on each part of the tractor took place at 2000 RPM only.

5.4 RECORDING OF SOUND PRESSURE LEVELS (SPL)

Digital sound level meter SL 4001 of IEC 61672 Class 2 type was utilized during experimentation for measuring the noise levels during farm tractor operation. Measurements have been made in A-weighting as it is said to be the best fit for the frequency response of the human ear. Due to the use of A-weighting scale in the study, unit of dB is denoted by dB(A) or dBA. Further, noise levels measured in dBA were also converted into equivalent micro-pascal quantities to describe the level of sound pressures generated which provided a different perspective to view at the noise levels and compare their pressure intensities.

5.5 ASSOCIATION BETWEEN NOISE LEVELS AND TRACTOR VIBRATIONS

The noise and vibration levels observed over different engine speeds of Tractor-1 & Tractor-2 revealed significant association between the two. Noise levels of Tractor-1 (mini tractor) in terms of respective longitudinal (X) vibration velocity levels (mm/s) could be expressed by linear equation $y = 0.2156x + 67.428$ with R^2 value of 0.9333. Similarly noise levels of Tractor-1 in terms of respective lateral (Y) & vertical (Z) vibration velocity levels could be expressed by linear equation $y = 0.2045x + 74.384$ & $y = 0.1539x + 74.608$ with R^2 value of 0.731 & 0.8597 respectively. Noise levels of Tractor-1 (mini tractor) in terms of respective longitudinal (X) vibration acceleration levels (m/s^2) could be expressed by linear equation $y = 0.9012x + 67.172$ with R^2 value of 0.9783. Similarly noise levels of Tractor-1 in terms of respective lateral (Y) & vertical (Z) vibration acceleration levels could be expressed by linear equation $y = 1.1404x + 67.528$ & $y = 0.9071x + 69.913$ with R^2 value of 0.0.9102 & 0.9999 respectively. Hence, in case of mini sized tractor (Tractor-1), vibration accelerations had more association with the resulting noise levels than the vibration velocities in different directions.

Noise levels of Tractor-2 in terms of respective longitudinal (X) vibration velocity levels (mm/s) could be expressed by linear equation $y = 0.1989x + 78.177$

with R^2 value of 0.9854. Similarly noise levels of Tractor-2 in terms of respective lateral (Y) & vertical (Z) vibration velocity levels could be expressed by linear equation y = 0.1668x + 78.328 & y = 0.1447x + 79.457 with R^2 value of 0.9992 & 0.9853 respectively. Noise levels of Tractor-2 in terms of respective longitudinal (X) vibration acceleration levels (m/s^2) could be expressed by linear equation y = 1.1115x + 65.441 with R^2 value of 0.8936. Similarly noise levels of Tractor-2 in terms of respective lateral (Y) & vertical (Z) vibration acceleration levels could be expressed by linear equation y = 1.3618x + 66.475 & y = 1.1533x + 68.334 with R^2 value of 0.0.7796 & 0.9705 respectively. Hence, in case of medium/big sized tractor (Tractor-2), vibration velocities had more association with the resulting noise levels than the vibration accelerations in different directions.

5.6 NOISE LEVEL OBSERVATIONS UNDER DIFFERENT MUFFLERS ON TRACTOR-1 & TRACTOR-2

The preliminary tests of SPL measurements were conducted on ten muffler prototypes made of different internal configurations. Each muffler was mounted on both tractors under test one by one and noise level measurements were made at two places on five engine speeds. The places of sound recording were: (i) at ear level (about 1 m away from engine exhaust) and (ii) 10 m away from the tractor. Sound level meter SL-4001 was used for recording of sound levels in dBA units.

Muffler-3 and muffler-7 (later renamed as **muffler-A** & **muffler-C** respectively) were selected for further experimentation on Tractor-1 (Mini Tractor) based on their performance. At 1500 RPM, Tractor-1 (mini tractor) produced lowest noise level (82.1 dBA) under muffler-3 at ear level among all mufflers under preliminary test. At 2000 RPM, Tractor-1 produced lowest among all level of noise (85.5 dBA) at ear level under muffler-7. Muffler-7 also emanated lowest level of noise among all mufflers under test at 10 m away from tractor at 2000 RPM. Hence, **muffler-A** (muffler-3) & **muffler-C** (muffler-7) were found more promising for further detailed experimentation on **Tractor-1** along with standard (company fitted) muffler.

Muffler-4 and muffler-7 (later renamed as **muffler-B** & **muffler-C** respectively) were selected for further experimentation on Tractor-2 based on their performance. At 1000 RPM, Tractor-2 produced lowest noise level (76.6 dBA) under muffler-7 at ear level among all mufflers under preliminary test. At 2000 RPM, Tractor-2 produced 88.6 dBA at ear level under muffler-4 which was lowest level of noise among all mufflers under preliminary test. At 10 m distance away from tractor, at 1500 & 2000 RPM, Tractor-2 produced lowest noise level under muffler-4 & muffler-7 (70.1 & 74.8 dBA respectively) among all mufflers under test. Hence, **muffler-B** (muffler-4) & **muffler-C** (muffler-7) were found more promising for further detailed experimentation on **Tractor-2** along with standard (company fitted) muffler.

Further averaging of the noise levels found during preliminary tests provided supplementary information for selection of mufflers (muffler-A & muffler-C for Tractor-1 and muffler-A & muffler-C for Tractor-2). At ear level, minimum average noise level (82.0 dBA) has been found under muffler-A on Tractor-1 (Mini Tractor) and minimum average noise level (82.8 dBA) has been found under muffler-B on Tractor-2. At 10 m distance from the tractor (exhaust noise source), minimum average noise level (67.0 dBA) has been found under standard muffler on Tractor-1 (Mini Tractor) and minimum average noise level (69.8 dBA) has been found under muffler-C on Tractor-2. Muffler-A & muffler-C were selected for detailed noise level test on Tractor-1 (Mini Tractor) while muffler-B & muffler-C were selected for Tractor-2. Muffler-C, having been found noise attenuating on Tractor-1 (Mini Tractor) and Tractor-2 both, it has been selected as common muffler for mounting on Tractor-1 & Tractor-2 both for further detailed noise level comparison with standard muffler mounting. The selected mufflers viz. muffler-A, muffler-B & muffler-C were further experimented for in-depth analysis of noise attenuation capability of the selected mufflers at given places of noise level measurement.

5.7 CONSTRUCTIONAL PARAMETERS OF SELECTED MUFFLERS UNDER TEST

The outer dimensions of all muffler variables were kept uniform. Length of circularly cross-sectional casing of the muffler was kept 40 cm with outer & inner diameter of 8.85 & 8.25 cm respectively. The thickness of M.S. pipe used for resonating chamber was 2 mm. Diameter of primary perforated pipe was also uniform (4.65 cm). Number of primary perforations were 28 in each muffler under test. Size of perforations were 6 mm in size (dia.). The variable construction parameters were measured and recorded (Table 4.17). The internal configurations of the muffler-A, B & C are presented in Fig. 4.22, 4.23 & 4.24 respectively.

Muffler-A had two splitters with perforated plates fitted facing one another. Thus expansion chambers were three in numbers. Muffler-B also consisted of two splitters, one secondary perforated smaller sized pipe and three expansion chambers. However, muffler-C was made up of single expansion chamber with one splitter provided to facilitate the flow of gases in second compartment for further exit to the outside environment.

5.8 INFLUENCE OF MUFFLER & ENGINE SPEED ON NOISE LEVELS OF TRACTOR-1 AND TRACTOR-2

The Split-Plot Design was used to statistically analyze the influence of muffler alterations and different engine speeds on the noise levels generated by Tractor-1 (Mini Tractor) and Tractor-2. Muffler types were treated as main treatments with different engine speed levels as sub treatments. The three mufflers viz. M1, M2 and M3 for Tractor-1 respectively referred to (i) Muffler-S, (ii) Muffler-A and (iii) Muffler-C. The three mufflers viz. M1, M2 and M3 for Tractor-2 respectively referred to (i) Muffler-S, (ii) Muffler-B and (iii) Muffler-C. The engine speed levels S1, S2, S3, S4 and S5 respectively represented tractor engine speeds of 1000, 1250, 1500, 1750 and 2000 RPM. Application of Split-Plot Design to the noise levels recorded at ear level and at 10 m distance under specified muffler conditions & engine speeds revealed useful information.

From output obtained from Split Plot Design of the experiment, it was concluded that at ear level on Tractor-1 (15 hp mini tractor), the mean noise level observed under muffler-C (82.95 dBA) was significantly lower than that recorded under muffler-S (83.09 dBA) but was not significantly different when compared with noise level obtained under muffler-A (83.04). Further the difference between noise levels of muffler-C & muffler-A was also found significant. The noise levels observed under different engine speeds of Tractor-1 (15 hp mini tractor) revealed significant increment in SPL at each & every increment of 250 RPM in the engine speed.

At ear level on Tractor-2 (60 hp), the noise levels observed under muffler-B (84.52 dBA) & muffler-C (84.46 dBA) both were significantly lower than that recorded under muffler-S (84.90 dBA). However, the difference in the noise levels under muffler-B & muffler-C was insignificant. The noise levels observed under different engine speeds of Tractor-2 (60 hp) revealed significant increment in SPL at each & every increment of 250 RPM in the engine speed.

For noise levels measured at 10 m distance away from Tractor-1 (15 hp mini tractor), it was concluded that the noise levels observed under muffler-A (67.44 dBA) & muffler-C (67.43 dBA) both were significantly lower than that recorded under muffler-S (68.09 dBA). However, no significant difference was observed between noise levels of muffler-A & muffler-C. The noise levels observed under different engine speeds of Tractor-1 (15 hp mini tractor) revealed significant increment in SPL at each & every increment of 250 RPM in the engine speed.

At 10 m distance away from Tractor-2 (60 hp), the noise levels observed under muffler-B (71.53 dBA) & muffler-C (71.90 dBA) both were significantly lower than that recorded under muffler-S (72.61 dBA). Further, the difference between noise levels under muffler-B & muffler-C was also significant i.e. Noise level observed under muffler-B was significantly lower than that observed under muffler-C on Tractor-2 at 10 m distance away from the tractor. The noise levels observed under different engine speeds of Tractor-2 (60 hp) revealed significant increment in SPL at each & every increment of 250 RPM in the engine speed.

For the noise levels measured at 30 m distance away from Tractor-1 (15 hp mini tractor), it was concluded that the noise levels observed under muffler-A (60.27 dBA) & muffler-C (59.92 dBA) both were significantly lower than that recorded under muffler-S (60.51 dBA). Further, the difference between noise levels under muffler-A & muffler-C was also significant i.e. Noise level observed under muffler-C was significantly lower than that observed under muffler-A on Tractor-1 at 30 m distance away from the tractor. The noise levels observed under different engine speeds of Tractor-1 (15 hp mini tractor) revealed significant increment in SPL at each & every increment of 250 RPM in the engine speed.

The difference between noise levels under muffler-B & muffler-C at 10 m distance away from Tractor-2 (60 hp) was however insignificant, the noise levels observed under muffler-B (62.72 dBA) & muffler-C (62.70 dBA) both were significantly lower than that of under muffler-S (62.89 dBA). The noise levels observed under different engine speeds of Tractor-2 (60 hp) revealed significant increment in SPL at each & every increment of 250 RPM in the engine speed.

5.9 NOISE ATTENUATION PERFORMANCE OF SELECTED MUFFLERS ON TRACTOR-1 (MINI TRACTOR)

Mean SPLs (dBA) obtained under varied engine speeds by selected muffler installations on Tractor-1 at ear level under field condition revealed lowest mean noise level generation (82.9 dBA) under muffler-C. Mean SPLs (dBA) obtained under varied engine speeds by selected muffler installations on Tractor-1 at 10 m distance under field condition revealed lowest mean noise level generation (67.4 dBA) under muffler-A & C. Mean SPLs (dBA) obtained under varied engine speeds by selected muffler installations on Tractor-1 at 30 m distance away from the tractor revealed lowest mean noise level generation (59.9 dBA) under muffler-C.

Noise attenuation produced by specified muffler mountings (Table 4.42) revealed maximum attenuation ability by muffler-C (3.3%), muffler-A & C (2.9%) & muffler-C (3.4%) at ear level, 10 m & 30 m distance respectively. When noise levels measured in dBA were converted into µPa (Table 4.43), muffler-C found to have produced maximum noise attenuation ability of 27.6% at ear level. At 10 m distance, the maximum noise attenuation (in terms of percent of µPa) was performed by muffler-A & C in equal amount (20.6%). At 30 m distance, the maximum noise attenuation (in terms of µPa) was obtained by muffler-C (21.5%).

From comparison of performances by selected mufflers, it was concluded that **muffler-C** exhibited highest level of noise attenuation on Tractor-1 i.e. mini tractor.

5.10 NOISE ATTENUATION PERFORMANCE OF SELECTED MUFFLERS ON TRACTOR-2

Mean SPLs (dBA) obtained under varied engine speeds by selected muffler installations on Tractor-2 at ear level under field condition revealed lowest mean noise level generation (84.5 dBA) under muffler-B & C. Mean SPLs (dBA) obtained under varied engine speeds by selected muffler installations on Tractor-2 at 10 m distance under field condition revealed lowest mean noise level generation (71.5 dBA) under muffler-B. Mean SPLs (dBA) obtained under varied engine speeds by selected muffler installations on Tractor-2 at 30 m distance away from the tractor revealed lowest mean noise level generation (62.7 dBA) under muffler-B & C.

Noise attenuation produced by specified muffler mountings (Table 4.44) revealed maximum attenuation ability by muffler-B & C (6.1%), muffler-B (5.3%) & muffler-B & C (4.9%) at ear level, 10 m & 30 m distance respectively. When noise levels measured in dBA were converted into µPa (Table 4.45), muffler-B & C were found to have produced maximum noise attenuation ability of 46.9% at ear level. At 10 m distance, the maximum noise attenuation (in terms of percent of µPa) was performed by muffler-B (36.9%). At 30 m distance, the maximum noise attenuation (in terms of µPa) was obtained by muffler-B & C in equal amount (30.8%).

From comparison of performances by selected mufflers, it was concluded that **muffler-B & muffler-C** both exhibited effective noise attenuation on Tractor-2.

5.11 FREQUENCIES OF TRACTOR NOISE (TRACTOR-1 & TRACTOR-2)

The frequency spectrum and the true spectrum (spectrogram) were obtained for the sounds of the noise recordings by suitable software applications namely Spectrumview and Spek respectively. The peak frequency observations could be collected from inputting the .wav formated sound clips of the tractor noise.

The analysis of mean peak frequency observations (Table 4.49) of tractor noise recorded at ear level at five different engine speeds on Tractor-1 (mini tractor) revealed lower mean peak frequency occurrences under muffler-C (542.1 Hz) than that obtained under standard muffler-S (701.8 Hz). The standard deviation and C.V. (%) for muffler-S and muffler-C were found 234.5 & 104.4 Hz and 33.4 & 19.3 percent respectively for Tractor-1 (Table 4.50).

The analysis of mean peak frequency observations of tractor noise recorded at 10 m distance away on Tractor-1 revealed lower mean peak frequency occurrences under muffler-C (581.1 Hz) than that obtained under muffler-S (727.1 Hz). The standard deviation and C.V. (%) for muffler-S and muffler-C were found 216.2 & 204.9 Hz and 29.7 & 35.3 percent respectively for Tractor-1.

The analysis of mean peak frequency observations of tractor noise recorded at ear level on Tractor-2 revealed lower mean peak frequency occurrences under muffler-S (971.6 Hz) than that obtained under muffler-C (1115.1 Hz). The standard deviation and C.V. (%) for muffler-S and muffler-C were found 162.7 & 158.3 Hz and 16.7 & 14.2 percent respectively for Tractor-2 (Table 4.84). The analysis of mean peak frequency observations of tractor noise recorded at 10 m distance away on Tractor-2 revealed lower mean peak frequency occurrences under muffler-C (606.3 Hz) than that obtained under standard muffler (940.6 Hz). The standard deviation and C.V. (%) for muffler-S and muffler-C were found 183.0 & 220.1 Hz and 19.5 & 36.3 percent respectively for Tractor-2 (Table 4.85).

5.12 AMPLITUDES OF TRACTOR NOISE FREQUENCIES (TRACTOR-1 & TRACTOR-2)

Percent amplitudes corresponding to different frequency ranges under different mufflers at different RPM at ear level on Tractor-1 (Mini Tractor) (Table 4.74 to Table 4.78) and on Tractor-2 (Table 4.110 to Table 4.114) revealed the following outcomes.

(i) At 1000 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (53.6%) were reduced on Tractor-1 by 9.1 & 12.3 % under standard muffler (44.5%) & muffler-C (41.3%) respectively while increment of 7.2% in amplitudes of 0-2.5 kHz frequencies was observed when no muffler (43.3%) was replaced by standard muffler (50.5%) on Tractor-2. Percent amplitudes of 5.0-7.5 & 2.5-5.0 kHz frequencies were found higher under muffler-C on Tractor-1 and Tractor-2 respectvely (41.3 & 30.9 respective percents).

(ii) At 1250 RPM, percent amplitudes of 5-7.5 kHz frequencies (higher frequencies) were found higher on Tractor-1 & Tractor-2 (38.6 & 33.3%) under standard muffler & no muffler respectively.

(iii) <u>At 1500 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting on Tractor-1 and Tractor-2 were increased by 2.2 & 1.9 % and 11.9 & 6.3 % under muffler-S & muffler-C respectively.</u>

(iv) <u>At 1750 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting on Tractor-1 and Tractor-2 increased by 7.6 & 3.1 % and 11.5% under muffler-S & muffler-C respectively.</u>

(v) At 2000 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting on Tractor-1 and Tractor-2 increased by 3.1 & 3.6 % and 4.8 & 1.6 % under muffler-S & muffler-C respectively.

Percent amplitudes corresponding to different frequency ranges under different mufflers at different RPM on Tractor-1 (Table 4.79 to 4.83) and Tractor-2 (Table 4.115 to 4.119) from the noise recorded at 10 m distance revealed the following outcomes.

(i) At 1000 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (83.0%) were reduced by 39.7 & 25.8 % under standard muffler (43.3%) & muffler-C (57.2%) respectively on Tractor-1 while at same RPM amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (56.5%) were increased by 4.7 & 4.6 % under standard muffler (61.2%) & muffler-C (61.1%) respectively on Tractor-2.

(ii) At 1250 RPM, percent amplitudes of 2.5-5.0 kHz frequencies were found higher (32.4%) under standard muffler on Tractor-1 and little higher (28.3%) under no muffler on Tractor-2.

(iii) At 1500 RPM, percent amplitudes of 2.5-5.0 were found higher under standard muffler on Tractor-1 and under no muffler on Tractor-2.

(iv) At 1750 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting decreased by 0.6% & increased by 22.9% under standard muffler & muffler-C respectively on Tractor-1 while increased by 15 & 0.2 % under standard muffler & muffler-C respectively on Tractor-2.

(v) At 2000 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting reduced by 7.4 & 11.0 % on Tractor-1 and increased by 21.1 & 11.8 % on Tractor-2 under muffler-S & muffler-C respectively.

5.13 CONCLUSIONS

The noise & vibration tests and their analysis conducted on Tractor-1 (mini tractor) and Tractor-2 revealed several important outcomes.

(i) During speed rise of tractor engine from 1000 to 1500 RPM, front axle, bonnet & foot rest vibrations of Tractor-1 & Tractor-2 (in terms of velocity & acceleration) increased in X, Y & Z directions with increase in the engine speed except reduction in the foot rest vibrations of Tractor-1 which took place in X & Z directions.

(ii) During speed rise of tractor engine from 1500 to 2000 RPM, front axle & bonnet vibrations (in terms of velocity) decreased in X, Y & Z directions on Tractor-1 while foot rest vibrations increased in X, Y & Z directions. However, accelerations showed deviation in the pattern in different directions in case of front axle & bonnet vibrations of Tractor-1 (mini tractor). Though, foot rest vibrations in terms of acceleration increased in X, Y & Z directions on Tractor-1 (mini tractor) as like velocity levels.

(iii) During speed rise of tractor engine from 1500 to 2000 RPM on Tractor-2, front axle, bonnet & foot rest vibration velocities & accelerations increased in X, Y & Z directions with increase in speed except reduction in accelerations on front axle in X & Z directions.

(iv) Maximum vibration velocity & acceleration in longitudinal direction (136.4 mm/s & 23.5 m/s^2 respectively) on Tractor-1 (mini tractor) were noticed on front axle while on Tractor-2, maximum vibration velocity & acceleration in longitudinal direction (81.8 mm/s & 32.4 m/s^2 respectively) were observed on bonnet of the tractor.

(v) Maximum vibration velocity & acceleration in vertical direction (101.2 mm/s & 23.7 m/s^2 respectively) on Tractor-1 (mini tractor) were noticed on front axle & bonnet respectively while on Tractor-2, maximum vibration velocity & acceleration in vertical direction (82.3 mm/s & 21.8 m/s^2 respectively) were observed on front axle & bonnet of the tractor respectively.

(vi) Maximum vibration velocity & accelerations (71.5 mm/s & 22.4 m/s^2 respectively) in lateral directions on Tractor-1 (mini tractor) took place on foot rest & bonnet respectively. While on Tractor-2, maximum vibration velocity & accelerations in lateral direction took place on front axle which was found 89.3 mm/s & 20.6 m/s^2 respectively.

(vii) Regression analysis of the noise & vibration parameters revealed quite a good extent of relationship between the two. The coefficient of determination (R^2) for the noise level expressions in terms of respective X, Y & Z direction vibration velocities on Tractor-1 (mini tractor) & Tractor-2 respectively ranged from 0.731 to 0.9333 & 0.9853 to 0.9992. The coefficient of determination (R^2) for the noise level expressions in terms of respective X, Y & Z direction vibration accelerations on Tractor-1 (mini tractor) & Tractor-2 respectively ranged from 0.9102 to 0.9999 & 0.7796 to 0.9705. Thus, noise levels (dBA) of Tractor-1 & Tractor-2 could better be expressed in terms of acceleration (m/s^2) & velocity (mm/s) respectively.

The analysis of noise levels observed under three muffler mountings on Tractor-1 (mini tractor) & Tractor-2 revealed significant effect of the internal muffler configurations. The noise levels (SPL in dBA) recorded at operator's ear level revealed following important outcomes.

(i) The mean noise level observed under muffler-C (82.95 dBA) on Tractor-1 (mini tractor) was significantly lower than that recorded under muffler-S (83.09 dBA) but was not significantly different when compared with noise level obtained under muffler-A (83.04). While, on Tractor-2, the noise levels observed under muffler-B (84.52 dBA) & muffler-C (84.46 dBA) both were significantly lower than that recorded under muffler-S (84.90 dBA).

(ii) The difference in noise levels of altered design mufflers on Tractor-1 (mini tractor) was found significant for muffler-A & C. But, difference in noise levels of altered design mufflers on Tractor-2 i.e. muffler-B & C was found insignificant.

(iii) The noise levels observed under different engine speeds of Tractor-1 (15 hp mini tractor) and Tractor-2 (60 hp tractor) both revealed significant increment in SPL at each & every increment of 250 RPM in the engine speed.

The noise levels (SPL in dBA) recorded at 10 m distance from the tractor revealed following important outcomes.

(iv) The mean noise level observed at 10 m distance away from Tractor-1 (15 hp mini tractor), the noise levels observed under muffler-A (67.44 dBA) &

muffler-C (67.43 dBA) both were significantly lower than that recorded under muffler-S (68.09 dBA). The mean noise levels observed at 10 m distance away from Tractor-2 (60 hp) under muffler-B (71.53 dBA) & muffler-C (71.90 dBA) both were significantly lower than that recorded under muffler-S (72.61 dBA).

(v) The difference in noise levels of altered design mufflers namely muffler-A & muffler-C on Tractor-1 (mini tractor) was not found significant. But, the noise level observed under muffler-B was significantly lower than that observed under muffler-C on Tractor-2 at 10 m distance away from the tractor.

(vi) The noise levels observed under different engine speeds of Tractor-1 (15 hp mini tractor) and Tractor-2 (60 hp tractor) both revealed significant increment in SPL at each & every increment of 250 RPM in the engine speed.

The noise levels (SPL in dBA) recorded at 30 m distance from the tractor revealed following important outcomes.

(vii) The mean noise level observed at 30 m distance away from Tractor-1 (15 hp mini tractor), the noise levels observed under muffler-A (60.27 dBA) & muffler-C (59.92 dBA) both were significantly lower than that recorded under muffler-S (60.51 dBA). The mean noise levels observed at 30 m distance away from Tractor-2 (60 hp) under muffler-B (62.72 dBA) & muffler-C (62.70 dBA) both were significantly lower than that recorded under muffler-S (62.89 dBA).

(viii) The difference in noise levels of altered design mufflers namely muffler-A & muffler-C on Tractor-1 (mini tractor) was found significant. Noise level observed under muffler-C was significantly lower than that observed under muffler-A on Tractor-1 at 30 m distance away from the tractor. But, the difference between noise levels under muffler-B & muffler-C in case of Tractor-2 was however insignificant.

(ix) The noise levels observed under different engine speeds of Tractor-1 (15 hp mini tractor) and Tractor-2 (60 hp tractor) both revealed significant increment in SPL at each & every increment of 250 RPM in the engine speed.

The noise attenuation performance of altered design mufflers was computed by deducting the noise level (SPL) recorded under the muffler from the noise levels generated without muffler mounting on Tractor-1 (mini tractor) and Tractor-2. The quantity of noise attenuation was then converted into percent noise attenuation.

The calculated noise attenuation in percent (%) under specific muffler mountings on Tractor-1 (mini tractor) & Tractor-2 both were compared and following conclusions were drawn.

(i) At operator's ear level, maximum noise attenuation of 3.3% could be achieved by mounting the altered design muffler-C on Tractor-1 (15 hp mini tractor). While on Tractor-2 (60 hp), maximum noise attenuation of 6.1% could be achieved by mounting the altered design muffler-B & C both. Hence, amount of noise attenuation produced by the same muffler (muffler-C) was greater on Tractor-2 than on Tractor-1 (mini tractor) at operator's ear level.

(ii) At 10 m distance away from the tractor, maximum noise attenuation of 2.9% could be achieved by mounting the altered design muffler-A & C both on Tractor-1 (15 hp mini tractor). While on Tractor-2 (60 hp), maximum noise attenuation of 5.3% could be achieved by mounting the altered design muffler-B.

(iii) At 30 m distance away from the tractor, maximum noise attenuation of 3.4% could be achieved by mounting the altered design muffler-C on Tractor-1 (15 hp mini tractor). While on Tractor-2 (60 hp), maximum noise attenuation of 4.9% could be achieved by mounting the altered design muffler-B & C both. Hence, amount of noise attenuation produced by the same muffler (muffler-C) was greater on Tractor-2 than on Tractor-1 (mini tractor) at 30 m distance away from the tractor.

Later, when decibel sound levels (dBA) were converted into micro pascal values, the amount of noise attenuation achieved in fact was found in greater amount than that anticipated by dBA unit of SPL measurement. The amount of noise attenuation in percent (%) under specific muffler mountings on Tractor-1 (mini tractor) & Tractor-2 were recalculated and following conclusions could be drawn.

(i) At operator's ear level, maximum noise attenuation of 27.6% could be achieved by mounting the altered design muffler-C on Tractor-1 (15 hp mini tractor). While on Tractor-2 (60 hp), maximum noise attenuation of 46.9% could be achieved by mounting the altered design muffler-B & C both. Hence, amount of noise attenuation produced by the same muffler (muffler-C) was greater on Tractor-2 than on Tractor-1 (mini tractor) at operator's ear level.

(ii) At 10 m distance away from the tractor, maximum noise attenuation of 20.6% could be achieved by mounting the altered design muffler-A & C both on Tractor-1 (15 hp mini tractor). While on Tractor-2 (60 hp), maximum noise attenuation of 36.9% could be achieved by mounting the altered design muffler-B.

(iii) At 30 m distance away from the tractor, maximum noise attenuation of 21.5% could be achieved by mounting the altered design muffler-C on Tractor-1 (15 hp mini tractor). While on Tractor-2 (60 hp), maximum noise attenuation of 30.8% could be achieved by mounting the altered design muffler-B & C both. Hence, amount of noise attenuation produced by the same muffler (muffler-C) was greater on Tractor-2 than on Tractor-1 (mini tractor) at 30 m distance away from the tractor.

The frequency and amplitude analysis of the noise clips recorded under three muffler mountings namely (i) No muffler mounting; (ii) Muffler-S; and (iii) Muffler-C on Tractor-1 (mini tractor) and Tractor-2 revealed specific kind of sound properties viz. peak frequency levels & percent level of frequency amplitudes. Based on analytical exercises, following conclusions could be drawn.

(i) Muffler-C mouting having alteration in the internal configuration design provided lower level of peak frequencies in the noise generated by Tractor-1 (mini tractor) at operator's ear level & at 10 m distance away from the tractor in comparison to muffler-S. Mean of the peak frequencies observed under muffler-C at ear level & at 10 m distance were found 542.1 & 581.1 Hz respectively which were lower than that observed under muffler-S with respective mean values of peak frequencies of 701.8 & 727.1 Hz.

The standard deviations observed in peak frequencies in the noise recorded at operator's ear level & at 10 m distance under muffler-C were 104.4 & 204.9 Hz respectively which were quite less than the respective standard deviations of 234.5 & 216.2 Hz as found under muffler-S on Tractor-1 (mini tractor).

(ii) Muffler-C mouting having alteration in the internal configuration design provided higher level of peak frequencies in the noise generated by Tractor-2 at operator's ear level but at 10 m distance, lower level of peak frequencies were observed under muffler-C in comparison to muffler-S. Mean of the peak frequencies observed under muffler-C at ear level & at 10 m distance were found 1115.1 & 606.3 Hz respectively with respective mean values of peak frequencies of 971.6 & 940.6 Hz under muffler-S.

The standard deviations observed in peak frequencies in the noise recorded at operator's ear level under muffler-C was 158.3 that was less than that observed under muffler-S which was 162.7 Hz. But, standard deviations observed in peak frequencies in the noise recorded at 10 m distance under muffler-C was 220.1 that was higher than that observed under muffler-S which was 183.0 Hz.

(iii) At 1500 RPM, amplitudes of 0-2.5 kHz frequencies were higher by 2.2 & 1.9 % under muffler-S & muffler-C respectively in comparison to that found under no muffler mounting on Tractor-1 (mini tractor) but on Tractor-2, amplitudes of 0-2.5 kHz frequencies were higher by 11.9 & 6.3 % under muffler-S & muffler-C respectively in comparison to that found under no muffler mounting.

(iv) At 1750 RPM, amplitudes of 0-2.5 kHz frequencies were higher by 7.6 & 3.1 % under muffler-S & muffler-C respectively in comparison to that found under no muffler mounting on Tractor-1 (mini tractor) but on Tractor-2, amplitudes of 0-2.5 kHz frequencies were higher by 11.5 % under muffler-S & muffler-C both in comparison to that found under no muffler mounting.

(v) At 2000 RPM, amplitudes of 0-2.5 kHz frequencies were higher by 3.1 & 3.6 % under muffler-S & muffler-C respectively in comparison to that found under no muffler mounting on Tractor-1 (mini tractor) but on Tractor-2, amplitudes of 0-2.5 kHz frequencies were higher by 4.8 & 1.6 % under muffler-S & muffler-C respectively in comparison to that found under no muffler mounting.

(vi) Increase in the proportional amount of lower frequencies (0-2.5 kHz) indicated reduction in the proportional amount of higher frequencies (>2.5 kHz) and thus considered beneficial outcome resulted from the concerned muffler.

At the end of study it was concluded on basis of the results that changes in the internal design of exhaust muffler configurations could make an impact of sigificant level on the SPL of noise generated from the tractor operation. Reduction in noise level by alteration in the design of exhaust muffler was found significant at all places of noise level measurements viz. operator's ear level, at 10 m distance and at 30 m distance with respective noise levels of 83.0, 67.4 & 59.9 dBA in case of mini tractor and 84.5, 71.9 & 62.7 dBA in case of bigger tractor under recommended muffler-C. Further, The noise levels observed under different engine speeds of Tractor-1 (15 hp mini tractor) and Tractor-2 (60 hp tractor) both revealed significant increment in SPL at each & every increment of 250 RPM in the engine speed under all muffler conditions. Noise measured consisted of exhaust noise and the noise of vibrations of different tractor parts. Mini tractor noise was comparatively more related with vibration acceleration levels with R^2 value upto 0.9999 for vertical (Z) vibrations while noise of bigger (medium sized) farm tractor was found more related with vibration velocity levels with R^2 value ranging upto 0.9992 for lateral (Y) vibrations. Effect of muffler design on the exhaust noise frequencies and corresponding amplitude levels has also been observed, however, more in-depth evaluation in that respect is still required. Peak frequency observations revealed better performance of muffler-C with lower frequency peaks (542.1 & 581.1 Hz at EL & at 10 m respectively) than standard muffler with frequency peaks of 701.8 & 727.1 Hz at EL & 10 m respectively in case of Tractor-1. In case of tractor-2, average of frequency peaks at EL & 10 m by muffler-C was lower (860.7 Hz) than that obtained by standard muffler (956.1 Hz).

SUGGESTIONS FOR FUTURE WORK

The study reported was conducted to measure and to analyze the existing noise levels of farm tractors operated at different engine speeds as affected by alteration in the design of exhaust mufflers as a low cost engineering intervention to study its effect on noise attenuation. Development of suitable sized cost economical muffler designs for increasing noise attenuation capability can be helpful in finding the cost effective solution that could be implemented in case of high noise exposure conditions utilising low cost materials particularly in cost sensitive rural farm-hold conditions of India. Still the level of noise attenuation as achieved during experimentation is not found that much effective which are normally obtained by application of HVAC. Therefore efforts must be made to further reduce the tractor noise levels to a greater extent by partial application of sound absorptive materials into the mufflers and by isolating the source of noise. Development of a low cost sound proof cabin may be useful to at least safeguard the tractor operator from the very high noise levels during field work.

REFERENCES

Anonymous, 1982. Measuring Vibration. Brűal & Kjær. Denmark.

Anonymous, 2000. National Standard for Occupational Noise [NOHSC: 1007(2000)]. 2nd Edition, National Occupational Health And Safety Commission, Australian Government, Canberra.

Anonymous, 2002a. Sound Attenuation. Silex. Available at www.silex.com/pdfs. (Accessed on 20-01-2014).

Anonymous, 2011. Occupational Safety And Health. Fifth India-EU Seminar on Employment and Social Policy held at New Delhi during September 19-20.

Anonymous, 2013a. How does a sound level meter work? Available at www.ehow.com/how-does_....html

Anonymous, 2013b. Live sound: Everything you wanted to know about SLMs. Available at http://www.prosoundweb.com/article/print/sound_level_meters_the_pr

Anonymous, 2013c. How to use a sound level meter. Available at www.ehow.com/how _5085290_use-sound-level-meter.html

Anonymous, 2013d. Noise Exposure - Permissible Level and Duration. The Engineering Tool Box. Available at: http://www.engineeringtoolbox.com/noise-exposure-level-duration-d_7... (Accessed on 16-07-2013).

Anonymous, 2013e. Available at: http://en.wikipedia.org/wiki/Vibration. (Downloaded in August-2013)

Anonymous, 2014a. Tractor & Construction Plant Wiki. Available at: http://tractors.wikia.com/wiki/Cab. Accessed on 02-08-2014 (dd-mm-yyyy).

Anonymous, 2013b. Available at: http://en.wikipedia.org/wiki/Vibration. (Downloaded in August-2013)

Anonymous, 2014a. Tractor & Construction Plant Wiki. Available at: http://tractors.wikia.com/wiki/Cab. Accessed on 02-08-2014 (dd-mm-yyyy).

Anonymous, 2015a. Flat Frequency Response in a Nutshell. Center Point Audio. Available at: http:// www.centerpointaudio.com. Accessed on 15/07/2015 (DD/MM/YYYY) at 1:50 PM.

Anonymous, 2015b. Plot Spectrum - Audacity Manual. Available at http://manual.audacityteam.org/o/man/plot_spectrum.html. Accessed on 22-07-2015 at 7.56 PM.

Anonymous, 2015c. Flat Frequency Response in a Nutshell. Center Point Audio. Available at: http:// www.centerpointaudio.com. Accessed on 15/07/2015 (DD/MM/YYYY) at 1:50 PM.

Anonymous, 2015d. Spectrum Analyzer -STUDIOTOOLZ – the best free audio & music prod... http://www.studiotoolz.net/audio-software/spectrum-analyzer/ 5/19/2015 5:07 PM.

Anonymous, 2015e. FFT (Fast Fourier Transform) Waveform Analysis. Available at: http://www.dataq.com/blog/analysis-software/fft-fast-fourier-transform. Accessed on 16/07/2015 at 6:09 PM.

Anonymous, 2015f. Plot Spectrum - Audacity Manual. Available at http:// manual.audacityteam.org /o/ man /plot_spectrum.html. Accessed on on 22/07/2015 at 7.56 PM and on 27/08/2015 at 1:13 PM.

Anonymous, 2015g. Histogram. Available at https://processing.org /examples /histogram.html. Accessed on 19/10/2015 at 04.18 PM.

Anonymous, 2015h. Audio Spectrum Analyzer - Free download. Help section. Accessed on 19/05/2015 (dd/mm/yyyy) at 5:42 PM. (http://download.cnet.com/ audio-spectrum-analyzer).

Anonymous, 2016. http:// www.rapidtables.com/ electric/ decibel.htm# Decibel_ Calculator.

Anonymous, 2016a. https:// www.osha.gov/ dts/ osta/ otm/ new_noise/ #decibles.

Anonymous, 2016b. https://explorable.com/print/two-way-anova.

Anonymous, 2016c. https://people.richland.edu/james/lecture/ m170/ ch13-2wy.htm

Antony, W.S. and Laird, J.W., 1994. Noise in cotton gins. Cotton Ginners Handbook, Agricultural Research Handbook No. 503. USDA: 279-286.

Arude, V.G. and Paralikar, K.M., 2004. Studies on noise pollution in cotton ginneries. Journal of Agricultural Engineering, Vol. 41(3): July-September, 2004.

Arude, V.G., Manojkumar, T.S. and Shukla, S.K., 2009. Evaluation of Vibrations of Ginning and Pressing Machinery in Cotton Ginneries. Journal of Agricultural Engineering Vol. 46(3): July-September, 2009.

Bansal, A.S., 1981. Survey of noise levels of wheat threshers. Paper presented at XVIII Annual Convention of Indian Society of Agricultural Engineers held at Karnal on Feb. 26 to 28.

Bansal, A.S., Behniwal, N.S. and Kumar, A., 1982. Survey of noise levels of tractors. Paper presented at XIX Annual Convention of Indian Society of Agricultural Engineers held at Udaipur on Feb. 15-17.

Bansal, A.S. and Thaper, S., 2000. Vibration isolation characteristics of tractor seats of Indian make and the design improvement. Inter-Noise 2000. The 29th International Congress and Exhibition on Noise Control Engineering. 27-30 August 2000, Nice, France.

Bean, T.L., 2008. Noise on the Farm Can Cause Hearing Loss. Fact Sheet: Agriculture and Natural Resources. Department of Food, Agricultural and Biological Engineering. Ohio State University Extension.

Celen, I.H. and Arin, S., 2003. Noise levels of agricultural tractors. P.J. of Biological Sciences 6(19): 1706-1711.

Chhatwal, C.R., Mehra, M.C., Satake, M., Katyal, T., Katyal, M. and Nagahiro, T., 1989. Environmental Noise Pollution and its Control. Anmol Publications, New Delhi. Pp.301.

Evans, J.P., Whyte, R.T., Price, J.S., Bacon, J.M., Semple, D.A., Scarlett, A.J. and Stayner, R.M., 2004. Practical solutions to noise problems in agriculture. Research Report 212, Health and Safety Executive Books, Sudbury Suffolk CO10 2WA (Website: www.hsebooks.co.uk).

Gite, L.P. and Singh, G., 1997. Ergonomics in Agricultural and Allied Activities in India. Central Institute of Agricultural Engineering, Bhopal. 51p.

Grandjean, E., 1982. Fitting the task to the man – An Ergonomic Approach. Taylor and Francis Ltd., London.

Gupta, O.S., 1978. Agricultural equipment testing at Budni. Agricultural Engineering Today, 2(5), pp:5-11.

Gupta, S.N., Gupta, P.K., Shekhar, C., Bansal, A.S. and Behniwal, N.S., 1981. Survey of temporary threshold shift of hearing of thresher operators. Paper presented at the Vth Annual Conference of Association of Otolaryagologists of India (NW zone) held at Amritsar on October 25.

Hagen, C.L., 2011. Examination of Noise Levels in Pre 1980 Agriculture Tractors. A Research Paper Submitted for the Masters of Science Degree In Risk Control. The Graduate School, University of Wisconsin-Stout. 44p.

Henderson, D. and Hamernik, R.P., 2012. The Use of Kurtosis Measurement in the Assessment of Potential Noise Trauma. Noise-Induced Hearing Loss: Scientific Advances. Springer Handbook of Auditory Research.

Harris C. M., 1957. Handbook of Noise Control, McGraw-Hill, New York.

Huang B.K. and Suggs, W.C., 1961. Vibration studies of tractor operators. Transaction of the ASAE, Vol. 10, No. 4, 478-482.

http://www.translatorscafe.com/ cafe/ EN/ units-converter/ sound/ c/

http://www.rapidtables.com/convert/electric/db-converter.htm

http://www.rapidtables.com/ electric/ decibel.htm#Decibel_Calculator

http://download.cnet.com/Audio-Spectrum-Analyzer/ 3000 – 20432 _4 - 75325061.html

http://download.cnet.com/windows/wd6cnf/3260-20_4-10119931.html (Audio Spectrum Analyzer)

http://download.cnet.com/Spek/3000-2170_4-75451631.html

http://download.cnet.com/windows/wd6cnf/3260-20_4-10119931.html.

http://spek.cc/

http://www.silisoftware.com/ tools/db.php

http://ocw.mit.edu/courses/ aeronautics – and – astronautics / 16-30-estimation – and – control – of – aerospace – systems – spring – 2004 / readings / appdx_a_ocr.pdf

http://download.cnet.com/Audio-Spectrum-Analyzer/3000-20432_4-75325061.html

https://commons.wikimedia.org/wiki/File:Voice_waveform_and_spectrum

ISO 2631: 1978. Guide for the Evaluation of Human Exposure to Whole-Body Vibration.

Jadhav, Vijay S. and Ghatage, Dhanaji M., 2000. Noise Attenuation of Diesel Engine With Different Types Mufflers. Mech. Engg. Deptt., Govt. COE, Karad (M.S.)

Jones, B. and Nachtsheim, C.J., 2009. Split-Plot Designs: What, Why and How. Journal of Quality Technology, Vol. 41, No. 4, October 2009.

Kothari, C.R., 2004. Research Methodology: Methods and Techniques. New Delhi, New Age International Publishers. Pp. 184-232.

Kumar, A., Mathur, N.N., Varghese, M., Mohan, D., Singh, J.K. and Mahajan, P., 2005. Effect of Tractor Driving on Hearing Loss in Farmers in India. AMERICAN JOURNAL OF INDUSTRIAL MEDICINE 47:341–348.

Kumar, R., (1994). Studies on the performance of exhaust mufflers of tractor engines and the design improvement. Unpublished M.Tech. Thesis, Punjab Agricultural University, Ludhiana.

Le Prell, C. G. and Henderson, D., 2012. Perspectives on Noise-Induced Hearing Loss. Noise-Induced Hearing Loss: Scientific Advances. Springer Handbook of Auditory Research. Springer Science+Business Media, LLC 2012. New York, NY 10013, USA.

Mathews, J., 1977. The ergonomics of tractors. ARC Research Review, 3(3):59-65 (Original not seen).

McPhee, Barbara, Foster, G. and Long, A., 2009. Bad Vibrations. A Handbook on Whole Body Vibration Exposure in Mining. Coal Services Health & Safety Trust.

Mehta, C.R., Shyam, M. and Sharma, P.K., 1997. Studies on noise and vibration levels of different tractors. Final report of research project, CIAE, Bhopal.

Mehta, C.R., 2013. Noise and Vibration in Tractor and Farm Equipment - A lecture note. By Dr. C R Mehta, Project Coordinator, AICRP on Farm Implements and Machinery, Central Institute of Agricultural Engineering, Nabi-bagh, Berasia Road, Bhopal – 462 038; E-mail: crmehta@ciae.res.in.

Motor Transport of India. 2003. Transport Research Wing, Ministry of Surface Transport, Government of India.

Munjal, M. L., 1987. Acoustics of Ducts and Mufflers, John Wiely and Sons, New York.

Murthy, B.S., 2002. How does an exhaust silencer work? The Hindu: Online edition, April-11, 2002. Available at: http://www.hindu.com/ thehindu /seta /2002 /04 /11 /stories /20020411001...

O'Haver, T., 2014. Intro. to Signal Processing: Signals and Noise. Available at: http://terpconnect.umd.edu/~toh/spectrum/SignalsAndNoise.html. accessed on 21-Aug-2014.

OSHA, 2013. How do I evaluate noise exposure? Noise and Hearing Conservation Technical Manual (Section III). Avaliable at: https://www.osha.gov/dts/osta/otm/ noise/exposure. Accessed on 16-Jul-2013.

Patrick N. B. and Peter S. J. L., 2006. Noise. Johns Hopkins Bloomberg School of Public Health, Johns Hopkins University.

Pawar, J.G., 1979. Ergonomic studies of power tiller – A review. Report of faculty programme in Human Engineering. Punjab Agricultural University, Ludhiana.

Pingle, S., 2012. Occupational Safety and Health in India: Now and the Future. Industrial Health, 50, 167-171.

Plakke, B.L. and Dare E., 1992. Occupational hearing loss in farmers. Public Health Reports. V.107(2); Mar-Apr 1992.

Prasad, N., 1996. Some investigations on tractor seat design with regard to Indian operators. Unpublished Ph.D. Thesis, Indian Institute of Technology, Kharagpur.

Rahman, M., Sharmin, T., Hassan, A. F. M. E. and Al Nur, M., 2005. Design and Construction of a Muffler for Engine Exhaust Noise Reduction. Proceedings of the International Conference on Mechanical Engineering, 28- 30 December 2005, Dhaka, Bangladesh.

Rajagopal, K., 2008. Engineering Physics. New Delhi, PHI Learning Private Limited. 338p.

Salokhe, V.M., Wongkhunkeaw, P. and Nalavade, P.P., 2008. Vibration and Noise Characteristics of a Brush Cutter. 42nd ISAE Annual Convention held at Bhopal, India.

Sam, Bini, 2006. Noise level on safe exposure limit of power tiller operator. Indian J. of Agric. Sc. 76 (12): 760-I, December-2006.

Selvan, M.M. and Mehta, C.R., 2008. Noise Attentuation Characteristics of Exhaust Mufflers with Medium Size Farm Tractors. Journal of Agric. Engg., Vol. 45(4), October-December, 2008.

Sharma, D.N. and Mukesh, S., 2008. Farm Machinery Design. New Delhi, Jain Brothers. 311p.

Sharma, P. K. and Shyam, M., 1993. Noise and vibration levels of indigenous tractor - a status report. Paper presented at XXVIII convention of ISAE held at CIAE, Bhopal.

Shreve, D.H., 1994. Introduction to Vibration Technology. IRD Mechanalysis, Inc. Columbus, Ohio 43229.

Simpson, E. W. Jr. and Deshayes, I. L., 1969. Tractors produce ear damaging noise. J. Environmental Health, 3 1(4), 347-350.

Smith III, J.O., 2007. Mathematics of the DFT with Audio Applications. Available at: http://www.dsprelated.com/ freebooks / mdft / Decibels.html Accessed on 15/07/2015 (DD/MM/YYYY) at 5:52 PM.

Takács, G. and Rohal, 2012. Model Predictive Vibration Control. DOI: 10.1007/978-1-4471-2333-0_2. Springer-Verlag London Limited.

Taylor, J.I., 2003. The Vibration Analysis Handbook. A practical Guide for Solving Rotating Machinery Problems. 2nd edition.

Tewari, V.K., Vidhu, K.P., Arudra, A.K. and Kumari, Sweeti, 2013. Reduction of hand transmitted and whole body vibrations experienced by tractor operators by using piezo crystal material. Agric Eng Int: CIGR Journal (Open access at http://www.cigrjournal.org) Vol. 15, No.2. 209-220.

Young, T., 2013. Everything You Wanted To Know About Sound Level Meters (SLMs). Available at: http://www.prosoundweb.com/article/sound_level_meters_the_primer_what_how_ why_ techniques_more.

APPENDICES

APPENDIX-I

Noise level (SPL) Observations Recorded under Different Muffler Mounting on Tractor-1 (Mini Tractor) at Different RPM

Table 1: Noise level (SPL) observations recorded under no muffler mounting on Tractor-1 (Mini Tractor) at different RPM at ear level (Replication-I)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	79.3	83.3	85.2	87.2	88.1
2	80.2	83	86.4	87.6	90.1
3	80.2	83.9	86.2	87.7	89.9
4	79.4	83.5	86.1	87.6	90.1
5	79.9	83.7	85.7	87.5	90.3
6	79.5	83.6	85.7	87.7	90.4
7	79.8	83.9	85.7	87.5	89.9
8	79.6	83.1	85.8	87.5	89.9
9	80	83.4	85.3	87.3	89.9
10	79.8	83.5	85.2	87.5	90
11	80.2	83.5	85.4	87.6	89.9
12	79.6	83.7	85.2	87.7	90
13	79.4	83.2	85.3	87.4	89.9
14	79.4	83.8	85.3	87.7	89.8
15	79	83.5	85.1	87.7	89.5
16	79.4	83.1	85.5	88.1	89.6
17	79.4	83.6	85.2	87.7	90
18	79.5	83.6	85.6	87.3	90.1
19	79.4	83.1	85.1	87.6	90
20	79.5	83.6	85.4	87.3	90.3
21	79.8	83.5	85.3	87.5	89.8
22	79.2	83.2	85.4	87.7	90.1
23	79.7	83.3	85.8	87.7	90.2
24	79	83.6	84.9	87.6	90.1
25	79.2	83.7	85.3	87.6	89.9
26	79.6	83.4	85.2	87.3	89.7
27	79.8	83.5	85.7	87.6	89.9
28	79.6	83.6	85.2	87.7	89.9
29	79.2	83.2	85.3	87.4	89.6
30	79.7	83.4	85.1	87.7	89.8
Mean	79.6	83.5	85.5	87.6	89.9
s	0.32	0.24	0.35	0.18	0.40
C.V. (%)	0.41	0.29	0.41	0.21	0.44

Table 2: Noise level (SPL) observations recorded under no muffler mounting on Tractor-1 (Mini Tractor) at different RPM at ear level (Replication-II)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	79.6	83.5	86.2	90.1	91.6
2	80.6	83.5	86.3	89.9	91.8
3	79.7	83.5	86.3	89.9	91.8
4	80.2	82.7	86.3	89.9	92.2

5	80.2	82.7	86.2	90.1	92.2
6	80.3	83.2	87.2	90.1	92.2
7	80	83.2	87.4	90.3	92.1
8	80	83.2	87.4	90.3	92.1
9	80.3	83.2	87.2	90.2	92.3
10	79.8	83.7	87.2	90.2	92.3
11	79.8	83.7	86.9	90.4	92
12	79.9	83.3	86.9	90.3	92
13	79.7	83.3	86.5	90.1	92
14	79.7	83.1	86.5	90.1	92.3
15	79.7	83.1	86.5	90.1	92
16	80.1	84	86.5	90.1	92
17	79.7	84	86.6	90	92.5
18	79.7	83.6	86.6	90	92.3
19	80.1	83.6	86.7	90	92.3
20	80.1	83.6	86.8	90.2	92.1
21	80	84.1	86.7	90.2	92.1
22	80	84.1	86.7	90	92.1
23	79.7	84.1	86.4	90.2	92.1
24	79.9	84.2	86.4	90.1	92.1
25	79.9	84.2	86.4	90.1	91.9
26	79.9	82.9	86.4	90.2	91.9
27	79.9	82.9	86.6	90.2	92.2
28	79.9	82.9	86.6	90.1	92.2
29	79.4	83.2	86.9	90.1	91.9
30	79.4	83.2	86.9	90.1	91.9
Mean	79.9	83.5	86.7	90.1	92.1
s	0.27	0.45	0.34	0.12	0.19
C.V. (%)	0.33	0.54	0.40	0.13	0.21

Table 3: Noise level (SPL) observations recorded under no muffler mounting on Tractor-1 (Mini Tractor) at different RPM at ear level (Replication-III)

Sr. No.	1000	1250	1500	1750	2000
1	79.9	83.2	86.2	90.1	92.1
2	79.9	83.2	86.2	90.2	92.1
3	79.9	83	86.8	90.2	92.2
4	80.1	83	86.7	90.1	92.2
5	80.1	83	86.7	90.1	92.2
6	80	83	86.9	90.5	92.2
7	79.7	83.2	86.9	90.1	91.6
8	79.7	83.2	86.9	90.5	91.9
9	80.5	83.9	86.9	90.5	91.9
10	80.9	83.9	86.9	90.3	91.9
11	80.1	83.3	86.9	90.3	92.1
12	80.1	83.3	86.5	90.2	92.1
13	80.2	83.6	86.5	90.2	92.2
14	80	83.6	86.5	90.2	92.2
15	80	83.6	86.5	90.4	92
16	79.6	83.9	86.6	90.4	92
17	79.6	83.9	86.6	90.5	92
18	80.5	83.9	86.6	90.5	92
19	80.5	84.1	86.8	90.4	92

20	80.4	84.1	86.8	90.4	92
21	80.4	83.6	86.9	90.4	92.3
22	79.8	83.6	86.8	90.5	92
23	79.8	83.6	86.8	90.4	92
24	80.1	83.6	87.1	90.4	92
25	80.1	83.6	87.1	90.4	91.9
26	80.3	83.6	87.1	90.4	92.1
27	80.1	83.9	87.1	90.3	92.1
28	80.1	83.9	87.1	90.3	92
29	79.5	83.6	86.2	90.3	92.1
30	80.4	83.6	86.2	90	92.1
Mean	80.1	83.6	86.7	90.3	92.1
s	0.32	0.34	0.28	0.15	0.14
C.V. (%)	0.40	0.40	0.32	0.16	0.15

Table 4: Noise level (SPL) observations recorded under standard muffler mounting on Tractor-1 (Mini Tractor) at different RPM at ear level (Replication-I)

Sr. No.	1000	1250	1500	1750	2000
1	78.3	82.3	83.7	85.3	86
2	78.3	82.3	83	85.3	85.9
3	78.9	82.3	83	85.2	85.9
4	78.9	82.3	83.3	85.2	85.9
5	78.6	82.3	83.3	85.2	85.9
6	78.6	82	83.1	85.5	85.9
7	78.6	82	83.1	85.5	86.2
8	78.5	81.6	83.1	85.3	86.2
9	78.5	81.6	82.8	85.3	86.2
10	78.5	82	82.8	84.8	86.3
11	78.7	82	83.2	85.1	86.3
12	78.7	82	83.2	85.1	86
13	78.7	82	83	85.1	86
14	78.6	82	83	85.2	86.2
15	78.6	81.7	83	85.2	86.2
16	78.6	81.7	83.2	85.2	86.4
17	78.1	81.7	83.2	85.2	86.4
18	78.1	81.7	83.3	85.1	86.3
19	78.1	81.7	83.3	85.1	86.3
20	78.1	82.4	83.3	84.9	86.3
21	79	82.4	83.1	84.9	86.3
22	79	82.4	83.1	84.9	86.3
23	79	81.6	83.1	84.9	86.3
24	78.9	81.6	83.7	84.9	86.4
25	78.9	81.6	83.7	84.7	86.4
26	78.9	81.7	83.3	84.7	86.4
27	78.9	81.7	83.3	85	86.3
28	78.9	81.9	83.5	85	86.3
29	78.9	81.9	83.5	85.1	86.5
30	78.9	81.9	83.2	85.1	86.5
Mean	78.6	81.9	83.2	85.1	86.2
s	0.29	0.28	0.23	0.20	0.19
C.V. (%)	0.37	0.34	0.28	0.24	0.22

Table 5: Noise level (SPL) observations recorded under standard muffler mounting on Tractor-1 (Mini Tractor) at different RPM at ear level (Replication-II)

Sr. No.	1000	1250	1500	1750	2000
1	78.9	81.9	83.2	85	86.4
2	78.9	81.9	83.6	85	86.4
3	78.9	81.9	83.6	85.1	86.4
4	78.9	81.9	83.1	85.1	86.4
5	78.9	82.2	83.1	85.2	86.4
6	78.2	82.2	82.9	85.2	86.4
7	78.2	82.2	82.9	84.8	86.4
8	78.2	82	83.4	84.8	86.3
9	78.7	82	83.4	85.4	86.3
10	78.7	82	83.3	85.4	86.3
11	78.6	82.1	83.3	85.6	86.3
12	78.6	82.1	83.3	85.6	86.3
13	78.5	82.1	83.3	85.6	86.6
14	78.3	82.1	83.3	85.3	86.6
15	78.3	82.1	83.3	85.3	86.6
16	78.3	82.2	83.5	85.2	86.4
17	78.3	82.2	83.5	85.2	86.4
18	78.3	82.1	83.7	85.4	86.3
19	78.4	82.1	83.7	85.2	86.3
20	78.4	81.7	83.7	85.2	86.1
21	78.4	82.1	83.7	85	86.1
22	78.6	81.7	83.7	85	86.1
23	78.6	81.7	83.6	85.1	86.5
24	78.6	82.2	83.6	85.1	86.5
25	78.6	82.2	83.7	84.1	86.4
26	78.6	81.9	83.7	84.1	86.4
27	78.8	81.9	83.2	85.4	86.2
28	78.8	81.9	83.2	85.4	86.2
29	78.8	81.8	83.5	85.4	86.3
30	78.5	81.8	83.5	85.5	86.3
Mean	78.6	82.0	83.4	85.2	86.4
s	0.24	0.16	0.24	0.36	0.13
C.V. (%)	0.30	0.20	0.29	0.42	0.15

Table 6: Noise level (SPL) observations recorded under standard muffler mounting on Tractor-1 (Mini Tractor) at different RPM at ear level (Replication-III)

Sr. No.	1000	1250	1500	1750	2000
1	78.5	81.7	84	85.5	86.3
2	78.5	81.7	84	85.2	86.1
3	79.1	82.1	84	85.2	86.4
4	79.1	82.1	83.3	85.2	86.4
5	79.1	82.2	83.3	85.2	86.4
6	79	82.2	83.5	84.9	86.2
7	79	81.6	83.5	84.9	86
8	79	81.6	83.2	85.5	86
9	79	81.6	83.2	85.5	86.2
10	79	82.3	83.7	85.4	86.2
11	78.8	82.3	83.7	85.4	86
12	78.8	81.9	83.3	85.4	86

13	78.8	81.9	83.3	85.7	86.1
14	78.5	82.4	83.3	85.2	86.1
15	78.5	82.4	83.3	85.2	86.1
16	78.5	82.6	83.3	85.1	86.1
17	78.8	82.6	83.5	85.1	86.1
18	78.8	82.7	83.6	85.5	86.2
19	78.4	82.7	83.6	85.5	86.2
20	78.4	82	83.6	85.4	86.2
21	78.4	82	83.3	85.4	86.3
22	78.7	82	83.3	85.2	86.3
23	78.7	81.9	83.2	85.2	86.4
24	78.7	81.9	83.2	85.6	86.4
25	78.3	82.4	83.3	85.6	86.4
26	78.3	82.4	83.3	85.7	86.4
27	78.3	82.2	83.5	85.7	86.4
28	78.3	82.2	83.5	85.6	86.4
29	78.3	81.8	83.2	85.6	86.4
30	78.3	81.8	83.2	85.7	86.4
Mean	78.7	82.1	83.4	85.4	86.2
s	0.29	0.33	0.24	0.23	0.15
C.V. (%)	0.36	0.40	0.29	0.27	0.17

Table 7: Noise level (SPL) observations recorded under muffler-3 (muffler-A) mounting on Tractor-1 (Mini Tractor) at different RPM at ear level (Replication-I)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	78.3	81.8	83.3	85.1	86.8
2	78.1	82.5	83.5	84.8	86.4
3	78.1	82.1	83.5	84.8	86.4
4	78.1	82.1	83.5	84.8	86.4
5	78.2	81.9	83.5	85.2	86.4
6	78.2	82.2	83.5	85.2	86.1
7	78.2	82.2	83	85.3	86.1
8	78.4	82.2	83	85.3	86.1
9	78.4	82.5	82.9	85.1	86.2
10	78	82.5	82.9	85.1	86.2
11	78	82.5	83.2	85.1	86.2
12	78.4	82.5	83.2	85.2	86.3
13	78.4	81.1	83.2	85.2	86.3
14	78.4	81.1	83.1	85.3	86.3
15	78	81.1	83.1	85.3	86.2
16	78	81.3	83.3	85.6	86.2
17	78	81.3	83.3	85.6	86.2
18	78	81.8	83.3	85.6	86
19	78	81.8	82.9	85.2	86
20	78.2	81.8	82.9	85.2	86
21	78.2	81.2	82.9	85.6	86.1
22	78.2	81.2	83.5	85.6	86.1
23	78.2	81.7	83.5	85.7	86.2
24	78.5	81.7	83.4	85.7	86.2
25	78.5	81.3	83.4	85.7	86.2
26	78.5	81.3	83.4	85.4	86.2
27	77.8	81.3	83.5	85.4	86.2

28	77.8	81.5	83.5	85.6	86.2
29	77.8	81.5	83.5	85.6	86.5
30	77.8	81.5	83.4	85.6	86.5
Mean	78.2	81.8	83.3	85.3	86.2
s	0.22	0.48	0.23	0.27	0.17
C.V. (%)	0.28	0.59	0.27	0.32	0.20

Table 8: Noise level (SPL) observations recorded under muffler-3 (muffler-A) mounting on Tractor-1 (Mini Tractor) at different RPM at ear level (Replication-II)

Sr. No.	1000	1250	1500	1750	2000
1	78.4	81.2	83.4	85.2	86.5
2	78.4	81.2	84	85.2	86.2
3	78.3	81.3	83.7	85.7	86.2
4	78.3	81.3	83.7	85.7	86.2
5	78.3	81.3	83.7	85.7	86.4
6	78.4	81.4	83.6	85.2	86.4
7	78.4	81.4	83.6	85.2	86.4
8	78.4	81.4	83.6	85.5	86.4
9	78.8	81.3	83.1	85.5	86.3
10	78.2	81.3	83.1	85.2	86.3
11	78.2	81.3	83.1	85.2	86.3
12	78.2	81.6	83.8	85.2	86.3
13	78.2	81.6	83.8	85.3	86.5
14	78.2	81.6	83.8	85.3	86.5
15	78.2	81.4	83.9	85.3	86.5
16	78	81.4	83.9	85.7	86.3
17	78	81.7	84.2	85.7	86.3
18	78.2	81.7	84.2	85.3	86.3
19	78.2	81.7	84.2	85.3	86.3
20	78.2	81.8	83.5	85.3	86.3
21	78.1	81.8	83.5	85.2	86.3
22	78.1	81.8	83.5	85.2	86.3
23	78.1	81.5	83.5	85.2	86.3
24	78.7	81.5	83.5	85.3	86.3
25	78.7	81.1	83.5	85.3	86.1
26	78.7	81.1	83.6	84.4	86.1
27	77.5	81.1	83.6	84.4	86.3
28	77.5	81.6	83.6	84.4	86.3
29	77.5	81.6	83.6	85.2	86.2
30	77.5	81.6	83.9	85.2	86.2
Mean	78.2	81.5	83.7	85.3	86.3
s	0.34	0.21	0.29	0.34	0.11
C.V. (%)	0.44	0.26	0.34	0.40	0.12

Table 9: Noise level (SPL) observations recorded under muffler-3 (muffler-A) mounting on Tractor-1 (Mini Tractor) at different RPM at ear level (Replication-III)

Sr. No.	1000	1250	1500	1750	2000
1	78.2	81.9	83.9	85.6	86.7
2	78.2	81.9	83.9	85.6	86.7
3	78.2	81.9	84.4	85.6	86.7
4	78.2	81.3	84.4	85.7	86.4
5	77.7	81.3	83.8	85.7	86.4

6	77.7	81.3	83.8	85.8	86.4
7	77.7	81.4	83.8	85.8	86.6
8	78.1	81.4	83.8	86.1	86.6
9	78.1	81.4	84.1	86.1	86.6
10	78.1	81.9	84.1	86.1	86.6
11	78	81.9	84.1	86.1	86.6
12	78	81.9	83.5	86.1	86.4
13	78	81.7	83.5	85.9	86.4
14	78.2	81.7	83.5	85.9	86.4
15	78.2	81.2	83.7	85.8	86.2
16	78.2	81.2	83.7	85.8	86.2
17	78.1	81.2	83.2	86	86.2
18	78.1	82.2	83.2	86	85.8
19	78.1	82.2	83.2	85.6	85.8
20	78.2	81.6	83.9	85.6	85.8
21	78.2	81.6	83.9	86.2	86.5
22	78.2	81.6	83.9	86.2	86.5
23	78.2	81.7	83.9	86	86.5
24	78	81.7	83.9	86.1	86.5
25	78	81.7	83.5	86.1	86.5
26	78	81.8	83.5	86.1	86.5
27	78.2	81.8	83.8	85.9	86.4
28	78.2	81.8	83.8	85.9	86.4
29	78.2	81.8	83.6	86.1	86.8
30	78.2	81.3	83.6	86.1	86.8
Mean	78.1	81.6	83.8	85.9	86.4
s	0.15	0.29	0.30	0.20	0.26
C.V. (%)	0.20	0.35	0.36	0.23	0.31

Table 10: Noise level (SPL) observations recorded under muffler-7 (muffler-C) mounting on Tractor-1 (Mini Tractor) at different RPM at ear level (Replication-I)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	78.8	81.7	83.4	84.4	86
2	78.7	81.7	83	84.4	86
3	78.7	81.7	83	84.8	86.1
4	78.7	81.5	82.3	84.8	86.1
5	78.7	81.9	82.3	84.8	86.1
6	79.6	81.7	82.6	84.5	85.7
7	79.6	81.7	82.6	84.5	85.7
8	79	82.5	82.6	84.2	86.2
9	78.8	82.5	82.4	84.2	86.2
10	78.8	81.8	82.4	84.3	86.2
11	78.8	81.8	82.4	84.3	86.1
12	78.9	81.9	82.6	84.7	86.1
13	78.9	81.8	82.6	84.7	86.1
14	78.8	81.8	82.6	85	86.1
15	78.8	81.2	82.6	85	86.1
16	78.8	81.2	82.6	85	86.1
17	79.1	81.3	82.7	84.5	86.1
18	79.1	81.3	82.7	84.5	86.2
19	79.1	81.8	82.6	84.6	86.2
20	78.9	81.8	82.6	84.6	86.2

21	78.9	81.4	82.6	85.1	86.4
22	79.1	81.4	82.5	85.1	86.4
23	79.1	81.5	82.5	85.1	86.4
24	79.1	81.5	83.6	85.3	86.5
25	79.5	81.7	83.6	85.3	86.5
26	79.5	81.7	83.3	85.1	86.5
27	78.7	81.3	83.3	85.1	86.5
28	78.7	81.5	83.3	85.1	86.5
29	78.8	81.5	82.7	85.3	86.5
30	78.8	81.5	82.7	85.3	86.3
Mean	79.0	81.7	82.8	84.8	86.2
s	0.27	0.31	0.37	0.35	0.22
C.V. (%)	0.35	0.38	0.45	0.42	0.25

Table 11: Noise level (SPL) observations recorded under muffler-7 (muffler-C) mounting on Tractor-1 (Mini Tractor) at different RPM at ear level (Replication-II)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	78.8	81.5	82.7	85.3	86.3
2	79.4	81.6	82.8	84.1	86.3
3	79.4	81.6	82.8	84.1	86.7
4	78.7	81.6	82.8	85.1	86.7
5	78.7	82	83.2	85.1	86.7
6	78.7	81.5	83.2	85.1	86.8
7	78.5	81.5	83	85.4	86.6
8	78.5	81.3	83	85.4	86.6
9	78.6	81.3	82.9	84.7	86.8
10	78.6	81.3	82.9	84.7	86.9
11	78.6	81.3	82.9	84.7	86.9
12	79	81.7	83.4	84.8	86.9
13	79	81.7	83.4	84.8	86.4
14	78.6	81.3	83.4	84.9	86.4
15	78.6	81.3	83.4	84.9	86.4
16	79.1	80.9	82.8	84.9	86.3
17	79.1	80.9	82.8	84.8	86.3
18	79.1	81.5	82.8	84.8	86.3
19	78.7	81.5	83.2	84.6	86.3
20	78.7	81.5	83.2	84.6	86.3
21	78.7	81.7	82.9	84.5	86.3
22	78.8	81.7	83.5	84.5	86.2
23	78.8	81.6	83.5	84.5	86.2
24	78.8	81.6	83.5	85.3	86.2
25	78.7	81.6	82.9	85.3	86.2
26	78.7	81.6	82.9	85	86.2
27	78.7	81.6	82.9	85	86.1
28	78.5	81.4	83.3	85.2	86.1
29	78.5	81.4	83.3	85.2	86.1
30	79	81.4	83.4	84.8	86.4
Mean	78.8	81.5	83.1	84.9	86.4
s	0.25	0.22	0.27	0.34	0.26
C.V. (%)	0.31	0.28	0.32	0.40	0.30

Table 12: Noise level (SPL) observations recorded under muffler-7 (muffler-C) mounting on Tractor-1 (Mini Tractor) at different RPM at ear level (Replication-III)

Sr. No.	1000	1250	1500	1750	2000
1	79	81.4	83.4	84.8	86.4
2	79	81.4	83.4	84.6	86.4
3	78.9	81.4	82.9	84.6	86.3
4	78.9	81.1	82.9	85.1	86.3
5	78.9	81.1	83	85.1	86.3
6	79.4	81.2	83	84.9	86
7	79.4	81.2	83.1	84.9	86
8	79.2	81.3	83.1	84.9	86.1
9	79.2	81.3	83.2	85.3	86.1
10	79.1	81.6	83.2	85.3	86.3
11	79.1	81.6	83.2	84.9	86.3
12	78.9	81.6	83.5	84.9	86.3
13	78.9	81.5	83.5	84.9	86.3
14	79	81.5	82.9	85.1	86.3
15	79	81.5	82.9	85.1	86.5
16	79.1	82	82.9	85.2	86.5
17	79.1	82	83.5	85.2	86.5
18	79.1	81.5	83.5	85.2	86.5
19	79.1	81.5	83.7	85.1	86.5
20	79.1	81.5	83.7	85.1	86.3
21	79.1	81.5	83.2	85	86.3
22	79.1	81.5	83.2	85	86.3
23	78.9	82.1	83.2	84.8	86
24	78.9	82.1	83.2	84.8	86
25	78.6	82.1	83.2	85.2	86
26	78.6	82	83.4	85.2	86.2
27	79	82	83.4	85.5	86.2
28	79	81.6	83.2	85.5	86.3
29	79.3	81.6	83.2	85.5	86.3
30	78.9	81.6	83.3	84.7	86.3
Mean	79.0	81.6	83.2	85.0	86.3
s	0.18	0.30	0.23	0.24	0.16
C.V. (%)	0.23	0.37	0.28	0.29	0.19

Table 13: Noise level (SPL) observations recorded under no muffler mounting on Tractor-1 (Mini Tractor) at different RPM at 10 m distance (Replication-I)

Sr. No.	1000	1250	1500	1750	2000
1	65.7	69	69.9	72.5	75.2
2	65.7	68.6	69.8	73	75
3	64.8	68.1	69.8	72.6	75.2
4	65.4	68.2	69.8	72.9	75.4
5	64.8	68.9	69.9	72.4	75
6	64.9	68.3	69.7	72.5	75.1
7	64.9	68.3	69.9	72.6	75.1
8	65.1	68.6	70.3	72.4	75
9	65.4	68.1	70.5	72.5	75.3
10	65.2	68.1	70.4	72.7	74.9
11	65.2	68.4	70.3	72.8	74.9

12	64.9	68.3	70.1	72.8	75.1
13	65.5	68.5	69.6	72.9	75.2
14	65	68.1	70.1	72.6	75.1
15	65	68.5	70.7	72.5	75.4
16	65	67.8	70	72.1	75.2
17	65.7	68.2	70.3	72.2	75.2
18	65	68	70	72.4	75.2
19	65.3	68.6	69.9	73.1	75
20	64.9	68.5	70.3	72.3	75.2
21	64.9	68.2	70.5	72.3	75.2
22	65	68.1	70	72.6	75.7
23	65	68.3	70.1	72.4	75.4
24	64.9	68.1	70.2	72.4	75.9
25	65.1	68.3	70.3	72.5	76.6
26	65.2	68.7	69.9	72.6	76.3
27	65.4	68.3	70.3	72.4	75.3
28	65	68.3	70.4	72.8	75.1
29	65.2	68.6	70.5	72.4	75.2
30	65.4	68.2	70.1	72.3	75.2
Mean	65.2	68.3	70.1	72.6	75.3
s	0.27	0.27	0.27	0.24	0.38
C.V. (%)	0.41	0.39	0.39	0.33	0.51

Table 14: Noise level (SPL) observations recorded under no muffler mounting on Tractor-1 (Mini Tractor) at different RPM at 10 m distance (Replication-II)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	63.5	65.9	69.3	71.9	73.2
2	62.9	65.9	69.3	72.3	73.2
3	63.9	65.9	69.3	72.3	73.4
4	63.2	65.6	69.3	71.7	73.5
5	63.2	65.6	69	71.9	73.4
6	63.2	65.6	69	71.9	73.5
7	63.2	66.2	69	71.9	73.4
8	63.6	66.2	69.3	71.5	73.4
9	63.5	66.3	69.3	71.5	73.4
10	63.5	66.3	68.7	71.5	73.4
11	64.2	66.3	68.7	71.8	73.4
12	63.9	66.3	68.8	71.8	73.4
13	63.9	65.4	68.8	71.8	73.4
14	63.5	66.2	69	71.7	73.7
15	63.5	66.2	69	71.7	73.4
16	63.5	66.2	69	71.7	73.4
17	63.4	66.1	69.1	71.5	73.4
18	64.1	66.1	69.1	71.5	73.4
19	64.1	66.1	68.8	71.7	73.4
20	64.1	66.3	68.8	72.3	73.4
21	63.5	66.3	68.8	72.3	73.1
22	63.5	65.4	68.5	72.3	73.1
23	63.7	65.4	68.7	71.9	73.1
24	63.7	65.4	68.7	71.9	73.3
25	63.4	66.7	68.6	72	73.3
26	63.7	66.7	68.6	72	73.3

27	63.1	66.7	68.6	72	73.3
28	63.1	65.8	68.4	72.3	73.2
29	63.9	66.3	68.4	72.3	73.1
30	63.9	66.3	68	72.3	73.1
Mean	63.6	66.1	68.9	71.9	73.3
s	0.34	0.39	0.32	0.28	0.14
C.V. (%)	0.54	0.58	0.47	0.39	0.19

Table 15: Noise level (SPL) observations recorded under no muffler mounting on Tractor-1 (Mini Tractor) at different RPM at 10 m distance (Replication-III)

Sr. No.	1000	1250	1500	1750	2000
1	63.9	66.3	68.6	71.7	73.1
2	63.9	66.1	68.6	71.7	73.1
3	63.8	66.1	68.6	71.6	73.5
4	63.8	66.1	68.6	71.6	73.3
5	63.8	65.6	68.3	71.6	73.3
6	63.8	65.6	69.1	71.6	73.3
7	63.7	66.4	69.1	71.6	73.6
8	64.1	66.4	69.1	72	73.6
9	64.1	66.7	69	72	73.6
10	64.1	66.7	69	72	73.6
11	63.3	66.3	69	71.7	73.6
12	64.6	66.3	69.1	71.7	73.2
13	64.6	65.6	69.1	72	73.2
14	64.6	65.6	68.6	72	73.2
15	64.4	66	68.6	72	73.3
16	64.4	66.6	68.6	71.9	73.3
17	64.4	66.6	68.6	71.9	73.3
18	64.4	66.1	68.6	71.9	73.6
19	63.4	66.1	68.6	72	73.6
20	63.9	65.8	68.6	72	73
21	64.3	65.9	68.6	72	73.6
22	64.3	65.9	68.9	71.8	73.9
23	64.1	66.5	68.9	71.8	73.8
24	64.1	66.5	68.9	72	73.7
25	64.1	66.5	68.5	72	73.6
26	64.1	66.1	68.5	72	73.6
27	64.1	66.1	68.9	71.8	73.9
28	64.1	66.1	68.9	71.8	73.6
29	63.9	65.8	68.9	71.9	73.3
30	64	65.9	68.7	71.9	73.3
Mean	64.1	66.1	68.8	71.9	73.5
s	0.32	0.33	0.23	0.15	0.24
C.V. (%)	0.50	0.51	0.33	0.22	0.33

Table 16: Noise level (SPL) observations recorded under standard muffler mounting on Tractor-1 (Mini Tractor) at different RPM at 10 m distance (Replication-I)

Sr. No.	1000	1250	1500	1750	2000
1	63.2	67.1	68.3	70	71.2
2	63.2	67.1	68.7	70	71.2
3	63.2	66.7	68.7	70	71.2
4	63.5	67.1	68.7	70	71.3

5	63.5	67.1	68.5	69.9	71.3
6	63.5	67.1	68.5	69.9	71.3
7	63	67	68.5	70	71.3
8	63	67	68.7	70	71.3
9	63	67	68.7	69.6	71.1
10	63.5	67	68.7	69.6	71.1
11	63.5	67	68.6	69.5	71
12	63.5	66.7	68.6	69.5	71
13	63.2	66.7	68.5	69.9	71
14	63.2	66.7	68.5	69.9	71.2
15	63.2	67	68.4	69.8	71.2
16	62.9	67	68.4	69.8	71.3
17	62.9	67.1	68.4	69.9	71.3
18	62.9	67.1	68.3	69.9	71.3
19	63.2	67.1	68.3	70	71.4
20	63.2	66.9	68.3	70	71.4
21	63.2	66.9	68.6	69.8	71.4
22	62.9	66.9	68.6	69.8	71.3
23	62.9	67	68.6	69.8	71.3
24	62.9	67	68.5	69.8	71.6
25	63.4	67	68.5	69.7	71.6
26	63.4	67	68.3	69.7	71.6
27	63.4	67	68.3	69.8	71.3
28	62.6	67.1	68.1	69.8	71.3
29	62.6	67.1	68.1	69.9	71.3
30	62.6	67.1	68.1	69.9	71.3
Mean	63.1	67.0	68.5	69.8	71.3
s	0.28	0.13	0.19	0.15	0.15
C.V. (%)	0.45	0.19	0.27	0.21	0.22

Table 17: Noise level (SPL) observations recorded under standard muffler mounting on Tractor-1 (Mini Tractor) at different RPM at 10 m distance (Replication-II)

Sr. No.	1000	1250	1500	1750	2000
1	63.5	67.1	68.5	69.9	71.3
2	63.5	67.1	68.5	70	71.2
3	63.5	67	68.5	70	71.2
4	63.1	67	68.3	69.9	71.2
5	63.1	67	68.3	69.9	71.3
6	63.1	67	68.3	69.7	71.3
7	63.4	67	68.1	69.7	71.3
8	63.4	66.9	68.1	69.7	71.1
9	63.4	66.9	68.2	69.7	71.1
10	63.4	66.9	68.2	69.8	71.1
11	64.7	67.2	68.2	69.8	71.1
12	62.3	66.8	68.3	69.8	71.1
13	62.3	66.9	68.3	69.8	71.3
14	62.3	66.9	68.1	69.8	71.3
15	64.2	67	68.1	70.1	71.3
16	64.2	67	68.3	70.1	71.3
17	64.8	67	68.3	69.9	71.3
18	64.8	67.2	68.7	69.9	71.3
19	64.8	67.2	68.7	69.9	71.3

20	64.8	67	68.7	69.9	70.9
21	64.8	67	68.5	70	70.9
22	64.9	67.1	68.5	70.2	70.9
23	64.9	67.1	68.4	70.2	71.3
24	64.9	67.1	68.4	70.2	71.3
25	65	67.1	68.4	69.9	71.3
26	65	67.1	68.4	69.9	71.3
27	65	66.8	68.2	70	71.3
28	64.8	66.8	68.2	70	71.3
29	64.8	67.3	68.5	70.2	71.3
30	64.8	67.3	68.5	70.2	71.1
Mean	64.1	67.0	68.4	69.9	71.2
s	0.92	0.13	0.18	0.16	0.13
C.V. (%)	1.43	0.20	0.26	0.23	0.19

Table 18: Noise level (SPL) observations recorded under standard muffler mounting on Tractor-1 (Mini Tractor) at different RPM at 10 m distance (Replication-III)

Sr. No.	1000	1250	1500	1750	2000
1	64.2	67.3	68.5	70.2	71.1
2	64.2	67.2	68.5	70.2	70.9
3	64.2	67.2	68.5	70.2	70.9
4	64.9	67	68.4	70	70.9
5	64.9	67	68.4	70	71.1
6	64.9	67	68.8	70	71.1
7	64.5	67.1	68.8	70	71.1
8	64.5	67.1	68.6	70.1	71.1
9	64.5	67.1	68.6	70.1	71.1
10	64.4	67.1	68.5	69.7	71.3
11	64.4	67	68.5	69.7	71.3
12	64.3	67	68.3	69.9	71.3
13	64.3	66.7	68.3	69.9	71.2
14	64.3	66.7	68.2	69.9	71.2
15	64.5	67.2	68.2	69.9	71.5
16	64.5	67.2	68.9	69.6	71.5
17	64.8	67.2	68.9	69.6	71.4
18	64.8	67	68.8	69.8	71.4
19	64.8	67	68.8	69.8	71.4
20	64.4	66.9	68.3	70	71.4
21	64.4	66.9	68.3	70	71.4
22	64.1	66.9	68.3	69.9	71.2
23	64.1	66.6	68.3	69.9	71.2
24	64.1	66.8	68.5	69.9	71.2
25	64.6	66.8	68.5	69.9	71.2
26	64.6	66.9	68.3	69.8	71.4
27	64.3	66.9	68.3	69.8	71.4
28	64.4	66.8	68.5	69.7	71
29	64.5	66.8	68.5	69.7	71
30	64.5	66.8	68.5	69.9	71.2
Mean	64.5	67.0	68.5	69.9	71.2
s	0.24	0.18	0.20	0.17	0.18
C.V. (%)	0.37	0.26	0.30	0.24	0.25

Table 19: Noise level (SPL) observations recorded under muffler-3 (muffler-A) mounting on Tractor-1 (Mini Tractor) at different RPM at 10 m distance (Replication-I)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	63	65.7	67.8	69.4	70.4
2	63	65.7	67.6	69.4	70.4
3	63.1	66.2	67.6	69.4	70.4
4	63.1	66.2	67.5	69.2	70.4
5	63.1	66.1	67.5	69.2	70.4
6	63	66.1	67.5	69.2	70.4
7	63	66	67.6	69.2	70.4
8	63	66	67.6	69.2	70.4
9	63.3	66.3	68	69.2	70.4
10	63.3	66.2	68	69	70.6
11	63.2	66.2	68	69	70.6
12	63.2	66.3	68.1	69	70.7
13	63.2	66.3	68.1	69.3	70.7
14	63.2	66.5	68.1	69.3	70.4
15	63.2	66.5	68.2	69.3	70.4
16	63.2	66.2	68.2	69.5	70.4
17	63.2	66.2	67.7	69.5	70.3
18	63.2	66.2	67.7	69.7	70.3
19	63.1	66.7	67.7	69.7	70.4
20	63.1	66.7	68	69.7	70.4
21	63.1	66.7	68	69.4	70.4
22	62.6	66.7	68	69.4	70.5
23	62.6	66.3	68	69.4	70.5
24	62.6	66.3	68	69.4	70.5
25	63	66.3	67.8	69.4	70.2
26	63	66.4	67.8	69.2	70.2
27	63	66.4	67.8	69.2	70.2
28	63.1	66	68.1	69.2	70.2
29	63.1	66	68.1	69.2	70.3
30	63.1	66.5	68.1	69.4	70.3
Mean	63.1	66.3	67.9	69.3	70.4
s	0.18	0.26	0.23	0.19	0.13
C.V. (%)	0.29	0.39	0.33	0.27	0.18

Table 20: Noise level (SPL) observations recorded under muffler-3 (muffler-A) mounting on Tractor-1 (Mini Tractor) at different RPM at 10 m distance (Replication-II)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	63.1	66.5	68	69.4	70.3
2	63.1	66.5	68	69.4	70.3
3	63.1	65.9	68	69.4	70.3
4	63.1	65.9	67.8	69.4	70.6
5	63.3	66.4	67.8	69.6	70.6
6	63.3	66.4	67.8	69.6	70.6
7	63.3	65.7	68	69.6	70.2
8	63.4	65.7	68	69.6	70.2
9	63.4	65.7	68	69.6	70.2
10	63.4	66.1	68	69.5	70.2
11	62.9	66.1	68	69.5	70.2
12	62.9	66.3	68	69.5	70.5

13	62.9	66.3	68	69.3	70.5
14	63.3	66.2	68	69.3	70.5
15	63.3	66.2	68	69.3	70.2
16	63.3	65.9	68	69.3	70.2
17	63	65.9	68	69.4	70.2
18	63	66.3	68	69.4	70.2
19	63	66.3	68	69.4	70.2
20	63.3	66.4	68	69.4	70.6
21	63.3	66.4	68	69.3	70.6
22	63.3	66.4	68.2	69.3	70.6
23	63	66.3	68.2	69.3	70.4
24	63	66.3	68.2	69.2	70.4
25	63	66.5	68	69.2	70.1
26	63.6	66.5	68	69.2	70.1
27	63.6	66.2	68	69.3	70.4
28	63.6	66.2	68.2	69.3	70.4
29	63.6	65.9	68.2	69.1	70.4
30	63.6	65.9	68.2	69.1	70.6
Mean	63.2	66.2	68.0	69.4	70.4
s	0.23	0.26	0.11	0.14	0.17
C.V. (%)	0.36	0.39	0.16	0.21	0.25

Table 21: Noise level (SPL) observations recorded under muffler-3 (muffler-A) mounting on Tractor-1 (Mini Tractor) at different RPM at 10 m distance (Replication-III)

Sr. No.	1000	1250	1500	1750	2000
1	62.8	66.2	68	69.3	70.6
2	62.8	66.2	68	69.3	70.5
3	62.8	66.2	68	69.3	70.5
4	62.8	66.3	68.4	69.2	70.5
5	63.5	66.3	68.4	69.2	70.6
6	63.5	66	68.4	69.7	70.6
7	63	66	68.4	69.7	70.6
8	63	66.2	68.1	69.7	70.5
9	63.6	66.2	68.1	69.6	70.5
10	63.6	66.2	68.1	69.6	70.5
11	63.6	66.2	68.2	69.6	70.5
12	63.2	66.1	68.2	69.4	70.5
13	63.2	66.1	68.2	69.4	70.2
14	63.2	66.2	68.1	69.9	70.2
15	63	66	68.1	69.3	70.2
16	63	66	68	69.3	70.4
17	63	66.3	68	69.3	70.4
18	63.2	66.3	68.4	69.3	70.5
19	63.2	66.2	68.4	69.3	70.5
20	63.1	66.2	68.2	69.3	70.3
21	63.1	66.1	68.2	69.5	70.3
22	63.1	66.1	68.1	69.5	70.3
23	63	66.5	68.1	69.5	70.5
24	63	66	68.1	69.3	70.5
25	63	66	68.3	69.3	70.5
26	63	66	68.3	69.3	70.5
27	63	66.1	68.3	69.3	70.9

28	63	66.1	68.2	69.3	70.9
29	63.1	66	68.2	69.3	70.9
30	63.1	66.2	68.3	69.3	70.6
Mean	63.1	66.2	68.2	69.4	70.5
s	0.23	0.12	0.14	0.18	0.18
C.V. (%)	0.37	0.19	0.20	0.25	0.26

Table 22: Noise level (SPL) observations recorded under muffler-7 (muffler-C) mounting on Tractor-1 (Mini Tractor) at different RPM at 10 m distance (Replication-I)

Sr. No.	1000	1250	1500	1750	2000
1	64.5	65.5	67.9	69.5	70.5
2	64.1	66	67.7	69.5	70.5
3	64.1	66	67.7	69.2	70.5
4	65.1	66	67.8	69.2	70.5
5	65.1	65.5	67.8	69.5	70.5
6	65.1	65.5	67.6	69.5	70.5
7	64.5	65.9	67.6	69.5	70.3
8	64.5	65.9	67.6	69.6	70.3
9	64.3	66	67.5	69.6	70.3
10	64.3	66	67.5	69.5	70.2
11	64.3	65.7	67.7	69.5	70.2
12	63.9	65.7	67.7	69.5	70.1
13	63.9	65.7	67.8	69.5	70.1
14	63.9	66.4	67.8	69.5	70.2
15	64.2	65.9	67.8	68.9	70.2
16	64.2	65.9	67.5	68.9	70.2
17	63.9	65.5	67.5	68.9	70.4
18	63.9	65.5	67.4	69.2	70.4
19	63.9	65.7	67.4	69.2	70.4
20	63.8	66.4	67.4	69.2	70.4
21	63.8	66.4	67.8	69.2	70.4
22	63.9	66.3	67.8	69.2	70.5
23	63.9	66.3	67.6	69.2	70.5
24	63.8	66.4	67.6	69.2	70.5
25	63.8	66.7	67.6	69	70.5
26	63.8	66.7	67.5	69	70.5
27	63.6	66.2	67.5	69	70.5
28	63.6	66.2	67.4	69.1	70.5
29	64.4	66.1	67.4	69.1	70.5
30	64.4	66.1	67.4	69	70.2
Mean	64.2	66.0	67.6	69.3	70.4
s	0.42	0.35	0.16	0.23	0.14
C.V. (%)	0.65	0.53	0.23	0.33	0.20

Table 23: Noise level (SPL) observations recorded under muffler-7 (muffler-C) mounting on Tractor-1 (Mini Tractor) at different RPM at 10 m distance (Replication-II)

Sr. No.	1000	1250	1500	1750	2000
1	63.5	66.1	67.3	69	70.4
2	63.5	66.5	67.3	69	70.4
3	63.5	66.5	67.4	68.9	70.4
4	64	66.2	67.4	68.9	70.4
5	64	66.2	67.8	69.5	70.3

6	64	66.1	67.2	69.5	70.3
7	63.9	66.1	67.2	69.5	70.3
8	63.9	66	67.3	69.2	70.3
9	63.9	66	67.3	69.2	70.3
10	63.9	66.1	67.3	68.9	70.4
11	63.8	66.1	67.5	68.9	70.4
12	63.8	66.1	67.5	68.9	70.4
13	64	66.1	67.5	68.8	70.4
14	64	66.2	67.6	68.9	70.4
15	64	66.2	67.6	68.9	70.4
16	64.3	65.8	67.6	68.9	70.4
17	64.3	65.8	67.4	68.8	70.2
18	63.9	67	67.4	68.8	70.2
19	63.9	67	67.4	68.9	70.4
20	64.1	66.9	67.4	68.9	70.4
21	64.1	66.9	67.4	69.1	70.4
22	64	66.1	67.4	69.1	70.2
23	64	66.1	67.6	69.3	70.2
24	64	65.9	67.6	69.3	70.4
25	64.5	65.9	67.5	69.1	70.4
26	64.5	66.3	67.8	69.1	70.4
27	64.2	66.3	67.8	69.1	70.4
28	64.2	66.1	67.8	68.9	70.4
29	64.1	66.1	67.8	68.9	70.3
30	64.1	66.3	67.8	68.6	70.3
Mean	64.0	66.2	67.5	69.0	70.4
s	0.24	0.33	0.19	0.22	0.07
C.V. (%)	0.38	0.50	0.28	0.32	0.10

Table 24: Noise level (SPL) observations recorded under muffler-7 (muffler-C) mounting on Tractor-1 (Mini Tractor) at different RPM at 10 m distance (Replication-III)

Sr. No.	1000	1250	1500	1750	2000
1	64.1	66.3	67.8	68.6	70.3
2	64.5	66.4	67.6	68.6	70.3
3	64.5	66.4	67.6	69.1	70.3
4	63.7	66.5	67.5	69.1	70.2
5	63.7	66.6	67.5	68.8	70.2
6	63.7	66.6	67.5	68.8	70.2
7	64.2	65.9	67.6	68.7	70.2
8	64.2	65.9	67.6	68.7	70.2
9	64.1	65.9	67.6	68.8	70.5
10	64.1	65.9	67.6	68.8	70.5
11	64.1	65.8	67.6	68.8	70.5
12	64.3	65.8	67.6	68.8	70.2
13	64.3	66.4	67.5	68.8	70.2
14	64	66.4	67.5	68.8	70.3
15	64	66.6	67.8	68.9	70.3
16	64.1	66.6	67.8	68.9	70.3
17	64.1	66.4	67.5	68.6	70.3
18	64.1	66.4	67.5	68.6	70.4
19	63.8	66.4	67.5	68.7	70.4
20	63.8	66.3	67.4	68.7	70.3

21	63.9	66.3	67.4	68.5	70.3
22	63.9	66.6	67.6	68.5	70.3
23	64.1	66.6	67.6	68.5	70.3
24	64.1	65.5	67.8	68.5	70.5
25	64.1	65.5	67.8	68.5	70.5
26	64.2	66.2	67.6	68.5	70.2
27	64.2	66.2	67.6	68.6	70.2
28	64.1	66.1	67.6	68.6	70.4
29	64.1	65.7	67.8	68.6	70.4
30	64.1	65.7	67.7	68.6	70.2
Mean	64.1	66.2	67.6	68.7	70.3
s	0.20	0.35	0.12	0.17	0.11
C.V. (%)	0.31	0.53	0.18	0.24	0.15

Table 25: Noise level (SPL) observations recorded under no muffler mounting on Tractor-1 (Mini Tractor) at different RPM at 30 m distance (Replication-I)

Sr. No.	1000	1250	1500	1750	2000
1	55.6	59.3	60.2	63.4	66.1
2	55.6	59.3	60.3	63.4	65.7
3	56	58.3	60.1	63.4	65.7
4	56	58.7	60.1	63.4	65.7
5	55.7	58.7	60.4	62.7	65.7
6	55.7	58.8	60.4	62.7	65.7
7	56.4	58.8	60.5	62.7	65.7
8	56.4	59.1	60.5	62.9	65.7
9	55.9	59.1	60.7	62.9	65.6
10	55.9	59.1	60.7	62.9	65.6
11	56.5	59.3	60.7	62.9	65.6
12	56.5	59.3	60.3	62.9	65.8
13	55.8	58.7	60.3	62.9	65.8
14	56.1	58.8	60.1	63.2	65.8
15	56.1	59	60.1	63.2	65.8
16	55.8	59	60.5	63.2	65.7
17	55.9	58.9	60.5	63.2	65.7
18	56.1	58.9	60.5	63.2	65.7
19	56.1	58.4	60.1	63	65.8
20	56.1	58.4	60.2	63	65.7
21	56.5	58.8	60.4	63	65.7
22	56.5	58.9	60.2	63.3	65.5
23	56.5	58.9	60.1	63.3	65.5
24	55.9	58.9	60.6	63.3	65.7
25	55.9	58.7	60.6	63	65.7
26	56.1	62.8	60.4	63	65.8
27	56.1	62.8	60.4	63	65.7
28	56.1	58.7	60.5	62.7	65.7
29	55.8	58.7	60.5	62.9	65.7
30	55.8	58.7	60.9	62.9	65.7
Mean	56.0	59.1	60.4	63.1	65.7
s	0.28	1.03	0.22	0.23	0.11
C.V. (%)	0.50	1.74	0.36	0.36	0.16

Table 26: Noise level (SPL) observations recorded under no muffler mounting on Tractor-1 (Mini Tractor) at different RPM at 30 m distance (Replication-II)

Sr. No.	1000	1250	1500	1750	2000
1	55.8	58.3	60.2	63	65.7
2	55.7	58.5	60.2	63	65.7
3	56.3	58.5	60.1	63.4	65.7
4	56.3	58.5	60.3	63.4	65.7
5	56.3	58.4	60.3	63.4	65.7
6	55.6	58.4	60.1	63.4	65.7
7	56.2	58.2	60.1	63.3	65.8
8	56.2	58.3	60.3	63.3	65.6
9	56.4	58.3	60.3	63.3	65.6
10	56.4	58.6	60.1	63.4	65.6
11	56.4	58.6	60.1	63.4	65.6
12	56.2	58.4	60.6	63.4	65.7
13	56.2	58.8	60.6	62.7	65.7
14	56.2	58.8	60.6	62.7	65.5
15	55.7	58.8	60.4	63.3	65.5
16	56.2	58.7	60.4	63.3	65.5
17	56.2	58.7	59.8	63.3	65.5
18	56.2	58.7	59.8	63.3	65.6
19	56.4	58.3	60.4	63	65.6
20	56.4	58.1	60.4	63	65.6
21	56.4	58.4	60.6	62.8	65.5
22	56.4	58.4	60.6	62.8	65.5
23	55.7	58.6	60.6	62.8	65.5
24	55.7	58.6	60.3	63	65.6
25	55.9	59.2	60.3	63	65.6
26	55.9	59.2	60.3	62.9	65.6
27	55.9	59.2	60.2	62.9	65.7
28	55.8	59.1	60.2	63.2	65.7
29	55.8	59.1	60.2	63.2	65.7
30	55.9	58.5	60.2	63.2	65.8
Mean	56.1	58.6	60.3	63.1	65.6
s	0.27	0.31	0.21	0.24	0.09
C.V. (%)	0.49	0.52	0.36	0.38	0.14

Table 27: Noise level (SPL) observations recorded under no muffler mounting on Tractor-1 (Mini Tractor) at different RPM at 30 m distance (Replication-III)

Sr. No.	1000	1250	1500	1750	2000
1	55.9	58.5	60.2	63.2	65.4
2	55.9	58.5	60.2	63.2	65.4
3	55.5	59.1	60.2	63.1	65.4
4	55.5	59.1	60.5	63.1	65.7
5	55.5	59.2	60.5	63.1	65.7
6	55.8	59.2	60.5	63.1	65.7
7	55.8	59.2	60.5	63.1	65.6
8	55.5	59.1	60	63.1	65.6
9	55.5	59.1	60.1	63.2	65.6
10	55.7	59.1	60.1	63.2	65.6
11	55.7	59.2	60.1	63.5	65.6
12	56.3	58.4	60.1	63.5	65.6

13	56.3	58.6	60.1	63.2	65.6
14	56.3	58	60.5	63.5	65.6
15	56	58.2	60.5	63.5	65.6
16	56	58.2	60.5	63.5	65.5
17	56	58.3	60.3	63.4	65.5
18	56	58.3	60.3	63.4	65.5
19	55.7	58.5	60.1	63.4	65.5
20	55.7	58.5	60.1	63	65.5
21	55.8	58.8	60.6	63.3	65.4
22	55.8	58.8	60.6	63.3	65.4
23	55.8	58.8	60.6	63.3	65.5
24	55.8	58.8	60.4	63.3	65.5
25	55.8	58.4	60.4	63.3	65.5
26	55.7	58.4	60.4	63.3	65.5
27	56	59	60.2	63.3	65.4
28	56	59	60.1	63.2	65.4
29	56	58.9	60.6	63.2	65.6
30	56	58.9	60.6	63.2	65.6
Mean	55.8	58.7	60.3	63.3	65.5
s	0.23	0.36	0.20	0.14	0.10
C.V. (%)	0.41	0.62	0.33	0.23	0.15

Table 28: Noise level (SPL) observations recorded under standard muffler mounting on Tractor-1 (Mini Tractor) at different RPM at 30 m distance (Replication-I)

Sr. No.	1000	1250	1500	1750	2000
1	56.7	59.3	61	61.7	62.9
2	56.3	59.3	61	61.7	62.9
3	56.3	59.7	61.1	61.6	62.9
4	56.3	59.7	61.1	61.6	63.2
5	56.9	59.6	61.5	61.6	63.2
6	56.9	59.6	61.5	61.6	63.2
7	56.9	59.6	61	61.5	63.6
8	57.3	59.9	61	61.5	63.6
9	57.3	59.9	60.8	61.8	63.1
10	57.3	59.9	60.8	61.8	63.1
11	56.5	60.3	60.8	61.4	63.2
12	56.5	60.3	60.9	61.4	63.2
13	56.9	60.3	60.9	61.4	62.9
14	56.9	60	60.9	61.4	62.9
15	56.9	60	60.8	61.4	63.2
16	57.4	59.8	60.8	61.4	63.2
17	57.4	59.8	60.8	61.4	63.2
18	57.4	59.8	60.8	61.8	63.2
19	57.1	59.8	60.8	61.8	63.2
20	57.1	59.6	60.9	61.7	63.2
21	56.8	59.6	60.9	61.7	63.2
22	56.8	59.6	61.2	61.7	63.2
23	56.8	59.7	61.2	61.7	63.3
24	56.8	59.7	61.2	61.7	63.3
25	56.8	59.8	61	61.8	63.3
26	56.8	59.8	61	61.4	63.2
27	56.8	59.8	61	61.4	63.2

28	56.8	59.6	60.9	61.4	63.6
29	56.8	59.6	60.9	61.5	63.6
30	57	59.6	60.9	61.5	63.6
Mean	56.9	59.8	61.0	61.6	63.2
s	0.31	0.24	0.19	0.15	0.21
C.V. (%)	0.55	0.41	0.31	0.25	0.33

Table 29: Noise level (SPL) observations recorded under standard muffler mounting on Tractor-1 (Mini Tractor) at different RPM at 30 m distance (Replication-II)

Sr. No.	1000	1250	1500	1750	2000
1	57	59.6	61	61.7	63.3
2	56.9	59.6	61	61.7	63.3
3	56.9	59.6	61	61.7	63.3
4	56.9	59.9	61	62	63.2
5	56.8	59.9	61	62	63.2
6	56.8	59.9	61.1	61.9	63
7	56.8	59.9	61.1	61.9	63
8	56.5	59.9	61.1	61.9	63
9	56.5	59.9	61.1	62	63.3
10	56.5	60	61.1	62	63.3
11	56.5	60	60.8	61.9	63.3
12	56.5	59.8	60.8	61.9	63.2
13	56.5	59.8	60.6	61.9	63.2
14	56.2	59.8	60.6	61.9	63.2
15	56.2	59.9	60.9	61.8	63.2
16	56.2	59.9	60.9	61.8	63.2
17	56.4	59.9	60.6	61.9	63.5
18	56.4	59.5	60.6	61.9	63.5
19	56.8	59.5	60.6	61.9	63.5
20	56.8	59.5	60.8	61.9	63.3
21	56.8	59.9	60.8	61.9	63.3
22	56.6	59.9	60.7	61.9	63.3
23	56.6	59.9	60.7	61.9	63.3
24	56.6	59.9	60.7	61.9	63.3
25	56.8	59.9	60.9	61.9	63.2
26	56.8	59.7	60.9	62	62.8
27	56.8	59.7	61	62	62.8
28	57	59.7	61	61.9	63.1
29	57	59.8	60.6	61.9	63.1
30	57	59.8	60.6	62.2	63.2
Mean	56.7	59.8	60.9	61.9	63.2
s	0.25	0.15	0.19	0.10	0.17
C.V. (%)	0.43	0.25	0.30	0.16	0.27

Table 30: Noise level (SPL) observations recorded under standard muffler mounting on Tractor-1 (Mini Tractor) at different RPM at 30 m distance (Replication-III)

Sr. No.	1000	1250	1500	1750	2000
1	57	59.8	60.7	62.2	63.2
2	56.8	59.7	60.7	62	63.2
3	56.8	59.7	60.7	62	63.2
4	56.6	59.7	60.5	62	63.2
5	56.6	59.4	60.5	62	63.4

6	56.6	59.4	60.5	61.9	63.4
7	56.6	59.4	60.5	61.9	62.9
8	56.9	59.1	60.5	62.4	62.9
9	56.9	59.1	60.5	62.4	62.9
10	57	59.1	61	62.4	63.1
11	57	59.3	61	62.1	63.1
12	56.7	59.3	60.6	62.1	63.1
13	56.7	59.3	60.6	62.3	63.4
14	56.7	59.8	60.9	62.3	63.4
15	56.6	59.8	60.9	62	63.4
16	56.6	59.8	61.1	62	63.4
17	56.6	60	61.1	62.1	63.4
18	56.6	60	61	62.1	63.1
19	56.6	60	61	62	63.1
20	57.1	60.1	60.8	62	63.4
21	57.1	60.1	60.8	62	63.4
22	57.3	60.1	61.2	62.5	63.1
23	57.3	60.1	61.2	62.5	63.1
24	57	60.1	61.2	62.3	63
25	57	59.7	61	62.3	63
26	56.8	59.7	60.7	62.1	63
27	57.2	59.7	60.7	62.1	63.3
28	57.2	59.9	60.7	62	63.3
29	56.9	59.9	60.7	62	63.4
30	56.9	59.9	60.7	62	63.4
Mean	56.9	59.7	60.8	62.1	63.2
s	0.23	0.32	0.23	0.18	0.18
C.V. (%)	0.40	0.54	0.38	0.29	0.28

Table 31: Noise level (SPL) observations recorded under muffler-3 (muffler-A) mounting on Tractor-1 (Mini Tractor) at different RPM at 30 m distance (Replication-I)

Sr. No.	1000	1250	1500	1750	2000
1	56.3	58.8	60.9	61.6	63.5
2	56.3	58.8	60.7	61.6	63.5
3	56.3	59.1	60.7	61.6	63.5
4	56.3	58.6	60.7	61.8	63.2
5	56.2	58.6	60.7	61.8	63.2
6	56.2	58.5	60.7	61.7	63.5
7	56.6	58.5	60.7	61.6	63.5
8	56.6	58.4	61.1	61.6	63.2
9	56.6	58.4	61.1	61.6	63.2
10	56.1	58.7	61.1	61.9	63.2
11	56.1	58.7	60.9	61.9	63.2
12	56.1	58.4	60.9	62.1	63.1
13	56.1	58.4	61.1	62.1	63.1
14	56.1	59.4	61.1	62.1	63.2
15	56.1	59.4	61.1	62	63.2
16	56.1	58.8	61.1	62	63.2
17	56.2	58.8	61.4	61.8	63.5
18	56.2	58.4	61.4	61.8	63.3
19	56.2	58.4	61.6	61.8	63.3
20	56.4	58.9	61.6	61.5	63.3

21	56.4	58.9	62	61.5	63.1
22	56.4	58.9	61.5	62.3	63.1
23	56.5	58.9	61.5	62.3	63.2
24	56.5	58.5	61	62.3	63.2
25	56.5	58.5	61	61.6	63.2
26	55.9	58.5	61.2	61.6	62.8
27	55.9	58.2	61.2	61.6	62.8
28	56.1	58.2	61.1	61.9	62.8
29	56.1	58.7	61.1	61.9	63
30	56.1	58.5	60.9	61.9	63
Mean	56.3	58.7	61.1	61.8	63.2
s	0.20	0.30	0.32	0.24	0.20
C.V. (%)	0.35	0.51	0.52	0.39	0.32

Table 32: Noise level (SPL) observations recorded under muffler-3 (muffler-A) mounting on Tractor-1 (Mini Tractor) at different RPM at 30 m distance (Replication-II)

Sr. No.	1000	1250	1500	1750	2000
1	56.3	58.5	60.9	61.9	63
2	56.3	58.5	60.9	61.9	63
3	56.3	58.6	61.3	61.9	63
4	56.4	58.6	61.3	61.9	63
5	56.4	58.6	60.8	61.9	63
6	56.8	58.9	60.8	61.9	62.9
7	56.8	58.9	61.2	61.8	62.9
8	56.6	58.9	61.2	61.8	62.8
9	56.6	58.3	61.4	61.9	62.8
10	56.6	58.3	61.4	61.9	63.2
11	56.6	58.6	61.4	61.9	63.2
12	56.4	58.6	60.9	62.2	63.2
13	56.4	58.9	60.9	62.2	63
14	56.2	58.9	60.9	62.2	63
15	56.2	59.2	60.9	62	62.9
16	56.2	59.2	60.9	62	62.9
17	56.2	59.2	61.2	62.4	63.5
18	56.3	58.6	61.2	62.4	63.5
19	56.3	58.6	61.6	62.4	63.5
20	56.3	58.8	61.6	62.4	63.3
21	56.4	58.8	61.9	62.4	63.3
22	56.4	58.8	61.9	62.4	63
23	56.4	59.1	61.1	62.1	63
24	56.1	59.1	61.1	62.1	63.5
25	56.1	58.8	60.5	62.1	63.5
26	56.4	58.8	60.5	62.1	63.5
27	56.4	59	60.5	62.1	63.2
28	56.4	59	60.8	62.4	63.2
29	56.1	58.8	60.8	62.4	63.2
30	56.1	58.8	61	62.4	63.4
Mean	56.4	58.8	61.1	62.1	63.1
s	0.19	0.25	0.37	0.22	0.23
C.V. (%)	0.33	0.42	0.60	0.35	0.37

Table 33: Noise level (SPL) observations recorded under muffler-3 (muffler-A) mounting on Tractor-1 (Mini Tractor) at different RPM at 30 m distance (Replication-III)

Sr. No.	1000	1250	1500	1750	2000
1	56.4	59.1	61	62.4	63.4
2	56.4	59.1	61	62.4	63.2
3	56.4	59.2	61	62	63.2
4	56.5	59.2	60.8	62	62.9
5	56.5	58.6	60.8	62	62.9
6	56.5	58.6	60.8	62.2	63.3
7	56.5	58.8	60.8	62.2	63.3
8	56.5	58.8	60.8	62.2	63.3
9	56.5	58.8	61	62.1	62.7
10	56.3	59.2	61	62.1	62.7
11	56.3	59.2	61	62.1	62.7
12	56	59.1	61	62.1	62.7
13	56	59.1	61	62.1	63.2
14	56	59.1	60.9	62.1	63.2
15	56.4	59.4	60.9	62	63.2
16	56.4	59.4	60.8	62	63.1
17	56.4	59	60.8	62	63.1
18	56.4	59	60.8	61.8	63.5
19	56.4	59	60.8	61.8	63.5
20	56.1	59.1	60.8	61.8	63.2
21	56.1	59.1	60.9	61.7	63.2
22	56.1	59	60.9	61.7	63.2
23	56	59	60.9	61.7	63.4
24	56	58.9	60.8	61.7	63.4
25	56.3	58.9	60.8	61.7	63.2
26	56.3	58.9	60.8	61.7	63.2
27	56.6	58.9	60.7	61.8	63.1
28	56.6	58.8	60.7	61.8	63.1
29	56.3	58.6	60.9	61.8	63.2
30	56.5	58.6	60.9	62	63.2
Mean	56.3	59.0	60.9	62.0	63.2
s	0.19	0.22	0.10	0.21	0.23
C.V. (%)	0.34	0.37	0.16	0.33	0.36

Table 34: Noise level (SPL) observations recorded under muffler-7 (muffler-C) mounting on Tractor-1 (Mini Tractor) at different RPM at 30 m distance (Replication-I)

Sr. No.	1000	1250	1500	1750	2000
1	56	58.8	61.4	61.3	62.2
2	56.2	58.8	61.4	61.3	62.5
3	56.2	58.8	61.2	61.2	62.5
4	56.6	58.8	61.2	61.2	62.5
5	56.6	58.4	61.3	61.1	62.5
6	56.9	58.4	61.3	61.1	62.5
7	56.9	58.6	61.3	61.4	62.7
8	57.1	58.6	61.3	61.4	62.7
9	57.1	58.6	61.3	61.7	62.6
10	57.1	58.3	61.3	61.7	62.6
11	57.2	58.3	61.3	61.7	62.6
12	57.2	58.4	61.2	61.5	62.8

13	57.2	58.4	61.2	61.5	62.8
14	56.3	58.2	61.8	61.5	62.6
15	56.3	58.2	61.8	61.5	62.6
16	56.3	58.2	61.2	61	62.6
17	56.4	57.8	61.2	61	62.5
18	56.4	57.8	61.2	61.4	62.5
19	56.2	57.9	61.4	61.4	62.4
20	56.2	57.9	61.4	61.6	62.4
21	56.2	57.9	61.1	61.6	62.4
22	56.5	58	61.1	61.5	62.2
23	56.5	58	61.1	61.5	62.2
24	56.5	57.9	61.1	61.4	62.2
25	56.1	57.9	61.2	61.4	62.3
26	56.1	58	61.2	61.2	62.3
27	56.8	58	61.2	61.2	62.7
28	56.8	58.1	61.3	61.7	62.7
29	56.8	58.1	61.3	61.7	62.7
30	56.2	58.3	61	61.4	62.7
Mean	56.6	58.2	61.3	61.4	62.5
s	0.38	0.32	0.17	0.21	0.18
C.V. (%)	0.68	0.55	0.28	0.34	0.29

Table 35: Noise level (SPL) observations recorded under muffler-7 (muffler-C) mounting on Tractor-1 (Mini Tractor) at different RPM at 30 m distance (Replication-II)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	56.2	58.3	61	61.4	62.7
2	56.2	58.3	61	61.2	62.7
3	56.3	58.5	60.9	61.2	62.5
4	56.3	58.5	60.9	61.2	62.5
5	56.3	58.5	61.2	61.5	62.6
6	57	58.2	61.2	61.5	62.6
7	57	58.2	60.9	61.1	62.8
8	57	58.2	60.9	61.1	62.8
9	56.4	58.6	61.7	61.9	62.8
10	56.4	58.6	61.7	61.5	62.8
11	56.9	58.7	61.7	61.5	62.7
12	56.9	58.7	60.9	61.6	62.7
13	56.3	58.7	60.9	61.6	62.7
14	56.3	58.8	60.9	61.9	62.6
15	56.3	58.8	61	61.9	62.6
16	56.3	58.6	61	61.7	62.8
17	56.3	58.6	61.1	61.7	62.8
18	56.1	58.7	61.1	61.5	62.5
19	56.1	58.7	61	61.5	62.5
20	56.1	58.7	61	61.2	62.2
21	56.1	58.6	61	61.2	62.2
22	56.1	58.6	61	61.7	62.2
23	56.5	58.4	60.8	61.7	62.1
24	56.5	58.4	60.8	61.7	62.1
25	56.5	58.3	60.7	61.3	62.9
26	56.7	58.2	60.7	61.3	62.9
27	56.7	58.2	60.7	61.3	62.6

28	56.7	58.7	60.7	61.1	62.6
29	56.7	58.7	60.4	61.1	62.5
30	56.7	58.4	60.4	60.7	62.5
Mean	56.5	58.5	61.0	61.4	62.6
s	0.30	0.20	0.31	0.29	0.23
C.V. (%)	0.53	0.34	0.51	0.47	0.36

Table 36: Noise level (SPL) observations recorded under muffler-7 (muffler-C) mounting on Tractor-1 (Mini Tractor) at different RPM at 30 m distance (Replication-III)

Sr. No.	1000	1250	1500	1750	2000
1	56.6	58.4	60.4	61.2	62.4
2	56.6	58.4	60.4	61.2	62.4
3	56.6	58.8	60.5	61.2	62.4
4	56.3	58.8	60.5	61.1	62.4
5	56.3	58.9	60.6	61.1	62.1
6	56.2	58.9	60.6	61.7	62.1
7	56.2	58.9	60.5	61.7	62.4
8	56.2	58.9	60.5	61.3	62.4
9	56.2	58.9	60.7	61.3	62.2
10	56.2	58.4	60.7	61.3	62.2
11	56.5	58.4	60.5	60.7	62.1
12	56.5	58.5	60.5	60.7	62.1
13	56.3	58.5	60.5	60.7	62.1
14	56.3	58.7	60.7	60.7	62.1
15	55.8	58.7	60.7	61.1	62.6
16	55.8	58.8	60.4	61.1	62.9
17	55.6	58.8	60.4	60.8	62.9
18	55.6	58.8	60.4	60.8	62.2
19	55.6	58.7	60.4	60.8	62.2
20	56.1	58.7	60.4	61.2	62.1
21	56.1	58.5	60.4	61.2	62.1
22	56.3	58.5	60.3	61.2	62.6
23	56.3	58.5	60.2	61	62.6
24	56.1	58.5	60.4	61	62.3
25	56.3	58.5	60.3	61	62.3
26	56.4	58.6	60.3	61.3	62.3
27	56.4	58.6	60.5	61.3	62.3
28	56.7	58.5	60.5	61.4	62.4
29	56.4	58.5	60.3	61.4	62.5
30	56.5	59.1	60.3	61.4	62.5
Mean	56.2	58.7	60.5	61.1	62.3
s	0.30	0.19	0.13	0.27	0.22
C.V. (%)	0.53	0.33	0.22	0.45	0.36

Table 37: Noise level (SPL) observations recorded for background noise (Replication-I, II & III)

Sr. No.	**R-I**	**R-II**	**R-III**
1	36	39.2	42.8
2	36.3	39.2	42.8
3	35.7	38.9	42.2
4	34.8	38.9	38.4
5	37	38.8	38.4
6	34.8	39.6	38.7
7	36.9	39.6	37.5
8	36.9	38.8	37.5
9	34.5	38.8	36.7
10	37.8	38.8	36.7
11	37.8	41.8	35.5
12	39.4	40	35.5
13	39.4	40	35
14	39.4	38.5	35.9
15	36.9	38.5	34.8
16	37	37.4	34.8
17	37	37.4	35.8
18	35.8	37	35.8
19	37.2	37	35
20	39.6	36	35
21	40.3	36	35.3
22	37.7	39	35.5
23	37.7	39	35.3
24	36.3	37	36
25	36.3	37	36
26	40.1	36.8	36.9
27	40.1	36.8	36.9
28	40.7	36.5	37.1
29	40.7	36.5	40.6
30	36.3	36.7	39.2
Mean	37.5	38.2	37.1
s	1.83	1.41	2.35
C.V. (%)	4.87	3.70	6.32

APPENDIX-II

Noise level (SPL) Observations Recorded under Different Muffler Mounting on Tractor-2 at Different RPM

Table 1: Noise level (SPL) observations recorded under no muffler mounting on Tractor-2 at different RPM at ear level (Replication-I)

Sr. No.	1000	1250	1500	1750	2000
1	80	82.8	87.3	90.1	93.1
2	79.7	83.2	87.2	90.4	93
3	80.2	83.1	87.2	90.3	93.3
4	79.7	82.9	87.4	90.4	93.2
5	79.2	83.2	87	90.4	93
6	80.1	83	87.1	90.1	93.1
7	79.8	83.1	87.2	90	93
8	80	82.7	87.1	90.1	93.3
9	79.5	83.2	87.4	90.7	93.4
10	79.1	83.1	87.2	90.5	93.4
11	78.9	82.9	87.5	90.6	93.6
12	79.3	83.1	87.3	90.5	93.5
13	79.3	83.1	87.2	90.7	93.2
14	79.2	83	87.4	90.6	93.2
15	79.4	83.7	87.2	90.3	93
16	79.1	83.1	87.1	90.6	93.3
17	79.1	83.2	87.4	90.2	93.4
18	79.3	83.3	86.6	90.3	93
19	80.2	82.8	87	90.3	93.4
20	79.4	82.9	87	90.4	93.1
21	78.9	83.5	87.2	90.8	93
22	79.8	83.2	86.9	90.5	92.8
23	79.8	83	87.6	90.5	93
24	79.1	83.2	86.9	90.6	93
25	79.2	83.5	87.3	90.4	93.1
26	79.3	83.5	87	90.4	92.8
27	79.1	83.3	87.2	90.6	92.8
28	79.2	83	87.6	90.6	93.2
29	79.4	82.9	86.9	90.7	93.2
30	79.5	83	87	90.6	93.1
Mean	79.5	83.1	87.2	90.4	93.2
s	0.38	0.23	0.22	0.20	0.20
C.V. (%)	0.48	0.28	0.26	0.23	0.22

Table 2: Noise level (SPL) observations recorded under no muffler mounting on Tractor-2 at different RPM at ear level (Replication-II)

Sr. No.	1000	1250	1500	1750	2000
1	84.1	88.3	92.2	96.1	98.8
2	83.8	88.4	92.2	95.5	98.8
3	83.8	88.4	92.2	95.5	98.9
4	83.4	88.2	92.2	95.8	98.9
5	83.4	88.2	92.4	95.8	98.9
6	83.2	88.3	92.4	95.7	98.9
7	83.2	88.3	92.4	95.7	98.8

8	83.3	87.9	92.4	95.8	98.8
9	83.3	87.9	92.1	95.8	98.8
10	83.5	87.9	92.1	95.7	98.5
11	83.5	87.9	92.4	95.7	98.5
12	83.1	87.9	92.4	95.7	98.3
13	83.1	88.5	92.4	95.7	98.7
14	83.1	88.5	92.6	95.7	98.7
15	83.1	87.9	92.6	95.7	98.7
16	83.4	87.9	92.3	95.8	98.7
17	83.4	88.4	92.3	95.6	99
18	83.7	88.4	92.6	95.6	99
19	83.7	88.3	92.6	95.5	98.9
20	83.8	88.3	92.7	95.5	98.9
21	83.4	88.3	92.7	95.7	98.8
22	83.4	88.1	92.7	95.7	98.8
23	83.3	88.1	92.7	95.8	98.6
24	83.8	88.4	92.4	95.8	98.6
25	83	88.7	92.4	96	98.6
26	83.1	88.7	92.2	96	98.6
27	83.1	87.9	92.2	95.7	98.6
28	83.4	87.9	92.7	95.5	98.8
29	83.3	87.9	92.7	95.5	98.5
30	83.3	88.4	92.1	95.4	98.5
Mean	83.4	88.2	92.4	95.7	98.7
s	0.27	0.26	0.21	0.16	0.17
C.V. (%)	0.33	0.29	0.22	0.17	0.17

Table 3: Noise level (SPL) observations recorded under no muffler mounting on Tractor-2 at different RPM at ear level (Replication-III)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	83.5	88.4	92.5	95.4	98.9
2	83.5	88	92.5	96	98.9
3	83.6	88	92.2	96	98.8
4	83.7	88	92.2	95.9	98.8
5	83.7	88.2	92.2	95.9	98.5
6	83.9	88.2	92.4	95.5	98.5
7	83.8	88.2	92.4	95.5	98.6
8	83.8	88.2	92.9	95.9	98.8
9	84	88	92.9	95.9	98.8
10	83.4	88	92.2	95.6	98.6
11	83.4	88.5	92.2	95.6	98.6
12	83.5	88.5	92	95.8	98.4
13	83.5	88.3	92	95.8	97.9
14	83.7	88.3	92.1	95.6	97.9
15	84.1	88.3	92.1	95.6	98.3
16	84.1	88.3	92.7	96	98.3
17	83.2	88.3	92.7	96	98.5
18	83.2	88.1	92.4	96.3	98.5
19	83.2	88.1	92.4	96.3	98.2
20	83.7	88.1	92.4	96	98.2
21	83.5	88.1	92.6	96	98.5
22	83.8	88.4	92.6	95.9	98.5

23	83.2	88.4	92.1	95.9	98.2
24	83.5	88.3	92.1	95.8	98.2
25	83.5	88.3	91.8	96.3	98.5
26	83.4	88.3	91.8	96.3	98.6
27	83.5	88.4	92.6	96.1	98.6
28	83.3	88.4	92.6	96.1	98.4
29	83.3	88.2	92.6	95.8	98.4
30	83.5	88.2	92.6	95.9	98.6
Mean	83.6	88.2	92.4	95.9	98.5
s	0.26	0.15	0.29	0.25	0.26
C.V. (%)	0.31	0.17	0.32	0.26	0.26

Table 4: Noise level (SPL) observations recorded under standard muffler mounting on Tractor-2 at different RPM at ear level (Replication-I)

Sr. No.	1000	1250	1500	1750	2000
1	80.6	82.5	84.5	86.9	89.1
2	80.6	82.8	84.5	86.8	89.2
3	80	82.8	84.6	86.8	89.2
4	80	83	84.6	86.9	89.2
5	80	83	84.8	86.9	89.2
6	79.8	83	83.7	86.9	89.2
7	79.8	83.2	83.7	87.1	89.2
8	79.8	83.2	83.7	87.1	89.2
9	79.5	83.2	84	87.1	89.3
10	79.5	83.2	84.4	87.2	89.3
11	79.5	83.2	84.4	87.2	89.4
12	79.7	83.2	84.4	87.2	89.4
13	79.7	83.1	84.3	87.2	89.4
14	79.7	83.1	84.3	87	89.3
15	79.7	83.3	84.3	87	89.3
16	79.7	83.3	84.3	87	89.3
17	79.7	83.3	84.3	87.2	89.4
18	79.7	83.2	84.3	87.2	89.4
19	79.7	83.2	84.3	87.2	89.4
20	79.8	83.2	84.3	87.2	89.5
21	79.8	83.1	84.4	87.3	89.5
22	79.8	83.1	84.4	87.3	89.5
23	79.7	83.1	84.4	87.3	89.6
24	79.7	83.1	84.2	87.7	89.6
25	79.7	83.1	84.2	87.7	89.6
26	79.8	83.1	84.2	87.7	89.5
27	79.8	83.1	84.2	87.9	89.5
28	79.8	83	84.2	87.9	89.5
29	79.8	83	84.2	88.1	89.5
30	79.8	83	84.2	88.1	89.5
Mean	79.8	83.1	84.3	87.3	89.4
s	0.25	0.17	0.25	0.37	0.14
C.V. (%)	0.31	0.20	0.30	0.43	0.16

Table 5: Noise level (SPL) observations recorded under standard muffler mounting on Tractor-2 at different RPM at ear level (Replication-II)

Sr. No.	1000	1250	1500	1750	2000
1	79.8	83	84.2	87.9	89.5
2	79.9	83	84.2	87.9	89.5
3	79.9	83	84.4	87.9	89.4
4	79.9	83	84.4	87.9	89.4
5	79.8	83	84.4	87.9	89.4
6	79.8	83	84.3	87.9	89.4
7	79.8	82.8	84.3	87.9	89.5
8	79.8	82.8	84.3	87.9	89.5
9	79.8	82.8	84.1	87.9	89.5
10	79.8	82.8	84.1	87.7	89.5
11	79.8	83	84.1	87.7	89.5
12	79.8	83	84.1	87.7	89.7
13	79.8	83	84.1	87.8	89.6
14	79.8	83	84.1	87.8	89.6
15	80	83	84.1	87.8	89.6
16	80	83.2	84	87.8	89.3
17	80	83.2	84	87.6	89.3
18	80	83.2	84	87.6	89.3
19	80	83.2	84.3	87.9	89.1
20	80	83.2	84.3	87.9	89.1
21	79.7	82.9	84.3	87.9	89.1
22	79.7	82.9	84.1	87.9	89.4
23	79.7	82.9	84.1	87.9	89.4
24	79.7	82.9	84.1	87.9	89.4
25	79.7	82.9	84.4	88.4	89.4
26	79.7	82.9	84.4	88.4	89.4
27	79.7	82.9	84.4	88.4	89.5
28	79.7	82.9	84.5	88.1	89.5
29	80	83	84.5	88.1	89.5
30	80	83	84.3	87.9	89.5
Mean	79.8	83.0	84.2	87.9	89.4
s	0.12	0.12	0.15	0.20	0.14
C.V. (%)	0.15	0.15	0.18	0.23	0.16

Table 6: Noise level (SPL) observations recorded under standard muffler mounting on Tractor-2 at different RPM at ear level (Replication-III)

Sr. No.	1000	1250	1500	1750	2000
1	80	83	84.3	87.2	90.9
2	79.9	83	84.3	87.2	90.6
3	79.9	82.9	84.3	87.2	90.6
4	79.9	82.9	84.3	87.2	90.6
5	79.9	82.9	84.3	87.2	90.6
6	79.9	82.9	84.3	87.2	90.7
7	79.9	83.1	84.4	87.2	90.7
8	79.9	83.1	84.4	87.2	90.5
9	79.9	83.1	84.4	87.2	90.5
10	79.9	83.1	84.2	87.4	90.6
11	79.9	83	84.2	87.4	90.7
12	79.9	83	84.2	87.3	90.7

13	79.9	83	84.2	87.3	90.9
14	79.9	83	84.2	87.3	90.9
15	79.9	83	84.2	87.3	90.6
16	79.9	83	84.2	87.3	90.6
17	79.7	83	84.2	87.4	90.8
18	79.7	83	84.2	87.4	90.8
19	80	83	84.3	87.5	90.5
20	80	83	84.3	87.3	90.6
21	80	83	84.3	87.3	90.6
22	80.1	83	84.3	87.3	90.7
23	80.1	83	84.3	87.6	90.7
24	80.1	83	84.3	87.6	90.7
25	79.9	83	84.3	87.9	90.7
26	79.9	82.9	84.2	87.6	90.7
27	79.9	82.9	84.2	87.8	90.7
28	79.9	82.9	84.2	87.6	90.9
29	80.1	83.2	84.3	88.1	90.9
30	80.1	83.2	84.3	88.1	90.7
Mean	79.9	83.0	84.3	87.4	90.7
s	0.10	0.08	0.07	0.26	0.12
C.V. (%)	0.12	0.10	0.08	0.30	0.13

Table 7: Noise level (SPL) observations recorded under muffler-4 (muffler-B) mounting on Tractor-2 at different RPM at ear level (Replication-I)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	78.8	82.1	85.1	87.2	90.6
2	78.9	82.1	84.9	87.3	90.2
3	78.9	81.7	84.9	86.9	90.2
4	79.1	81.7	84.9	86.9	90.2
5	79.1	82	84.8	87.1	90.2
6	79.1	82	84.8	87.1	90.5
7	79.1	82	84.8	87.1	90.5
8	79.1	81.8	84.7	87	90.5
9	78.9	81.8	84.7	87	90.7
10	78.8	82.2	84.8	87	90.7
11	78.8	82.2	84.8	87.1	90.8
12	79	82.2	84.6	87.1	90.1
13	79	82.1	84.6	87.1	90.6
14	78.9	82.1	84.6	87	90.6
15	78.9	82.2	84.6	87	90.4
16	78.8	82.2	84.6	87	90.4
17	78.9	81.9	84.6	87	90.4
18	78.9	81.9	85	87	90.4
19	78.8	81.9	85	87.2	90.4
20	78.8	82	85	87.2	90.2
21	78.9	82	85.5	86.9	90.2
22	78.8	82	85.8	86.9	90.2
23	78.8	82	85.8	86.9	90.2
24	78.8	82	85.6	86.9	90.2
25	78.9	82	85.6	86.9	90.4
26	78.6	82	85.6	86.9	90.4
27	78.4	82.1	85.6	87.2	90.4

28	78.4	82.1	85.6	87.2	90.2
29	78.5	82.1	85.3	87.2	90.2
30	78.7	81.7	85.3	87.2	90.2
Mean	78.8	82.0	85.1	87.1	90.4
s	0.19	0.15	0.41	0.12	0.19
C.V. (%)	0.24	0.18	0.48	0.14	0.21

Table 8: Noise level (SPL) observations recorded under muffler-4 (muffler-B) mounting on Tractor-2 at different RPM at ear level (Replication-II)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	79.1	81.7	83.9	87.2	90.1
2	79.1	81.7	83.9	87.3	90.1
3	79.1	81.5	83.7	87.3	90.1
4	79	81.5	83.7	87.2	90.1
5	79	81.5	83.9	87.2	90.2
6	79	81.5	83.9	87	90.2
7	79.1	81.4	83.6	87	90.2
8	79.1	81.4	83.6	87.1	90.2
9	79.1	81.4	83.7	87.1	90.2
10	78.9	81.7	83.6	87.2	90.2
11	78.9	81.7	83.6	87.2	90.2
12	78.9	81.7	83.8	87.2	90.2
13	78.9	81.7	83.8	87	90.2
14	78.9	81.6	83.8	87	90.2
15	78.9	81.6	83.8	87	90.2
16	78.9	81.6	83.8	87	90.2
17	79	81.6	83.8	87.1	90.1
18	79	81.6	83.8	87.1	90.1
19	79	81.6	83.8	86.9	90.1
20	78.9	81.7	83.8	86.9	90.2
21	78.9	81.7	83.8	86.9	90.2
22	78.9	81.7	83.8	86.9	90.2
23	78.8	81.5	83.9	86.9	90.2
24	78.8	81.5	83.9	86.9	90.3
25	79.2	81.7	83.9	86.8	90.3
26	79.2	81.7	83.9	86.8	90.3
27	79	81.7	83.9	86.6	90.3
28	79	81.9	83.9	86.7	90.3
29	78.8	81.9	83.9	86.7	90.3
30	78.8	81.9	83.9	86.7	90.3
Mean	79.0	81.6	83.8	87.0	90.2
s	0.11	0.14	0.10	0.19	0.07
C.V. (%)	0.14	0.17	0.12	0.22	0.08

Table 9: Noise level (SPL) observations recorded under muffler-4 (muffler-B) mounting on Tractor-2 at different RPM at ear level (Replication-III)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	79.3	82.3	84	87.6	90.2
2	79.1	82.3	84	87.6	90.2
3	79.1	82.5	83.5	87.4	90.1
4	79	82.5	83.5	87.4	90.1
5	79	82.1	83.8	87.4	90.3

6	79.1	82.1	83.8	87.4	90.3
7	79.1	82.1	83.8	87.4	90.3
8	79.1	81.9	84	87.5	90.2
9	79.1	82.1	84	87.7	90.2
10	79.1	82.1	84	87.7	90.2
11	79.1	82.1	84	87.4	90.2
12	79.1	81.9	83.4	87.6	90.2
13	78.9	81.9	83.4	87.7	90.2
14	78.9	82.1	83.7	87.7	90.3
15	79.3	82.1	83.7	87.5	90.3
16	79.3	82.1	83.6	87.5	90.3
17	79.3	82.3	83.6	87.5	90.3
18	78.8	82.1	83.7	87.4	90.5
19	78.8	82	84.1	87.4	90.5
20	78.8	81.9	84.1	87.6	90.4
21	79.1	81.8	84.1	87.6	90.4
22	79.1	82	83.9	87.6	90.2
23	79.1	82	83.9	87.9	90.2
24	79.1	82	84	87.6	90.2
25	79.1	81.9	84	87.6	90.2
26	79.1	81.9	83.7	87.7	90.2
27	79.3	81.9	83.7	87.5	90.2
28	79.3	81.8	83.8	87.5	90.4
29	79.3	81.8	83.8	87.5	90.4
30	79.1	81.8	83.9	87.6	90.1
Mean	79.1	82.0	83.8	87.6	90.3
s	0.15	0.19	0.21	0.13	0.11
C.V. (%)	0.19	0.23	0.25	0.14	0.12

Table 10: Noise level (SPL) observations recorded under muffler-7 (muffler-C) mounting on Tractor-2 at different RPM at ear level (Replication-I)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	78.8	82.4	84.7	87.6	89.2
2	78.8	82.3	85	87.6	89.5
3	78.8	82	85	86.8	89.5
4	79.1	82	85.2	86.8	89.6
5	79	82.2	85.2	87.2	89.5
6	79	82.2	85.2	87.2	89.5
7	79	82.2	85.2	87.2	89.5
8	79	82.2	85.2	87.2	89.6
9	79	82.2	85	87.2	89.6
10	79	82.2	85	87.4	90
11	79	82.1	85.1	87.4	90
12	78.9	82.1	85.1	87.4	89.9
13	78.9	82.1	85.1	87.4	89.9
14	78.9	81.9	84.9	87.5	89.7
15	78.9	81.9	84.9	87.5	89.8
16	78.9	81.9	85	87.5	89.8
17	78.9	81.9	85	87.5	89.8
18	78.9	82	85.2	87.5	89.8
19	78.9	82.2	85.2	87.3	89.8
20	78.3	81.4	84.9	87.3	89.6

21	78.3	82	84.9	87.5	89.6
22	78.3	81.4	85	87.5	89.6
23	78.3	81.4	85	87.4	89.5
24	78.4	81.6	85	87.4	89.5
25	78.4	81.6	84.9	87.2	89.5
26	78.4	81.6	84.9	87.2	89.5
27	78.7	81.6	85.2	87.2	89.5
28	78.7	81.6	85.2	87.7	89.6
29	78.7	81.4	85.2	87.6	89.6
30	78.5	81.4	83.9	87.6	89.4
Mean	78.8	81.9	85.0	87.4	89.6
s	0.26	0.32	0.25	0.21	0.18
C.V. (%)	0.33	0.39	0.29	0.25	0.21

Table 11: Noise level (SPL) observations recorded under muffler-7 (muffler-C) mounting on Tractor-2 at different RPM at ear level (Replication-II)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	78.9	82.4	83.4	86.9	89.4
2	78.9	82.4	83.9	86.9	89.4
3	78.7	82.5	83.9	86.9	89.4
4	78.7	82.5	83.8	86.9	89.4
5	78.7	82.5	83.8	86.9	89.5
6	78.7	82.5	84	86.8	89.5
7	78.7	82.5	84	86.8	89.5
8	78.7	82.6	84.1	86.8	89.7
9	78.6	82.6	84.1	87.1	89.7
10	78.6	82.5	83.8	87.1	89.7
11	78.6	82.5	83.8	86.8	89.6
12	78.8	82.3	83.9	87.1	89.6
13	78.8	82.3	83.9	86.7	89.5
14	78.8	82.4	84	86.7	89.5
15	79.1	82.5	84	86.8	89.5
16	79.1	82.5	84	86.9	89.5
17	79.1	82.4	83.9	86.9	89.5
18	78.5	82.4	83.9	86.8	89.6
19	78.5	82.4	83.9	86.8	89.6
20	78.5	82.4	83.9	86.7	89.6
21	78.9	82.4	84.1	86.8	89.8
22	78.9	82.4	84.1	86.9	89.6
23	78.9	82.3	84.1	86.9	89.7
24	78.8	82.3	83.9	86.8	89.7
25	78.8	82.4	83.9	87.2	89.8
26	78.8	82.4	84.2	87.2	89.8
27	78.7	82.1	84.2	87.1	89.9
28	78.7	82.1	84	87.1	89.9
29	78.8	82.1	84	86.9	89.7
30	78.6	82.1	84	86.9	89.7
Mean	78.8	82.4	84.0	86.9	89.6
s	0.17	0.14	0.15	0.14	0.14
C.V. (%)	0.21	0.17	0.18	0.16	0.16

Table 12: Noise level (SPL) observations recorded under muffler-7 (muffler-C) mounting on Tractor-2 at different RPM at ear level (Replication-III)

Sr. No.	1000	1250	1500	1750	2000
1	79.3	82.8	84	86.6	89.9
2	79.3	82.7	84.2	86.6	89.8
3	79.3	82.6	84.2	86.6	89.9
4	79.3	82.7	83.9	86.6	89.9
5	79.6	82.7	83.9	86.7	89.7
6	79.4	82.5	84	86.7	89.7
7	79.4	82.5	84	86.8	89.7
8	79.4	82.4	84	86.8	89.8
9	79.3	82.4	84	86.6	89.8
10	79.3	82.6	84.1	86.6	89.8
11	79.4	82.6	84.1	86.6	90.1
12	79.4	82.4	84.1	86.8	90.2
13	79.4	82.4	84.1	86.8	90
14	79.4	82.4	84.4	86.8	90
15	79.3	82.4	84.4	86.8	90.2
16	79.3	82.7	84.2	86.5	90.2
17	79.3	82.4	84.2	86.7	89.9
18	79.3	82.4	84.2	86.7	89.9
19	79.2	82.5	84.3	86.7	89.9
20	79.2	82.1	84.3	86.8	89.7
21	79.2	82.1	84.3	86.8	89.7
22	79.4	82.1	84.3	86.9	90
23	79.2	82.1	84.3	86.7	89.9
24	79.2	82.3	84.2	86.6	89.9
25	79.3	82.3	84.2	86.8	90.2
26	79.3	82.3	84.1	86.8	90.2
27	79.3	82.3	84.1	86.8	90.1
28	79.1	82.3	84.2	86.8	89.9
29	79.1	82.4	84.2	86.7	89.9
30	79.4	82.4	84.2	87.1	90
Mean	79.3	82.4	84.2	86.7	89.9
s	0.10	0.19	0.13	0.12	0.16
C.V. (%)	0.13	0.23	0.16	0.14	0.18

Table 13: Noise level (SPL) observations recorded under no muffler mounting on Tractor-2 at different RPM at 10 m distance (Replication-I)

Sr. No.	1000	1250	1500	1750	2000
1	68.2	71.8	76.1	80.9	82.9
2	67.9	71.4	76.5	80.7	83.4
3	67.6	71.4	76.8	80.9	82.4
4	68.1	71	76.7	80.4	82.8
5	67.7	71.3	76.9	80.1	83.3
6	67.6	71.3	76.6	81	82.6
7	67.6	71.8	77	80.9	82.7
8	67.8	71.4	77.5	80.1	83.2
9	67.4	71.4	76.8	80.6	85
10	67.7	71.3	76.6	80.9	83.4
11	67.9	71.5	76.2	80.5	82.4

12	68.1	71.6	76.6	81	82.7
13	67.9	71.9	77	80.4	81.5
14	68.1	71.9	76.6	80.4	82.4
15	67.9	72.2	77.2	81.1	82.7
16	67.5	72.3	77.2	81	83.4
17	67.9	72.8	76.8	80.8	82.3
18	67.9	71.3	77.3	80.9	82.3
19	68	72	77.5	80.4	82.4
20	67.8	71.8	77.1	80.5	82.7
21	67.7	72.1	76.8	80.4	82.7
22	68.4	72.1	77.1	81	82.6
23	68	72.1	76.6	80.3	82.5
24	67.9	72	76.6	80.4	82.5
25	67.7	71.5	76.5	80.7	82.7
26	67.8	71.9	77	80.4	82.9
27	67.8	71.8	77.6	80.4	82.4
28	68	71.5	76.5	80.5	82.9
29	67.7	71.5	77.1	80.3	82.7
30	67.8	72	76.5	80.2	82.7
Mean	67.8	71.7	76.8	80.6	82.8
s	0.21	0.39	0.37	0.30	0.58
C.V. (%)	0.32	0.54	0.48	0.37	0.70

Table 14: Noise level (SPL) observations recorded under no muffler mounting on Tractor-2 at different RPM at 10 m distance (Replication-II)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	67.8	73	76.8	78.9	82.7
2	68.4	73	76	79	82.7
3	68.4	73	76	79	82.7
4	67.9	72.3	76	78.3	82.7
5	67.4	72.3	75.6	78.2	82.5
6	67.4	72.1	75.6	78.2	82.5
7	67.3	72.1	75.8	78.6	82.2
8	67.2	72.5	75.8	78.6	82.2
9	67.2	72.5	76.4	78.9	82.4
10	67.4	72.5	76.4	78.9	82.4
11	67.4	72.2	75.6	78.6	82.3
12	67.4	72.2	75.6	78.6	82.9
13	67.6	71.7	75.8	78.5	82.9
14	67.6	71.7	75.8	78.5	82.3
15	68.3	72.5	75.6	78.2	82.3
16	73.7	72.5	75.6	78.2	82.9
17	73.7	72.5	75.6	78.8	82.9
18	69.7	73	75.6	78.4	82.3
19	70	73	75.6	78.4	82.4
20	70	72.6	75.7	78.1	82.4
21	67.8	72.6	75.9	78.1	82.7
22	67.3	71.8	75.9	78.8	82.7
23	67.2	71.8	75.7	78.8	82.4
24	67.2	72.6	75.7	78.7	82.3
25	67.6	72.6	75.4	78.7	82.3
26	67.6	72.2	75.4	78.5	82.1

27	67.5	72.2	76.1	78.5	82.1
28	67.6	72.2	76.1	78.3	82.2
29	67.6	72.4	76.8	78.3	82.2
30	67.7	72.4	76.8	78.5	82.1
Mean	68.2	72.4	75.9	78.5	82.5
s	1.68	0.38	0.39	0.27	0.26
C.V. (%)	2.46	0.52	0.52	0.35	0.31

Table 15: Noise level (SPL) observations recorded under no muffler mounting on Tractor-2 at different RPM at 10 m distance (Replication-III)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	67.3	72.1	75.6	78.5	82.1
2	67.3	72.1	75.6	78.3	82.4
3	67.5	72.1	75.7	78.3	82.1
4	67.7	72	75.7	78.8	82.1
5	67.4	72	75.7	78.8	82
6	67.3	72.2	75.8	79.2	82
7	67.3	72.2	75.8	79.2	82.2
8	67.1	72.3	75.8	79	82.2
9	67.6	72.3	75.9	77.8	82.3
10	67.6	72	75.9	77.8	82.2
11	67.8	72	76.4	79.2	82.2
12	67.8	71.6	76.1	79.2	82.6
13	67	71.6	76.1	78.8	81.8
14	67.1	72	76	78.8	81.8
15	67.5	72	76	79	81.9
16	67.5	72	75.7	79	81.9
17	67	71.8	75.3	79.3	82.3
18	67.5	71.8	75.3	78.8	82.3
19	67.5	71.6	76.6	78.6	82
20	67.5	71.6	76.6	78.7	82
21	67.5	71.1	76	78.7	81.9
22	67.7	71.1	75.5	78.8	82
23	67.1	71.9	75.5	78.8	82
24	67.1	71.4	75.5	79.3	82.3
25	67.6	71.4	75.5	79.3	82.3
26	67.9	71.4	75.7	78.8	81.9
27	67.9	72	75.7	78.8	81.9
28	67.7	72.4	75.1	78.5	81.9
29	67.8	72.4	75.1	78.5	81.8
30	67.8	72.2	75.2	78.7	81.8
Mean	67.5	71.9	75.7	78.8	82.1
s	0.27	0.36	0.38	0.39	0.20
C.V. (%)	0.40	0.50	0.50	0.49	0.25

Table 16: Noise level (SPL) observations recorded under standard muffler mounting on Tractor-2 at different RPM at 10 m distance (Replication-I)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	67.8	70.6	72.8	74.8	76.6
2	67.8	70.6	72.8	74.8	77.2
3	68.4	70.6	72.9	74.9	77.2
4	67.9	70.6	72.9	74.9	77.2

5	67.9	70.7	72.9	74.9	77.2
6	67.9	70.7	72.7	74.9	77.3
7	67.9	70.7	72.7	74.4	77.3
8	67.9	70.7	72.7	74.4	76.8
9	67.7	70.9	72.4	74.4	76.8
10	67.7	70.9	72.4	74.7	76.9
11	67.7	70.9	72.4	74.7	76.9
12	67.9	70.5	72.4	74.7	76.9
13	67.9	70.5	72.4	74.8	76.8
14	67.9	70.6	72.4	74.8	76.8
15	67.9	70.6	72.4	74.8	76.8
16	67.9	70.6	72.4	74.8	76.8
17	67.9	70.3	72.4	74.7	76.8
18	67.9	70.3	72.4	74.7	76.7
19	67.8	70.3	72.4	74.7	76.7
20	67.8	70.5	72.4	74.9	76.7
21	67.8	70.5	72.4	74.9	76.7
22	67.7	70.5	72.4	74.9	76.5
23	67.7	70.5	72.4	74.7	76.4
24	67.7	70.5	72.4	74.7	76.7
25	67.7	70.5	72.1	74.7	76.7
26	68.2	70.6	72.1	74.7	76.3
27	68.2	70.6	72.1	74.7	76.3
28	68.2	70.6	72.5	75.1	76.3
29	67.8	70.4	72.5	75.1	76.8
30	67.8	70.4	72.5	75.1	76.8
Mean	67.9	70.6	72.5	74.8	76.8
s	0.17	0.16	0.22	0.18	0.28
C.V. (%)	0.25	0.22	0.30	0.24	0.36

Table 17: Noise level (SPL) observations recorded under standard muffler mounting on Tractor-2 at different RPM at 10 m distance (Replication-II)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	68.2	70.4	72.5	74.8	76.8
2	68.2	70.6	72.4	74.8	76.8
3	68.2	70.6	72.4	74.8	76.8
4	67.8	70.6	72.4	75	76.8
5	67.8	70.3	72.1	75	76.6
6	67.8	70.3	72.1	75	76.6
7	67.8	70.3	72.1	74.8	76.8
8	67.9	70.5	72.1	74.8	76.8
9	67.9	70.5	72.1	74.8	76.5
10	67.9	70.5	72.1	75	76.5
11	67.9	70.3	72.3	75	76.5
12	68.1	70.3	72.3	75	76.6
13	68.1	70.3	72.3	75.1	76.6
14	68.1	70.3	72.3	75.1	76.6
15	68.1	70.4	72.4	75.1	76.8
16	68	70.4	72.4	75	76.8
17	68	70.4	72.4	75	76.8
18	68	70.4	73.5	75	76.9
19	68	70.4	73.5	75	76.9

20	67.9	70.4	73.7	75.1	76.6
21	67.9	70.7	73.7	75.1	76.6
22	67.9	70.7	73.8	75.1	76.6
23	67.8	70.7	73.8	75.1	76.8
24	67.8	70.7	73.8	75.1	76.8
25	67.8	70.4	73.8	74.9	76.8
26	67.9	70.4	73.8	74.9	76.8
27	67.9	70.4	73.5	74.9	76.8
28	67.9	70.5	73.5	75	76.8
29	67.9	70.5	73.8	75	76.7
30	67.7	70.5	73.7	75	76.7
Mean	67.9	70.5	72.9	75.0	76.7
s	0.14	0.13	0.72	0.11	0.12
C.V. (%)	0.20	0.19	0.99	0.14	0.16

Table 18: Noise level (SPL) observations recorded under standard muffler mounting on Tractor-2 at different RPM at 10 m distance (Replication-III)

Sr. No.	1000	1250	1500	1750	2000
1	67.7	70.4	73.4	74.7	76.6
2	67.7	70.4	73.6	74.7	76.6
3	68.1	70.4	73.6	74.7	76.6
4	68.1	70.5	73.6	74.7	76.8
5	68.1	70.5	73.7	74.5	76.8
6	68	70.5	73.7	74.5	76.8
7	68	70.5	73.7	74.5	76.8
8	68	70.5	73.8	74.5	76.8
9	68.1	70.5	73.8	74.9	76.8
10	68.1	70.5	73.8	74.9	76.8
11	68.1	70.6	73.7	74.9	76.6
12	68.1	70.6	73.7	75.2	76.6
13	67.9	70.6	73.7	75.2	76.6
14	67.9	70.6	73.6	74.8	76.6
15	67.9	70.6	73.6	74.8	76.6
16	67.9	70.7	73.6	74.8	76.7
17	67.7	70.7	73.7	74.9	76.7
18	67.7	70.7	73.7	74.9	76.6
19	67.7	70.7	73.7	74.9	76.6
20	67.7	70.7	73.5	74.7	76.4
21	67.9	70.6	73.5	74.7	76.4
22	67.9	70.6	73.5	74.7	76.4
23	67.9	70.6	73.7	75	76.3
24	67.7	70.7	73.7	75	76.3
25	67.7	70.7	73.7	75	76.5
26	67.7	70.7	73.7	75	76.5
27	67.7	70.7	73.7	75	76.5
28	67.8	70.7	73.7	75	76.7
29	67.8	70.7	73.4	75.1	76.7
30	67.8	70.5	73.4	75.1	76.4
Mean	67.9	70.6	73.6	74.8	76.6
s	0.16	0.10	0.11	0.20	0.15
C.V. (%)	0.23	0.15	0.15	0.27	0.20

Table 19: Noise level (SPL) observations recorded under muffler-4 (muffler-B) mounting on Tractor-2 at different RPM at 10 m distance (Replication-I)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	67.2	68.7	72.4	73.9	76.2
2	66.6	68.7	72.2	74.1	76.2
3	66.6	69	72.2	74.1	76.1
4	66.6	69	72.2	74.3	76.1
5	66.5	69	72	74.3	76.4
6	66.5	68.7	72	74.3	76.4
7	66.4	68.7	71.7	74.3	76.3
8	66.4	68.7	71.7	74.3	76.3
9	66.4	68.7	71.5	74.3	76.3
10	66.1	68.7	71.5	74.1	76.3
11	66.1	68.7	71.5	74.1	76.3
12	66.1	68.5	71.6	74.2	76.6
13	66.1	68.5	71.6	74.2	76.6
14	66.4	68.5	71.6	74.2	76.5
15	66.4	68.9	71.8	74.3	76.5
16	66.4	68.9	71.7	74.3	76.4
17	66.7	68.9	71.7	74.3	76.4
18	66.7	68.6	71.6	74.3	76.4
19	66.4	68.6	71.6	74.3	76.4
20	66.4	68.6	71.6	74.3	76.6
21	66.3	68.6	71.5	74.3	76.6
22	66.3	68.6	71.5	74.4	76.5
23	66.3	68.6	71.8	74.4	76.5
24	66.3	68.9	71.8	74.4	76.5
25	66.6	68.9	71.8	74.3	76.6
26	66.6	68.9	71.6	74.3	76.6
27	66.6	68.9	71.6	74.5	76.6
28	66.5	68.9	71.6	74.5	76.6
29	66.5	68.9	71.9	74.5	76.6
30	66.4	68.8	71.9	74.3	76.6
Mean	66.4	68.8	71.8	74.3	76.4
s	0.22	0.16	0.24	0.13	0.16
C.V. (%)	0.33	0.23	0.34	0.17	0.21

Table 20: Noise level (SPL) observations recorded under muffler-4 (muffler-B) mounting on Tractor-2 at different RPM at 10 m distance (Replication-II)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	66.4	68.8	71.7	74.3	76.6
2	66.8	69	71.8	74.6	76.5
3	66.8	69	71.8	74.6	76.5
4	66.3	69	71.7	74.3	76.5
5	66.3	68.8	71.7	74.3	76.4
6	66.4	68.8	71.7	74.3	76.4
7	66.4	68.8	71.6	74.3	76.4
8	66.4	68.9	71.6	74.3	76.4
9	66.3	68.9	71.6	74.2	76.4
10	66.3	68.9	71.8	74.2	76.4
11	66.5	68.6	71.8	74.3	76.3
12	66.5	68.6	71.8	74.3	76.3

13	66.5	68.6	71.7	74.3	76.4
14	66.4	68.9	71.7	74.1	76.4
15	66.4	68.9	71.7	74.1	76.4
16	66.2	68.8	71.9	74.1	76.6
17	66.2	68.8	71.9	74.1	76.6
18	66.2	68.8	71.9	74.1	76.6
19	66.2	68.9	71.7	74	76.3
20	66.2	68.9	71.7	74	76.3
21	65.2	68.8	71.7	74	76.2
22	65.2	68.8	71.9	74	76.2
23	64.8	68.8	71.9	74.2	76.2
24	64.8	68.9	72	74.2	76.1
25	64.8	68.9	72	74.2	76.1
26	66.3	68.9	72	74.2	76.4
27	66.3	68.9	71.4	74.2	76.4
28	66.4	68.9	71.4	74.4	76.4
29	66.4	68.7	71.4	74.4	76.5
30	66.4	68.7	71.6	74.4	76.5
Mean	66.1	68.8	71.7	74.2	76.4
s	0.56	0.11	0.17	0.16	0.14
C.V. (%)	0.85	0.16	0.23	0.21	0.18

Table 21: Noise level (SPL) observations recorded under muffler-4 (muffler-B) mounting on Tractor-2 at different RPM at 10 m distance (Replication-III)

Sr. No.	1000	1250	1500	1750	2000
1	66.4	69.4	72.5	74.4	76.5
2	66.4	69	72.5	74.3	76.6
3	66.5	69	72.5	74.3	76.6
4	66.5	69	72.3	74.3	76.4
5	66.5	68.8	72.3	74.3	76.4
6	66.5	68.8	72.2	74.3	76.4
7	66.4	69.3	72.2	74	76.7
8	66.4	69.3	72.2	74	76.7
9	66.4	69.3	72.2	74	76.7
10	66.4	69.1	72.5	74	76.3
11	66.4	69.1	72.5	74	76.3
12	67.1	68.9	72.5	74.1	76.3
13	67.1	68.9	72.1	74.1	76.3
14	67.1	68.9	72.3	74.3	75.9
15	66.8	69	72.3	74.3	75.9
16	66.8	69	72.3	74.3	76.4
17	66.8	69	72.2	73.9	76.4
18	66.2	69.1	72.2	73.9	76.4
19	66.2	69.1	72.1	74.1	76.6
20	66.3	69.1	72.1	74.1	76.6
21	66.3	68.8	72.1	73.8	76.6
22	66.3	68.8	71.9	73.8	76.4
23	66.3	68.8	72.1	73.8	76.4
24	66.3	68.8	72.1	73.9	76.8
25	66.6	68.8	72.1	73.9	76.8
26	66.6	68.5	71.9	73.9	76.4
27	66.6	68.5	71.9	73.9	76.4

28	66.6	68.5	71.9	73.9	76.2
29	66.6	68.9	72	73.8	76.2
30	66.4	68.9	72	73.8	76.5
Mean	66.5	68.9	72.2	74.1	76.4
s	0.25	0.23	0.19	0.20	0.22
C.V. (%)	0.38	0.33	0.27	0.26	0.29

Table 22: Noise level (SPL) observations recorded under muffler-7 (muffler-C) mounting on Tractor-2 at different RPM at 10 m distance (Replication-I)

Sr. No.	1000	1250	1500	1750	2000
1	66.7	69.6	72.5	74.3	75.9
2	66.8	70.1	72.5	74.5	76.2
3	66.8	70.1	72.5	74.5	76.2
4	66.5	69.9	72.9	74.2	76
5	66.6	69.9	72.9	74.2	76
6	66.6	69.9	72.7	74.2	76.1
7	66.3	69.9	72.5	74.2	76.1
8	66.3	69.7	72.5	74.2	76.4
9	66.4	69.7	72.6	74.2	76.4
10	66.4	69.8	72.6	74.2	75.9
11	66.4	69.8	72.7	74.1	75.9
12	66.6	70	72.7	74.1	75.9
13	66.6	70	72.5	73.9	75.9
14	66.6	70	72.6	73.9	75.9
15	66.6	70	72.6	74.3	75.9
16	66.2	69.9	72.6	74.3	76.1
17	66.2	69.9	72.6	74.3	76.1
18	66.6	70.1	72.4	74.3	76
19	66.6	70.1	72.4	74.3	76
20	66.5	69.7	72.4	74.3	76.3
21	66.5	69.7	72.4	74.2	76.1
22	66.3	69.8	72.7	74.2	76.1
23	66.3	70.1	72.7	74.1	75.9
24	66.7	70.1	72.6	74.1	75.9
25	66.7	69.8	72.6	74.4	75.9
26	66.7	69.8	72.6	74.4	75.7
27	67	70	72.6	74.4	75.7
28	67	70	72.6	74.4	76.2
29	66.5	69.8	72.5	74.4	76.2
30	66.5	69.8	72.5	74.4	76.1
Mean	66.6	69.9	72.6	74.3	76.0
s	0.20	0.15	0.13	0.15	0.17
C.V. (%)	0.31	0.21	0.17	0.20	0.23

Table 23: Noise level (SPL) observations recorded under muffler-7 (muffler-C) mounting on Tractor-2 at different RPM at 10 m distance (Replication-II)

Sr. No.	1000	1250	1500	1750	2000
1	66.8	69.8	72.5	74.3	76.1
2	66.8	69.8	72.5	74.3	75.8
3	66.8	69.8	72.7	74.3	75.8
4	66.5	69.7	72.7	74.3	76
5	66.5	69.7	72.4	74.3	76

6	66.9	69.8	72.5	74.3	75.8
7	66.9	70	72.5	74.2	75.8
8	66.6	70	72.6	74.2	75.8
9	66.6	69.9	72.6	74.3	75.9
10	66.5	69.9	72.3	74.3	75.9
11	66.5	70.2	72.3	74.2	76
12	66.7	70.2	72.2	74.2	75.8
13	66.7	70.2	72.2	74.2	75.8
14	66.8	70	72.6	74.2	75.7
15	66.8	70	72.6	74.2	75.7
16	66.6	69.7	72.4	74.2	75.7
17	66.6	69.7	72.4	74.2	75.9
18	66.6	70.2	72.6	74	75.9
19	66.8	70.2	72.7	74	75.7
20	66.8	70.1	72.7	74.2	75.7
21	66.7	70.1	72.6	74.2	76
22	66.7	70.6	72.6	74	76
23	66.7	70.6	72.6	74	76
24	66.4	70.3	72.6	74.4	75.8
25	66.6	70.3	72.6	74.4	75.8
26	66.6	70.1	72.7	74.3	75.8
27	66.6	70.1	72.7	74.3	75.8
28	66.8	69.8	72.4	74.4	75.8
29	66.8	69.8	72.4	74.4	75.9
30	66.8	69.8	72.5	74	75.9
Mean	66.7	70.0	72.5	74.2	75.9
s	0.13	0.25	0.15	0.12	0.11
C.V. (%)	0.20	0.36	0.20	0.17	0.15

Table 24: Noise level (SPL) observations recorded under muffler-7 (muffler-C) mounting on Tractor-2 at different RPM at 10 m distance (Replication-III)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	66.6	70.3	72.5	74	76.6
2	66.6	70.3	72.5	74.3	76.6
3	66.8	70.4	72.5	74.3	76.5
4	66.8	70.4	72.5	74.2	76.5
5	66.8	70	72.5	74.2	76.5
6	66.6	70	72.5	74.4	76.4
7	66.6	69.7	72.3	74.4	76.4
8	66.6	69.7	72.3	74.3	76.6
9	66.6	69.7	72.3	74.3	76.5
10	66.9	69.9	72.1	74.1	76.5
11	66.9	69.9	72.1	74.1	76.6
12	66.9	69.9	72.3	74.3	76.4
13	66.8	69.9	72.3	74.3	76.8
14	66.8	70.1	72.5	74.2	77.1
15	66.5	70.1	72.5	74.2	77.1
16	66.5	69.9	72.3	74.3	76.6
17	66.5	69.9	72.3	74.3	76.6
18	66.9	70.1	72.3	74.3	76.7
19	66.9	70.1	72.3	74.3	76.7
20	66.9	70	72.4	74.2	76.8

21	66.9	70	72.4	74.2	76.8
22	66.9	69.8	72.2	74.1	76.5
23	66.8	69.8	72.2	74.1	76.4
24	66.8	69.8	72.3	74.3	76.7
25	67	69.8	72.3	74.1	76.6
26	67	69.8	72.3	74.1	76.1
27	67	69.8	72.3	74.3	76.1
28	66.9	69.8	72.1	74.3	75.8
29	66.9	70.1	72.1	74.4	75.8
30	66.9	70.1	72.5	74.3	75.9
Mean	66.8	70.0	72.3	74.2	76.5
s	0.16	0.20	0.13	0.10	0.32
C.V. (%)	0.24	0.28	0.19	0.14	0.41

Table 25: Noise level (SPL) observations recorded under no muffler mounting on Tractor-2 at different RPM at 30 m distance (Replication-I)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	59.6	62.1	65.3	69.1	73.7
2	59.2	62.1	65.3	69.1	73.7
3	59.2	62.8	66.5	68.5	74.2
4	59.1	62.8	66.5	68.5	74.2
5	59.1	62.8	66.5	68.6	74.3
6	59.3	63.1	66.8	68.6	74.3
7	58.5	63.1	66.8	68.8	73.8
8	58.5	62.5	66.9	68.8	73.8
9	59.6	62.9	66.9	68.9	73.5
10	59.6	62.2	66.7	68.9	73.5
11	59.8	62.2	66.7	68.9	73.7
12	59.6	63	66.3	69.2	73.7
13	59.9	63	66.3	69.3	73.4
14	59.7	63	66.5	69.3	73.4
15	59.7	62.7	65.5	69.3	73.6
16	59.8	62.7	66	69.3	73.6
17	59.8	62.7	66	68.9	73.4
18	58.9	62.5	66	68.9	74.3
19	58.9	62.5	66	68.9	74.3
20	58.9	62.5	67	69.1	73.7
21	58.7	62.2	66.7	69.1	73.7
22	58.7	62.2	66.7	69.3	74.6
23	59.5	62	65.8	69.3	74.6
24	59.5	62	65.6	69.1	74.3
25	59.5	62	66.5	69.1	74.3
26	59.2	61.5	66.5	69.2	74.3
27	59.2	61.5	66.5	69.2	74.3
28	59.2	61.5	66.5	69.2	74.1
29	59.3	62.4	66.1	68.7	74.1
30	59.3	62.4	66.1	68.7	73.7
Mean	59.3	62.4	66.3	69.0	73.9
s	0.39	0.47	0.47	0.26	0.37
C.V. (%)	0.67	0.75	0.71	0.37	0.50

Table 26: Noise level (SPL) observations recorded under no muffler mounting on Tractor-2 at different RPM at 30 m distance (Replication-II)

Sr. No.	1000	1250	1500	1750	2000
1	59	62.4	66	69.3	73.7
2	59	62.7	66	69.3	74.2
3	59	62.7	66.3	69	74.2
4	59.1	62	66.3	69	73.6
5	59.1	62	66.9	68.9	73.6
6	59.2	62	66.9	68.9	74.4
7	59.2	62.7	67.1	68.5	74.4
8	59.3	62.7	67.1	68.5	70.1
9	59.7	62.8	66.2	68.7	71.9
10	58.7	62.6	66.1	68.7	71.8
11	58.7	62.6	66.1	68.9	71.6
12	58.7	62.6	66.3	68.9	71.2
13	58.6	62.6	66.3	68.8	71.2
14	58.6	63.4	65.4	68.8	71.8
15	59.9	62.7	65.4	68.7	71.8
16	59.9	62.7	65.4	68.7	72.4
17	59.9	62.9	65.4	68.9	72.4
18	59.6	62.9	65.7	68.9	72.4
19	59.6	62.9	65.7	68.9	72.4
20	59.6	63	65.3	68.5	72.1
21	58.3	63	66.2	68.5	72.1
22	58.3	62.7	66.2	68.4	71
23	58.9	62.7	65.9	68.4	71.8
24	58.9	63.2	65.9	68.9	71.8
25	58.9	63.2	66.1	68.5	71.9
26	59.9	62.4	66.1	68.5	71.9
27	58.8	62.4	66.3	68.5	71.9
28	58.8	62.4	66.3	69.2	71.9
29	59.7	62.6	66.1	69.2	72.2
30	59.7	62.6	66.1	68.5	72.2
Mean	59.2	62.7	66.1	68.8	72.3
s	0.49	0.33	0.48	0.27	1.07
C.V. (%)	0.83	0.53	0.72	0.39	1.47

Table 27: Noise level (SPL) observations recorded under no muffler mounting on Tractor-2 at different RPM at 30 m distance (Replication-III)

Sr. No.	1000	1250	1500	1750	2000
1	58.8	62.8	65.7	68.5	72.9
2	58.8	62.8	65.7	68.3	72.3
3	58.8	62.8	66.1	68.3	72.3
4	58.8	62.7	66.1	69.1	73.9
5	58.8	62.7	66.1	69.1	73.9
6	58.4	62.3	66.3	68.3	71.4
7	58.4	62.3	66.3	68.3	71.4
8	58.4	62.8	66.3	68.7	72.5
9	58.5	62.8	65.7	68.4	72.5
10	58.5	62.5	66.1	68.4	72.5
11	58.7	62.5	66.1	68.9	72.5
12	58.7	63	66.7	68.9	73.3

13	58.6	63	65.7	68.6	72.4
14	58.6	62.2	65.8	68.6	72.4
15	58.6	62.2	65.8	68.6	71.6
16	58.8	62.3	65.7	68.6	72.1
17	58.8	62.3	65.7	68.5	72.1
18	58.8	61.9	66.1	68.5	71.4
19	58.8	61.9	66.1	68.4	71.4
20	58.8	62.5	66.3	68.4	72.5
21	58.6	62.5	66.3	68.9	72.5
22	58.6	62.2	65.7	68.9	72
23	58.6	62.2	65.7	68.8	72.1
24	58.6	61.6	65.8	68.8	72.1
25	59.1	62	65.8	68.4	71.4
26	58.5	62	65.8	68.4	71.4
27	59.6	62.6	66.6	69.8	72
28	59.8	62.6	65.8	69.8	70.7
29	59.9	62.9	65.8	69.8	70.7
30	59.7	63.2	66.5	69	71.4
Mean	58.8	62.5	66.0	68.7	72.1
s	0.41	0.38	0.30	0.44	0.77
C.V. (%)	0.69	0.61	0.46	0.64	1.07

Table 28: Noise level (SPL) observations recorded under standard muffler mounting on Tractor-2 at different RPM at 30 m distance (Replication-I)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	57.7	60.7	63.6	65.8	67.5
2	57.5	60.7	63.4	65.5	67.7
3	57.5	60.7	63.4	65.5	67.7
4	57.5	60.5	63.4	65.5	67.7
5	58.2	60.5	63.2	65.5	67.7
6	58.2	60.5	63.2	65.5	67.7
7	58	60.8	63.5	65.8	67.7
8	58	60.8	63.5	65.8	67.7
9	58	60.8	63.5	65.8	67.7
10	57.8	60.8	63.4	65.8	67.7
11	57.8	60.8	63.4	65.8	67.9
12	57.8	60.8	63.4	65.8	67.9
13	57.8	61	63.3	65.5	67.9
14	57.6	61	63.3	65.5	67.4
15	57.6	60.7	63.3	65.6	67.4
16	57.6	60.7	63.2	65.6	67.4
17	57.8	60.7	63.2	65.6	67.4
18	57.8	60.2	63.2	65.6	67.4
19	57.8	60.2	63.2	65.6	67.4
20	58.1	60.2	63.2	65.6	67.4
21	58.1	60.5	63.2	65.6	67.8
22	58	60.5	63.1	65.6	67.8
23	58.1	60.5	63.1	65.4	67.8
24	58.1	60.5	63.1	65.4	68.1
25	57.7	60.5	63.1	65.5	68.1
26	57.7	60.5	63.1	65.5	67.8
27	57.7	60.5	63.6	65.5	68.1

28	57.7	60.3	63.6	65.6	68.1
29	57.7	60.3	63.4	65.6	68.1
30	57.7	60.3	63.4	65.6	67.1
Mean	57.8	60.6	63.3	65.6	67.7
s	0.21	0.22	0.16	0.13	0.26
C.V. (%)	0.36	0.37	0.25	0.19	0.39

Table 29: Noise level (SPL) observations recorded under standard muffler mounting on Tractor-2 at different RPM at 30 m distance (Replication-II)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	58.1	60.3	63.4	65.9	67
2	57.7	60.3	63.6	65.9	67.4
3	57.7	60.3	63.6	65.6	67.4
4	57.7	60.3	63.6	65.6	67.4
5	57.7	60.3	63.5	65.5	67.3
6	57.7	60.3	63.5	65.5	67.3
7	57.6	60.4	63.5	65.5	67.4
8	57.6	60.4	63.5	65.5	67.4
9	57.6	60.4	64	65.5	67.4
10	57.5	60.4	64	65.5	67.4
11	57.5	60.4	64	65.6	67.4
12	57	60.4	63.8	65.6	67.5
13	57	60.2	63.8	65.7	67.5
14	57	60.2	63.3	65.7	67.3
15	57.7	60.2	63.3	65.7	67.3
16	57.8	60.2	63.3	65.6	67.2
17	58.2	60.4	63.2	65.6	67.2
18	58.1	60.4	63.2	65.6	67.2
19	58.4	60.4	63.2	65.9	67
20	58.4	60.1	63.2	65.9	67
21	57.4	60.1	63.2	65.9	66.7
22	58.1	60.1	63.2	65.9	66.7
23	57.8	60.5	63	65.4	67
24	57.8	60.5	63	65.4	67
25	57.8	60.5	63	65.4	67.1
26	57.8	60.4	63.4	65.4	67.1
27	57.8	60.4	63.4	65.4	67.1
28	57.8	60.4	63.4	65.4	67.1
29	57.7	60.6	63.3	65.4	67
30	57.7	60.6	63.3	65.4	67
Mean	57.7	60.3	63.4	65.6	67.2
s	0.34	0.13	0.28	0.18	0.22
C.V. (%)	0.60	0.22	0.45	0.28	0.32

Table 30: Noise level (SPL) observations recorded under standard muffler mounting on Tractor-2 at different RPM at 30 m distance (Replication-III)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	57.8	60.4	63.3	65.5	66.9
2	57.7	60.4	63.3	65.5	66.9
3	57.7	60.4	63.3	65.4	66.9
4	57.7	60.5	63.3	65.4	66.9
5	57.9	60.5	63.2	65.4	66.9

6	58	60.9	63.2	65.2	67.3
7	58	60.9	63.2	65.2	67.3
8	58	60.9	63.2	65.3	67.1
9	58	60.4	63.2	65.3	67.1
10	58.1	60.4	63.2	65.3	67.4
11	58.1	60.4	63.2	65.3	67.4
12	57.8	60.4	63.2	65.3	67.4
13	57.8	60.4	63.2	65.3	67.5
14	57.8	60.5	63.2	65.4	67.5
15	57.6	60.5	63.2	65.4	67.5
16	57.8	60.5	63	65.4	67.5
17	57.8	60.4	63	65.4	67.5
18	57.8	60.4	63	65.4	67.7
19	58.1	60.4	63.2	65.4	67.7
20	58.1	60.3	63.2	65.4	67.7
21	58	60.3	63.3	65.4	67.4
22	58	60.3	63.3	65.4	67.4
23	57.8	60.1	63.3	65.4	67.5
24	57.8	60.1	63.2	65.4	67.5
25	57.6	60.1	63.2	65.6	67.4
26	57.6	60.3	63.2	65.6	67.4
27	57.8	60.3	63	65.5	67.4
28	57.8	60.3	63	65.5	67.5
29	58.1	60.1	63	65.2	67.5
30	58.1	60.1	63.3	65.2	67.3
Mean	57.9	60.4	63.2	65.4	67.3
s	0.16	0.21	0.10	0.11	0.24
C.V. (%)	0.28	0.35	0.16	0.16	0.36

Table 31: Noise level (SPL) observations recorded under muffler-4 (muffler-B) mounting on Tractor-2 at different RPM at 30 m distance (Replication-I)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	57.6	59.7	62.1	66	67.7
2	57.6	59.7	62.1	65.2	67.7
3	57.8	60.3	63	65.2	67.7
4	58	60.3	63	65.4	67.9
5	58	60.3	63	65.4	67.8
6	57.9	60.3	63.2	65.4	67.8
7	57.9	60.3	63.2	65.5	67.7
8	57.9	60.3	63.3	65.5	67.7
9	57.7	60.3	63.3	65.5	67.6
10	57.7	60.3	63.3	65.5	67.6
11	57.7	59.7	63.2	66.9	67.7
12	57.6	59.7	63.2	66.9	67.7
13	57.6	59.7	63.2	66.8	67.3
14	57.6	59.7	63.2	66.8	67.4
15	57.4	59.7	63.2	66	67.4
16	57.4	59.7	63.2	66	67.6
17	57.4	59.9	63.2	66	67.7
18	57.4	59.9	63.2	65.1	67.7
19	57.4	59.7	63.3	65.1	67.9
20	57.6	59.7	63.3	65.2	67.9

21	57.6	59.7	63.3	65.2	68
22	57.6	60	63.3	65.5	68
23	57.3	60	63.3	65.5	67.7
24	57.3	60	63.1	65.5	67.8
25	57.3	60.3	63.1	65.4	67.8
26	57.7	60.3	63	65.4	67.8
27	57.7	60.3	63	65.6	67.9
28	57.7	59.8	63.1	65.6	67.9
29	57.5	59.8	63.1	65.6	67.9
30	57.5	59.8	63.3	65.4	67.9
Mean	57.6	60.0	63.1	65.7	67.7
s	0.20	0.27	0.29	0.53	0.17
C.V. (%)	0.35	0.45	0.47	0.81	0.25

Table 32: Noise level (SPL) observations recorded under muffler-4 (muffler-B) mounting on Tractor-2 at different RPM at 30 m distance (Replication-II)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	57.5	59.6	63.3	65.4	67.7
2	57.3	59.6	63.3	65.5	67.7
3	57.3	59.6	63.3	65.5	67.7
4	57.3	60	63.3	65.5	67.6
5	57.4	60	63.3	65.6	67.6
6	57.4	60	63.3	65.6	67.5
7	57.4	59.6	63.2	65.4	67.5
8	57.1	59.6	63.2	65.4	67.4
9	57.1	59.6	63	65.4	67.4
10	57.1	59.8	63	65.4	67.4
11	57.6	59.8	63	65.4	67.6
12	57.6	59.8	63.3	65.7	67.6
13	57.6	59.8	63.3	65.7	67.8
14	57.6	59.8	63.3	65.7	67.8
15	57.8	59.8	63.3	65.4	67.5
16	57.8	59.5	63.3	65.4	67.7
17	57.8	59.5	63.1	65.2	67.7
18	57.2	59.5	63.1	65.2	67.7
19	57.2	59.5	63.4	65.2	67.5
20	57.8	59.5	63.4	65.5	67.7
21	57.8	59.5	63.2	65.5	67.7
22	57.8	59.4	63.2	65.5	67.7
23	57.4	59.4	63.3	65.4	67.6
24	57.4	59.3	63.3	65.4	67.6
25	57.4	59.3	63.4	65.4	67.4
26	57.4	59.8	63.4	65.3	67.4
27	57.4	59.8	63.2	65.3	67.6
28	57.4	59.8	63.2	65.4	67.6
29	57.7	59.5	63.3	65.4	67.6
30	57.7	59.5	63.3	65.4	67.7
Mean	57.5	59.6	63.3	65.4	67.6
s	0.23	0.20	0.11	0.13	0.12
C.V. (%)	0.40	0.33	0.18	0.20	0.18

Table 33: Noise level (SPL) observations recorded under muffler-4 (muffler-B) mounting on Tractor-2 at different RPM at 30 m distance (Replication-III)

Sr. No.	1000	1250	1500	1750	2000
1	57.7	59.5	63	65.3	67.7
2	57.3	59.3	63	65.3	67.7
3	57.3	59.3	63	65.3	67.6
4	57.3	59.3	63.1	65.3	67.6
5	57.4	59.4	62.8	65.1	67.4
6	57.4	59.3	62.8	65.1	67.4
7	57.4	59.5	62.8	65.1	67.4
8	57.8	59.5	62.7	65.4	67.4
9	57.8	59.6	62.9	65.4	67.6
10	57.8	59.6	62.9	65.2	67.6
11	57.8	59.6	63	65.2	67.6
12	57.8	59.7	63	65.2	67.7
13	57.8	59.7	62.9	65.5	67.7
14	57.8	59.8	62.9	65.5	67.7
15	57.8	59.8	63.1	65.3	67.6
16	57.7	59.8	63	65.3	67.6
17	57.7	59.8	63	65.2	67.6
18	57.8	59.8	63	65.2	67.6
19	57.8	59.9	63	65.4	67.6
20	57.8	59.9	63.3	65.4	67.6
21	57.9	59.8	63.3	65.4	67.6
22	57.9	59.8	63.3	65.4	67.6
23	57.9	59.7	63.2	65.4	67.6
24	57.8	59.7	63.2	65.5	67.6
25	57.8	59.7	63.4	65.5	67.6
26	57.8	59.7	63.3	65.5	67.6
27	58	59.6	63.3	65.5	67.4
28	58	59.6	63.2	65	67.4
29	58	59.6	63.2	65	67.3
30	57.9	59.6	63.5	65.1	67.3
Mean	57.7	59.6	63.1	65.3	67.6
s	0.21	0.18	0.20	0.16	0.12
C.V. (%)	0.36	0.30	0.31	0.24	0.18

Table 34: Noise level (SPL) observations recorded under muffler-7 (muffler-C) mounting on Tractor-2 at different RPM at 30 m distance (Replication-I)

Sr. No.	1000	1250	1500	1750	2000
1	57.9	60.4	63.2	64.8	67.6
2	57.9	60.6	63	65.2	67.3
3	57.8	60.8	63.4	65.3	67.2
4	57.8	60.8	63.6	65.3	67.2
5	57.4	60.8	63.6	65.1	67.2
6	57.4	60.8	63.2	65.1	67.2
7	57.4	60.5	63.2	64.8	67
8	57.3	60.5	63	64.8	67
9	57.3	60.5	63	64.9	66.8
10	57.7	60.5	63.2	65.1	66.8
11	57.7	60.4	63.2	65.1	67.2
12	57.7	60.4	63	65.1	67.2

13	57.6	60.4	63	64.6	67
14	57.6	60.4	63.1	65.1	67
15	57.4	60.7	63.1	65.1	66.8
16	57.4	61.1	63.3	65	66.6
17	57.4	61.1	63.3	64.6	66.6
18	57.6	61.2	63.6	64.6	66.7
19	57.6	60.5	63.6	64.5	66.7
20	57.6	60.5	63.6	65.1	66.9
21	57.6	60.2	63.3	64.8	66.9
22	58.4	60.2	63.3	64.8	66.9
23	58.4	60.8	62.9	64.3	66.9
24	58.4	60.8	63.3	64.3	66.7
25	57.6	60.8	63.3	64.8	66.7
26	57.6	61.3	63.4	64.8	66.7
27	57.4	61.3	63.4	64.7	66.7
28	57.3	60.6	63.4	64.7	66.7
29	57.3	60.7	63.6	64.8	67.1
30	57.6	60.3	63.6	64.8	67.1
Mean	57.6	60.7	63.3	64.9	66.9
s	0.31	0.30	0.22	0.26	0.24
C.V. (%)	0.54	0.50	0.35	0.41	0.37

Table 35: Noise level (SPL) observations recorded under muffler-7 (muffler-C) mounting on Tractor-2 at different RPM at 30 m distance (Replication-II)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	57.6	60.3	63.4	65	67.1
2	57.5	60.5	63.4	65	67.1
3	57.5	60.5	63.4	64.9	67
4	57.3	60.5	63.4	64.9	67.1
5	57.3	60.5	63.3	64.9	66.9
6	57.3	60.6	63.2	64.9	66.9
7	57.4	60.6	63.2	65.5	67.1
8	57.4	60.7	63.2	65	67.1
9	57.3	60.7	63.3	65	67
10	57.3	61	63.3	65.1	67
11	57.4	60.6	63.2	65.1	67.1
12	57.3	60.6	63.3	64.9	67.1
13	57.3	60.6	63.3	64.9	67.4
14	57.3	60.7	63.1	65.4	67.4
15	57.3	60.8	63.3	65.4	67.2
16	57.4	60.8	63.5	65.1	67.2
17	57.4	60.5	63.5	65.1	67.4
18	57.3	60.5	63.1	64.9	67.4
19	57.3	60.5	63.1	64.9	67.1
20	57.5	60.5	62.7	64.9	67.1
21	57.5	60.4	63.1	64.9	67.5
22	57.5	60.4	63.1	65.1	67.5
23	57.5	60.2	63.1	65.1	67.5
24	57.6	60.2	63.1	64.7	67.5
25	57.6	60.6	63	64.7	67.5
26	57.6	60.5	63.2	64.8	67.5
27	57.5	60.5	63.2	64.8	67.2

28	57.5	60.4	63.3	64.9	67.2
29	57.5	60.4	63.3	64.9	67.2
30	57.5	60.4	63.2	65	67.5
Mean	57.4	60.5	63.2	65.0	67.2
s	0.11	0.17	0.16	0.19	0.20
C.V. (%)	0.19	0.28	0.26	0.29	0.30

Table 36: Noise level (SPL) observations recorded under muffler-7 (muffler-C) mounting on Tractor-2 at different RPM at 30 m distance (Replication-III)

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	57.5	60.6	63.2	64.8	67.3
2	57.5	60.8	63.1	64.9	67.4
3	57.5	60.8	63.1	64.9	67.4
4	57.7	60.8	63.5	65.1	67.5
5	57.7	60.8	63.1	65.1	67.5
6	57.7	60.5	63	65	67.4
7	57.4	60.5	63	64.9	67.4
8	57.8	60.2	63	64.9	67.1
9	57.6	60.2	63.4	65.2	67.2
10	57.8	60.7	63.4	65.2	67.2
11	57.8	60.7	63.4	64.7	67.6
12	57.8	60.4	63.4	64.9	67.6
13	57.6	60.4	63.4	64.6	67.4
14	57.6	60.3	63.4	64.6	67.4
15	57.7	60.4	63.4	64.6	67.3
16	57.7	60.6	63.4	64.6	67.7
17	58	60.4	63.2	64.8	67.2
18	58	60.6	63.2	64.4	67.1
19	58.1	60.6	63.5	64.4	67.1
20	58.1	60.6	63.2	65.1	67.3
21	57.5	60.5	63.4	65.1	67.5
22	57.5	60.9	63.4	64.9	67.3
23	57.5	60.4	63.6	64.9	67.3
24	57.6	60.6	63.3	64.9	67.4
25	57.6	60.7	63.6	65.2	67.4
26	57.7	60.5	63.2	65.2	67.3
27	57.7	60.7	63.8	65.2	67.3
28	57.9	60.9	63.2	64.9	67.3
29	57.9	60.8	63.1	64.9	67.3
30	58	60.5	63.1	65.1	67.2
Mean	57.7	60.6	63.3	64.9	67.3
s	0.19	0.19	0.20	0.23	0.15
C.V. (%)	0.33	0.32	0.31	0.36	0.22

Table 37: Noise level (SPL) observations recorded for background noise (Replication-I, II & III)

Sr. No.	R-I	R-II	R-III
1	34.6	42.2	42.5
2	34.6	42.2	42.5
3	33.9	42.2	42.6
4	35	41.4	42.6
5	35	41.4	42.6
6	35.8	41.6	41.9
7	35.6	41.6	41.9
8	35.6	41.5	41.4
9	37.1	41.5	41.4
10	35.3	41.5	41.4
11	36.3	41.5	41.6
12	37.1	41.9	41.6
13	39.4	41.9	41.2
14	36	41.9	41.2
15	36	42.5	41.2
16	36.1	42.5	42.7
17	36.1	42.5	42.7
18	35.7	42.7	42.7
19	35.7	42.7	41.7
20	34.6	41.4	41.7
21	34.6	41.4	41.7
22	35.6	41.3	41.8
23	35.6	41.3	41.8
24	35	42.1	42.2
25	35	42.1	42.2
26	36.4	42.2	42.8
27	36.4	42.2	42
28	36.6	41.4	42
29	36.4	41.4	42
30	36.4	41.5	42
Mean	35.8	41.9	42.0
s	1.04	0.46	0.51
C.V. (%)	2.90	1.09	1.21

APPENDIX-III

Peak Frequency Observations Recorded under Different Muffler Mounting on Tractor-1 (Mini Tractor) at Different RPM

Table 1: Peak frequency observations recorded under no muffler mounting on Tractor-1 (Mini Tractor) at different RPM at ear level

Sr. No.	1000	1250	1500	1750	2000
1	969.1	547.2	278.4	2069.7	559.5
2	607.8	583.4	233.7	2070	355.3
3	824.2	598	320.7	345	281
4	602.1	229.9	330.9	349	857.8
5	173.2	1546.2	609.1	200.3	163
6	1482.3	334.8	613.8	281.9	364.3
7	1544.4	647.7	1547.4	934.2	175.2
8	171.1	168.5	1556.8	1234.4	167.7
9	1183.5	1502.1	1551.6	168.6	236.6
10	1543.9	185	1549.9	183.7	164.1
11	171.4	596.8	1545.2	339.5	353.4
12	177.9	601.1	1539.4	356.6	273
13	1547.9	299.7	1537.1	366.9	778.6
14	176.9	159.5	700.4	236.9	169.9
15	1178.5	564.8	357.9	2160.7	360.1
16	610.3	897.7	362.8	1175.3	173
17	173.9	837.1	363.8	174	164.3
18	719.9	594.3	344.2	330.7	234.2
19	1555	340.4	342.4	348.1	163.6
20	178.6	599.5	344	360.5	348.1
21	909.7	560.4	342.1	328.6	239.1
22	1549.5	887.7	336.3	191.2	1443.7
23	175.3	840.3	166.5	1265	165.2
24	1225.6	241.7	166.1	169	359.3
25	286.4	604.5	163.6	343.9	273.4
26	180.2	333.8	164.5	347.3	171.7
27	642.9	163	163.9	381.1	554
28	1555.8	562.1	168.1	236.1	161.3
29	171.4	1470.1	166.3	175.5	362.6
30	1146.6	1460.3	170.5	297.1	325
31	597.2	570.3	164.6	612.7	1367.5
32	1484.9	601.7	163.1	1781.7	162
33	602.1	356.1	162.2	236.4	326.3
34	178.3	335.2	169.9	272.9	278.5
35	1167.1	572.4	1448.6	2290.8	178.4
36	1552.9	790.3	1455.6	1366.1	165.6
37	187.7	580.3	897	168	371.2
38	565.8	292.3	277.3	169.3	165.8
39	1543.8	332.1	270.8	1462.7	334.7
40	577.4	158.1	232.1	325.1	240.3
41	1210.5	944.3	1579	332.1	1398
42	603.6	240.3	359.1	1958.1	166.7
43	186.6	382	330	273	343.3
44	584.7	172.5	297.8	2069.7	238.5

45	180	160.7	173.5	171.2	187.1
46	1544.3	281.7	181.1	176.2	1638.2
47	183	1513.5	171.6	174.8	291.9
48	567.3	565	163.8	311	169.3
49	589	566.7	162.3	314.9	169.8
50	580.8	1497.8	168.4	614.5	589.7
Mean	762.45	597.42	537.3	650.04	383.62
Median	603.6	566.7	330	339.5	273.2
Maximum	1555.8	1546.2	1579	2290.8	1638.2
Minimum	171.1	158.1	162.2	168	161.3
s	524.44	397.79	523.36	662.86	356.68
C.V. (%)	68.784	66.584	97.405	101.97	92.978

Table 2: Peak frequency observations recorded under no muffler mounting on Tractor-1 (Mini Tractor) at different RPM at 10 m distance

Sr. No.	1000	1250	1500	1750	2000
1	595.3	575.7	157.3	1286.8	180.7
2	582.6	226.5	168.5	1263.1	233.8
3	767.8	665.9	578.5	602.3	182.6
4	600.3	247.6	594.1	1185.8	603.3
5	150.4	139.2	607.4	521.7	170.4
6	606.4	229.7	635.9	607.2	235.6
7	570.9	234	798	228.3	320.2
8	658.8	567.5	637.2	1545.1	181.5
9	147.7	610.8	229.4	1285.4	555.6
10	649.9	235.2	328.2	599.5	237.3
11	567.4	138.4	199.3	583.8	189.9
12	525.3	111.6	175.8	1350.5	267.8
13	616	1405.5	188.3	559.5	200.7
14	576.1	572.7	193.1	589.1	271.4
15	520.8	284	199.1	615.8	325.5
16	609.2	572.4	201	273.4	165
17	578.8	138.5	605.2	204.2	238.5
18	519.8	604.6	606.6	1358.8	242.1
19	632	111.5	591.2	250.9	201.6
20	199.9	228.2	596	603.6	149.4
21	234.1	568.1	561.2	732.7	142.2
22	654	613.9	297.8	613.6	230.6
23	202.9	570.2	340	330.6	145.7
24	182.9	139.7	326.4	227.6	272.9
25	174.4	130.9	560.2	1447.1	148
26	579	107.5	547.1	1353.9	139.9
27	178.5	226.1	547.9	687.3	239.4
28	553.9	615.2	532.5	591.2	279.3
29	230.8	288.3	558.7	596.6	194.1
30	181	137	318.2	193.2	175.9
31	182.9	575.4	173.4	197	232
32	571.3	1530.9	156.5	1546.1	238.3
33	179.9	228	157.1	606.6	189.5
34	613.8	546.4	160.2	628	597.4
35	233.4	576.1	165.6	574.1	209.4

36	144.5	137.2	175.7	656	144.2
37	611.5	600.3	158.7	580.8	275.4
38	198.8	108.6	606.9	603.5	283.3
39	150.3	229.7	214.2	318.7	139.8
40	178.4	598	557.4	202.6	141.3
41	201.7	570.4	290.1	252.4	235.6
42	556.8	134.6	187	604.2	274.8
43	150.8	139.1	194.7	1228.5	173.4
44	584.5	235.2	201.9	572.6	181.2
45	573.9	579	193.1	555.4	243
46	594	602.1	576.7	565.3	198.9
47	145.6	567.5	608.2	228.6	585.6
48	587.7	133.1	610.7	200.7	139.9
49	564.4	231.2	607.6	1358.8	229.8
50	148.5	562.2	608.5	227.6	148.6
Mean	420.4	403.6	389.7	679.9	239.6
Median	555.4	265.8	327.3	598.1	219.6
Maximum	767.8	1530.9	798.0	1546.1	603.3
Minimum	144.5	107.5	156.5	193.2	139.8
s	210.1	299.7	201.3	416.2	114.2
C.V. (%)	50.0	74.2	51.7	61.2	47.7

Table 3: Peak frequency observations recorded under standard muffler mounting on Tractor-1 (Mini Tractor) at different RPM at ear level

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	334.5	630.6	589.9	587.2	182.5
2	578	464.4	1839.4	341.2	317.5
3	749.7	1776.5	607.9	226.7	612.3
4	340.2	450.3	341.3	328.1	585.6
5	1547.6	568.8	515.4	612	1168.2
6	182.6	431.9	137.3	229	225.6
7	602.6	885.8	604	869.8	608.2
8	836.8	595.8	315.2	599.6	290.2
9	1026.7	368.2	289.3	587.9	599.1
10	1653	576.9	342.5	183.6	298.7
11	697.9	594.1	611.4	321.2	597.7
12	783.2	651.1	615.7	1500.1	193.4
13	1517.3	882.5	608.2	1549.5	989.9
14	1670.2	598.6	329.5	233.8	322
15	605.6	364.8	340.9	1546.3	599.8
16	500.6	641.8	602.1	601.9	591.4
17	355.8	593.4	2280.6	588.9	287.4
18	1689.9	852.1	1889.5	335.1	1491.8
19	1507.9	526.6	296	308.1	310.7
20	614.7	607.2	661.1	317.9	176
21	1043.9	1495.6	618.4	1505.9	602.2
22	1085.5	1556.5	2007.7	224.4	186.1
23	282.9	601.1	2284	320.6	603.9
24	274.8	1174.9	2260.5	595.6	282.7
25	254.1	614.6	141.3	596.6	293
26	622.6	1494.5	606.1	568.2	577.2
27	322.3	845.6	606.5	192.4	296.9

28	521.3	607.5	568.8	316.6	588.4
29	615	1932.6	505.5	1542.4	610.9
30	612.1	614	468	226.9	218.1
31	527.9	664.1	187	883.7	618.5
32	592.1	576.2	144.2	887.5	263.7
33	954.1	619.6	1872.7	604.2	190.9
34	153.7	1907.6	514.6	588.6	283.5
35	236.4	598.1	132	568.1	314.4
36	611.4	1900.5	497.8	306.2	284.5
37	613.6	598.4	125.8	321.3	597.1
38	592.4	1918.3	127.4	1506.1	223.2
39	516	1440.9	1867.7	1514.2	944
40	590.1	269.1	1871.4	236.2	601.2
41	1543.2	549.8	507	903.6	286.5
42	1505.4	1927	508.7	623.5	300.7
43	233.7	582.9	127.5	2023.8	592.9
44	249.9	284.7	520.5	596.7	611.7
45	182.6	845	511.7	180	671.9
46	969.4	614.3	512.9	320.1	281.6
47	608.7	1934.7	242.6	884.3	605.2
48	1034.2	1452.2	243.6	231.9	292.6
49	283.6	287.8	2275.3	601.1	575.9
50	1637.8	565.2	2283.1	618.1	285.1
Mean	741.31	870.69	779.15	647.13	470.65
Median	611.4	614.3	515.4	588.6	322
Maximum	1689.9	1934.7	2284	2023.8	1491.8
Minimum	153.7	269.1	125.8	180	176
s	466.2	521.2	715.2	465.8	268.6
C.V. (%)	62.9	59.9	91.8	71.9	57.1

Table 4: Peak frequency observations recorded under standard muffler mounting on Tractor-1 (Mini Tractor) at different RPM at 10 m distance

Sr. No.	1000	1250	1500	1750	2000
1	561.5	146	1960.2	623.3	618.3
2	602.9	1958.6	1954.3	813.7	224.8
3	831.6	611	1960	1784.8	236.8
4	564.4	1872.1	1932.9	555	555.9
5	593.7	590	655.2	135	602.3
6	592.2	586.4	639.4	563.3	613.9
7	603.3	111.4	611.9	597.2	224.7
8	595.8	603.2	621.8	1697	239.4
9	1730.8	1837.9	579.5	749.6	247.4
10	570.9	1504.8	1600.4	600.2	596.6
11	1571.1	575.8	550.5	578	786.5
12	575.9	127.4	573	598.5	224.4
13	584.5	1970	611.3	318.2	270.8
14	580.8	622.6	600.1	136.5	389.7
15	284.7	768.3	725.3	523	616.1
16	841.7	590.6	576.4	598.7	586.5
17	1643	97.1	560.7	591.6	316.9
18	600.4	1920.7	597.1	594.9	593.9
19	575.3	605.3	599.2	266.1	415.1

20	648.5	235.7	605.4	572.1	321.6
21	674.2	610	606.8	132.5	226.9
22	574.4	595.7	606.8	607.5	594.3
23	595.4	1960	788.9	606.4	244.1
24	832.8	592.7	592.9	573.6	593.6
25	551	594.3	1542.4	608.4	351.5
26	1683.2	705.3	1558.3	298	231
27	842	598.9	1957.6	882.8	616.7
28	613.2	1926.4	1961.6	1774.9	385.1
29	604	616.3	611	617.9	600
30	1599.1	231	611.9	141.3	598.2
31	1702.7	1606	603.7	603.4	605.1
32	570.4	573.2	622.1	597.6	238.1
33	322.1	1955.5	606.7	136	588.9
34	637.4	552.6	573.8	794.3	660.1
35	588.7	568.3	557.8	599.1	225.5
36	1827.8	579.9	545.9	548	621.3
37	621.3	575.7	707.3	578.3	248.2
38	324.8	842.7	563.8	512.4	595.4
39	1638.6	1970.2	607	596.7	238.3
40	1688.6	647.1	590.5	595.8	214.3
41	622	92.4	593.4	586.8	522.3
42	1658.4	180.2	597.9	595.7	231.7
43	1590.7	593.7	603.4	609.3	383
44	638.9	560	583.4	594.6	616.4
45	574.3	98	576.8	273.3	600.4
46	1821.2	223.9	1560.8	899.4	578.7
47	597.3	604.9	1552	127.7	239.7
48	330.1	1866.5	563.4	597.2	557.3
49	1825.2	577.2	576.6	598.7	379.9
50	830.1	567.1	640.6	1770.8	649
Mean	882.7	820.0	863.6	627.1	442.3
Median	608.6	595.0	606.8	596.3	468.7
Maximum	1827.8	1970.2	1961.6	1784.8	786.5
Minimum	284.7	92.4	545.9	127.7	214.3
s	498.8	624.1	500.1	386.2	175.5
C.V. (%)	56.5	76.1	57.9	61.6	39.7

Table 5: Peak frequency observations recorded under muffler-C mounting on Tractor-1 (Mini Tractor) at different RPM at ear level

Sr. No.	1000	1250	1500	1750	2000
1	330.7	600.5	857.5	360.9	346.6
2	575.8	558.2	1911.3	315.2	365.5
3	281.2	374.8	1550.8	566.6	337.6
4	650.8	600.8	580.5	897.6	364.4
5	842.3	569	345.8	463.3	374.8
6	285.7	202.8	346.3	1528.6	272.2
7	888	834.1	334.2	134.2	336.9
8	587.6	602.7	341.7	737.2	333
9	830.1	746.1	341.9	333.5	707.4
10	335.7	617.4	340.9	370.9	369
11	345.3	580.2	338.8	262.5	791

12	596.8	497.4	332.2	281.1	575.3
13	1544.1	233.8	353.9	134.3	367.2
14	846.1	337.3	369.8	612.6	364.8
15	1515.6	740.5	177.2	132.8	780.3
16	207.2	597.5	466	269.9	602.3
17	715.5	600.5	598.6	349.8	340.5
18	574.9	382.2	180.2	1552.9	326.5
19	774.9	592.4	616.3	887.3	827.1
20	330.5	321.5	652.4	1532.9	594.2
21	596.2	410.1	606.9	139	376.4
22	198	590.6	598.5	577.5	776.9
23	556.2	710.7	1537.6	150.7	605.9
24	591.3	413.7	597.7	370.6	338.2
25	812.2	337.1	133.3	354.4	318.9
26	580.7	758.4	586.2	412.1	340.7
27	724.4	588.9	587.3	555.3	369.2
28	524.2	577.2	278.7	602.9	390.9
29	1543	674.2	1315.2	361.9	596.2
30	596.5	594.6	575.3	571.2	337.2
31	426.4	333.9	570.9	279	320.6
32	802.5	583.9	578.5	565.1	712.9
33	554.4	468.8	577.4	545	151
34	793.1	792.8	566.2	342.9	371
35	752.2	243.1	564.8	357	415.7
36	332.6	520.1	576.9	305.3	812.8
37	588.9	461.4	551.8	508.7	339.1
38	566.7	561.4	743	325.5	323.6
39	470.9	647.8	575.4	365.1	474
40	602.2	248.6	597.9	370	568.3
41	602.5	609.7	1017.1	353.3	369.6
42	234.4	345.6	1488	600.9	383.8
43	609.5	487.5	133.4	414.5	605.1
44	606.2	603.1	788.9	526.6	342.6
45	781.7	709.2	798.3	1029.6	329.7
46	337.8	368.2	792.3	581.5	592.1
47	572	593.9	287.4	334.9	357.8
48	663.4	337.8	375.5	359.8	417.3
49	265.5	714.2	375.2	614	335.4
50	1556.9	230.1	287	421.8	348.6
Mean	638.03	522.13	601.98	500.4	447.96
Median	596.2	577.2	575.4	370.9	369.2
Maximum	1556.9	834.1	1911.3	1552.9	827.1
Minimum	198	202.8	133.3	132.8	151
s	325.9	162.5	379.3	326.9	165.1
C.V. (%)	51.1	31.1	63.0	65.3	36.9

Table 6: Peak frequency observations recorded under muffler-C mounting on Tractor-1 (Mini Tractor) at different RPM at 10 m distance

Sr. No.	1000	1250	1500	1750	2000
1	1481.7	616	1783.7	576.5	1641.4
2	591.4	589.2	666	580.6	592.8
3	219.8	609	1788.3	589.2	598.2
4	618.7	251.1	674.9	596.9	596
5	236.7	849.7	1770.9	580	798.2
6	613.2	619	1770.8	645.7	595.6
7	646.9	590.7	1405.7	1690.2	611.4
8	1489.9	611.6	571.2	319	227.5
9	330.1	192.8	579	813.9	610.3
10	813.3	600	578.1	601.4	219
11	1506.8	595.7	1776.1	575.7	228.7
12	247.1	576.5	747.3	583.6	602
13	223.2	600.2	905.1	606.5	255.5
14	606.1	251	594.7	326	607.1
15	594.7	667.6	454	1814.3	743.6
16	249.2	562.2	176.8	575.8	241.6
17	599.8	106.6	777.6	582.6	239.4
18	575.5	99.7	580.6	572.9	232
19	600.7	571.2	1644.9	324.4	619.9
20	621.7	194.6	574.3	600.8	245.2
21	230.1	610.3	578.9	1797.9	609
22	611.6	581	1776.9	1754.2	245
23	592.8	97.1	574.3	595.7	585.4
24	245	602.4	557.7	591.9	242.6
25	570.8	650.3	577.9	150.5	196.6
26	221.5	251.4	575.3	320.2	252.5
27	607.3	568.3	583.4	584.3	572.4
28	596	580.7	575.8	578.9	255.3
29	798	615.6	280.3	1792.1	219.4
30	581.4	101.4	274.4	576.6	209.1
31	242.9	575.3	592.2	590.2	252.2
32	576.6	137.2	572.8	326.7	461
33	629.7	253.2	253.8	588.2	600.7
34	605	699.3	593	620.4	607.1
35	597.8	560.9	602.4	588.5	217.6
36	606.6	578.5	277.2	284.6	224.9
37	547.3	97.9	606.3	600	225.8
38	570.9	237.1	275.6	581.6	265.1
39	245.6	608.6	594.2	578.6	237.5
40	612.6	105.9	290.3	573.9	571.3
41	264.7	568.8	637.4	608.7	244.1
42	834.6	100.3	1771.6	598.9	587.5
43	597.5	254.4	109.5	1779.5	252.2
44	569.5	570.4	124.3	565.6	237.5
45	586.3	546.6	1780.4	606.7	613.8
46	580.2	272.6	1792.6	239.3	246.2
47	273.9	98.5	245.8	284.9	575.1
48	605.6	182.3	238.9	556.8	246.9
49	660.7	598.4	1809.5	583.7	225

50	600.9	139.3	572	590.5	200.5
Mean	574.6	432.0	798.3	680.9	419.7
Median	595.4	569.6	582.0	584.0	253.9
Maximum	1506.8	849.7	1809.5	1814.3	1641.4
Minimum	219.8	97.1	109.5	150.5	196.6
s	290.4	223.5	561.9	425.9	258.6
C.V. (%)	50.5	51.7	70.4	62.5	61.6

APPENDIX-IV

Peak Frequency Observations Recorded under Different Muffler Mounting on Tractor-2 at Different RPM

Table 1: Peak frequency observations recorded under no muffler mounting on Tractor-2 at different RPM at ear level

Sr. No.	1000	1250	1500	1750	2000
1	1216.1	861	1250.2	1276.2	1264.8
2	1028.3	1935.7	2380.9	1962.3	2050
3	846.7	852	671.5	2064.8	1210.9
4	787.3	1208.8	665.4	3267.2	2053.5
5	891.1	1581.8	666.8	1307.1	1305.8
6	885	1929.1	706.3	1305	1270.2
7	853	1265.1	862.1	1592.3	1292.1
8	862.7	1220.5	888	1277.7	2027.7
9	979.8	659.6	1280.3	2026.5	1285.1
10	1497.9	1530.3	942.4	2012.7	2072
11	869.6	1214.4	1886.9	1998.4	2094.5
12	781.4	1217.5	1258.7	2425.3	1304.6
13	1471.8	1228.4	1260.3	1949.6	1277.6
14	885.6	1266.6	1248.2	2004.5	1261.3
15	858	1270.2	1234.9	1979.7	1353
16	759	1271.2	1215.5	2016.7	1292.1
17	852.7	1251.4	1215.7	1644.5	2124.8
18	869.9	660.1	1267.4	2013.6	1310.5
19	747.4	1262.2	2187.2	1582.7	1277.9
20	665.4	1036.9	1221.4	1584.5	1635.8
21	799.8	1274	1536.4	2019.8	2055.1
22	882.1	1250.1	1920.5	1302.6	2074.2
23	897.8	1033.9	1875	1591.9	1309.4
24	881.1	1884	1226.8	1263.5	2121.4
25	1208.3	1012.7	2382	1271.3	2045.1
26	807.3	847.2	1562.5	1275.9	1597.3
27	826.2	1253.8	1960.1	1592.7	2022.1
28	1917.2	1249.2	1911.9	2101.1	2477.7
29	802.7	1871.3	899.2	1301.1	2056.5
30	1217.7	1883.8	1299.3	1274	3075
31	983	1046.3	1274.4	1261.4	2029
32	1699.4	645.8	706.9	1904.2	2909.8
33	1548	1254	1579.8	1324.4	2994.9
34	638.6	860.9	1266.2	1274.1	2956.9
35	783.9	1239	2061.6	1257.8	2467.4
36	1916.8	1042.6	1227.9	1316.2	2013.5
37	1543.4	1177	2339.4	1292.1	3281.7
38	796.3	1225.5	1983.6	2839	2064.3
39	1260.8	1823.8	2012.9	1278.8	3376.6
40	1468	1871.8	1219.3	1604.5	3371.7
41	1892.3	839.1	1932.6	1310.9	1345.6
42	750.2	1224.7	1188.1	1278.3	3084.7
43	1050.7	1351.5	1951.3	2817.3	1354.7
44	1260.7	520.4	1200.4	2406.3	1310

45	1155.1	1251	1252.4	1254.6	2028.7
46	1525.8	1257.5	1923.3	1616.6	2045.7
47	1225.2	1226.1	1413.6	1547.5	2028.9
48	1225.6	1218.5	992.7	1610.8	2058.7
49	1584.2	1224.3	1255.2	1256.1	2050.7
50	1227.8	1033.7	2011.3	1250.3	2957.8
Mean	1087.7	1232.3	1433.5	1679.7	1986.6
Median	894.5	1227.3	1263.3	1588.2	2037.1
Maximum	1917.2	1935.7	2382.0	3267.2	3376.6
Minimum	638.6	520.4	665.4	1250.3	1210.9
s	347.3	341.1	482.4	478.1	649.5
C.V. (%)	31.9	27.7	33.7	28.5	32.7

Table 2: Peak frequency observations recorded under no muffler mounting on Tractor-2 at different RPM at 10 m distance

Sr. No.	1000	1250	1500	1750	2000
1	93	1985.9	2077	1609.3	1611.5
2	102.9	287.5	1587.4	1611.7	1624.4
3	1524.8	108.7	1584.7	1608.8	1606.8
4	1539.6	224.2	1580.9	1983.6	1592.1
5	698.9	1987.1	1935.7	1608.6	1592
6	1592.3	156.4	1996.1	1609.7	1939.3
7	96.1	1536.7	1980.3	1585.6	1629.4
8	103.7	239	1581.3	1973.5	1603.6
9	1789.8	1963.1	1563.2	1590.2	1653.3
10	1500.2	136.7	2393.7	1610.8	1640.6
11	609.9	288.8	1989.1	1975.6	1627.7
12	1939.9	268.2	2015	1606.5	2042.2
13	92.9	1962.7	1566.1	1957.4	1598.1
14	1952	147.9	1930.1	1972.2	2057.2
15	227.2	230	1982.3	1635.5	2045.3
16	90.4	112.5	2009.3	1958.3	1595.2
17	93	111.8	1977.5	1592.9	2055.1
18	1530.2	1919.3	1998.8	1591.5	1635.6
19	1917	239.9	1963.3	1687.9	2028.6
20	98.7	197.6	2001.5	1608.8	1663.5
21	98.2	1923	1584	1587.6	1633.2
22	1767.4	1907	2016.5	2011.1	1600
23	95.4	1983	1960.6	1974.3	1620.9
24	84.4	1927.9	2004.5	1979.1	1639.4
25	529.1	1960.4	1592.9	1599	1655.3
26	1951.1	111.4	1957.6	1643.6	1603.7
27	99.5	1980.1	1963	1597.3	1604.9
28	1921.2	2007.1	1976.1	2000.7	2012.1
29	1772.3	1577.9	2003.5	1590.8	1634.8
30	95.3	1967.4	1965.2	1604.4	1645.3
31	83.1	1551	1998.2	1629.5	1635.7
32	1550.8	1872.5	1577.9	1622.3	2049.3
33	86.6	1983.8	1567.3	2016.7	2022.8
34	1870.4	1526.9	1559.2	1624.6	1628.8
35	91	1551.2	1938.7	1985.8	1627.4
36	103.7	1535.6	2356.2	1962	1676.4

37	1504.3	1587.8	1559.7	1632.5	1648.8
38	1581.2	2331.6	2376	1590.9	2060.5
39	83.3	1461.7	2379.4	1635.2	2019.6
40	1927.5	1970.8	1562.8	1940.8	2017.3
41	95.5	1536.5	1586.7	1609.1	1619.3
42	1961.9	1535.1	1581.8	1639	2063.5
43	1737.7	1580	1594.8	1595.5	2025.8
44	1576.9	1569.4	1932.6	1606.6	2066.9
45	1955.8	1932.9	2379.6	1637.2	2065.7
46	84.2	186.6	1561.6	1627.8	1640.7
47	1918	1918.6	2373.5	2401.8	1635.4
48	96.8	1514.9	1585.9	2391.4	2055.3
49	105.7	1576	2390.9	1995.6	1640.7
50	1740.2	1516.7	2395.4	1604.9	2030.3
Mean	923.2	1273.8	1899.9	1754.3	1774.4
Median	654.4	1551.1	1963.2	1628.7	1640.7
Maximum	1961.9	2331.6	2395.4	2401.8	2066.9
Minimum	83.1	108.7	1559.2	1585.6	1592.0
s	821.6	774.5	282.9	214.8	200.1
C.V. (%)	89.0	60.8	14.9	12.2	11.3

Table 3: Peak frequency observations recorded under standard muffler mounting on Tractor-2 at different RPM at ear level

Sr. No.	1000	1250	1500	1750	2000
1	947	1536.7	1835.8	322.7	807.4
2	1195.5	983	1824.8	830.2	274.8
3	1152.6	1746.4	1547.8	1401.7	834
4	941.3	983.6	1543.5	893.1	280.5
5	965.4	812.7	917.7	1457.2	844.3
6	1219	800.8	945.4	807.4	433.3
7	979.8	1024.8	944.7	368.2	531.9
8	962.1	1036.7	944.3	464.2	469.5
9	1178	799.3	339.1	846.1	910.4
10	977.9	986.6	796.5	805.1	897.2
11	899.3	1500.8	895.7	790.8	849.6
12	899.9	1186.7	886.3	502.1	794.1
13	1082.3	1399.5	2064.3	1398.4	240.8
14	857.2	916.8	1252.2	373.1	506.1
15	1167.1	1544.9	837.3	1390.5	265.6
16	938.9	1060.9	1208.8	1453.9	624.1
17	987.2	1402.9	809.7	1370.2	563.4
18	1160.2	1505.3	1231.3	320	271.4
19	817.4	1186.6	382.3	338.1	476
20	824.9	1165	2059.7	519.2	597.2
21	1023.1	1399.7	442.9	505.6	840.8
22	810.6	1491.2	1702.9	1366.4	894.1
23	1179.5	1159.4	446.1	365.4	787.4
24	1531.9	1053	1397.9	314.4	523.3
25	971.6	1669.3	1392.2	339.9	800.9
26	855.2	1314.4	886.4	523.9	522.6
27	1215.6	1502.2	1365	746.2	795.3
28	1632.7	913.5	906.5	1452.5	645.1

29	1134.8	851.6	898.2	898.1	502.6
30	1729.5	833.7	843.7	983.8	505
31	893.1	1038.1	928.7	1397.7	532.2
32	947.4	1510.2	775.4	1816.7	826
33	828.4	1730.6	748.7	1821.5	611.2
34	986.6	1181.4	454.4	1436.1	826.9
35	1596.4	1397.4	785.1	711.1	852.7
36	984.5	1729.2	1590.9	840.6	500.1
37	906.5	856.6	1585	1750.7	903.1
38	845	1598.8	889	707.5	879.6
39	967.8	1176.8	937	1343	844.8
40	973.4	1506.5	464.1	892.6	875.2
41	833.4	898.1	922	653.7	764.2
42	886.5	1021.5	458.4	835.6	245.5
43	1789.9	1640	1252.4	532.6	267.9
44	691.2	922.6	1261.5	561.6	481.5
45	920.7	889.3	463.6	840.2	594.3
46	795.5	945.4	948.7	516.3	269.7
47	1025.4	793.9	1603.3	529.3	869.1
48	1790.2	795.9	2026.5	786	871.7
49	1216.3	928	1745.3	733.2	896.8
50	1832.3	1268.4	804.3	854.7	241.8
Mean	1079.0	1191.9	1083.9	874.2	628.9
Median	975.7	1162.2	932.9	806.3	617.7
Maximum	1832.3	1746.4	2064.3	1821.5	910.4
Minimum	691.2	793.9	339.1	314.4	240.8
s	285.2	300.6	469.6	435.2	228.5
C.V. (%)	26.4	25.2	43.3	49.8	36.3

Table 4: Peak frequency observations recorded under standard muffler mounting on Tractor-2 at different RPM at 10 m distance

Sr. No.	1000	1250	1500	1750	2000
1	801.8	785.6	651.9	576.7	1057.4
2	1646.8	783.4	285.7	1484.7	598.6
3	1731.2	1635.6	782.4	346.2	197.3
4	614.4	1683.6	790.3	1511.6	194.6
5	753.9	1668.8	1641.8	324	1072.2
6	1686.1	295.2	768.1	1457.3	200.2
7	769.9	1671.3	809.7	1515.6	194.3
8	1448.8	1646	807.8	786.5	218.4
9	559.6	1649	603.2	555.6	201
10	995	1668.2	1808.3	1505.1	1107.9
11	1907.6	945.2	597.2	358	805.1
12	788.4	1592.4	1547.6	335	192.3
13	1603.7	1626.4	785.4	357.7	188
14	810.1	1644.5	1549.6	340.3	196
15	573.4	787.5	1636.3	788.3	194.7
16	805.2	1518.3	1593.6	554.8	202.5
17	1744.1	1512.1	781.7	352.8	193.1
18	1486.3	1647.1	1549.4	247.9	514.6
19	947.9	1656.3	794	191.1	199.1
20	1728.7	1644.5	778.5	343.9	181.5

21	779	1677.8	1422.3	994.1	1356.3
22	1695.9	1644.9	653.6	333.4	185.8
23	1839	1514	754.7	331.2	194
24	1721.7	1499.8	596.8	333.8	198
25	796.9	1649	1634.3	356.5	190.4
26	1541.7	763.5	1630	565.3	521.8
27	1883.4	769.6	1625	348.9	202.2
28	1530.7	1511.8	1628.1	512.1	202.8
29	1696.3	1517	1607	527.6	970.8
30	743.8	758.1	815.6	1545.9	189
31	975.6	1674.5	806.5	1077.9	198.2
32	740.3	748.4	1841.1	322	559.2
33	1633.6	246.7	1810.6	340.4	898.4
34	1088.2	531.2	1638.1	352.9	191.8
35	579.3	765.1	741.9	344.6	511.2
36	1600.1	796.7	747.2	355.1	289.3
37	1830.9	1601.9	1732.1	1486	205.9
38	1640.9	1597.4	1729.3	347.8	206.7
39	755.6	977.3	1754.6	332	215.4
40	546.8	1692.6	1591.8	521.9	190.4
41	748.4	772.6	1742.8	520.1	196.9
42	1635.5	766.7	1547.9	1508.1	219
43	1644.5	1642.4	1042	1115.8	655
44	982.2	985.4	274.7	744.6	190.9
45	970.7	968.5	1584.7	788.3	570.5
46	1687.4	1633.9	800.7	322.3	187.5
47	1698	1506.8	1626.4	780.3	190.1
48	1732.5	997.5	1775.3	517.9	520.8
49	700.4	975.7	288	351.7	195.6
50	705.4	756	1645.3	344.5	191.6
Mean	1230.6	1260.1	1193.0	645.1	374.1
Median	1268.5	1513.1	1485.0	435.1	200.6
Maximum	1907.6	1692.6	1841.1	1545.9	1356.3
Minimum	546.8	246.7	274.7	191.1	181.5
s	472.0	442.9	501.7	430.4	307.6
C.V. (%)	38.4	35.1	42.0	66.7	82.2

Table 5: Peak frequency observations recorded under muffler-C mounting on Tractor-2 at different RPM at ear level

Sr. No.	1000	1250	1500	1750	2000
1	948.4	892.3	903.8	933.4	1417.3
2	789	936.5	1253.2	510.4	426.9
3	896.4	1642.4	1258.8	1035.4	503.3
4	805	1483	1673.5	285.6	544.7
5	842.6	1965.3	1210.3	655.8	1515.3
6	1345.8	1163.7	977.4	748.6	1307.4
7	842.2	831.3	1263.5	1175.3	524.4
8	1694.1	850.8	893.7	1300.8	1204.6
9	904.1	1655.4	1272.4	517.8	526.6
10	876	1700.7	1258.8	559.8	517.7
11	979.6	1197.9	767.6	1203.9	1272.6
12	891.4	1270.5	1219.8	529.3	523.6

13	1021.3	1450.6	1731.3	751.5	1597
14	1780.9	1187.6	843.8	1460.2	409.8
15	1357.8	1268.8	889.6	1176	531
16	1628	1549.8	2210.6	473.5	525.1
17	785.5	1509.5	1922	715.3	646
18	782.3	829.2	1177.5	783.8	508
19	938.2	1125.8	1769.5	610.4	419.5
20	1219	1062.3	1213	1188.4	1213.4
21	1087.8	978.7	1316.2	644.7	1170.4
22	982.8	1416.6	1313.3	938.3	838.4
23	1265.2	1179.6	1301.4	506.2	1209.1
24	1037.3	1413.9	1195.3	783.8	548.4
25	1342.6	1366.7	892	1410	1324.3
26	1687.3	1029.9	1797	1173.9	976.3
27	802.1	1688.3	1602.3	503.2	562
28	1226.4	1340.6	1276.9	1206.6	614.6
29	1352	1277.3	1924.2	664	721.6
30	1682.3	1065.5	1842.1	1248.6	1637.1
31	846.3	1707.7	856.5	505.2	659.9
32	1085.2	1168.8	1264.8	1229.4	1558.7
33	1159.5	1044.1	1377.3	1221.2	856.3
34	881	933.5	2048.1	1353.6	562.3
35	893.1	1167.2	1814.3	321.5	2339
36	838.6	1471	1141.4	842.8	931.7
37	805.8	1027.8	1315.3	1167.6	833.4
38	766.8	1059.7	1172.9	762.6	1638.5
39	1163.1	1550.1	1915.9	1365.7	1276.6
40	1205.7	1726.7	1260.5	741	890.5
41	1277.7	1381.4	1270.3	757.5	561.2
42	1736.8	1215.3	1364	1318.5	1181.4
43	1365.3	1927.9	1378.5	610	1690.8
44	1680.8	1601.9	1262.8	470.5	311.5
45	950.5	1405.2	1731.1	614.5	842.5
46	1646.5	1394.7	1266.1	669.6	516.7
47	948	1210.8	1375	1473.2	797.3
48	814.5	882.5	769.9	669.6	841.4
49	1323.4	838.4	1912.2	1315.5	854.9
50	1119.4	1632.9	1906.5	750.3	483.9
Mean	1126.0	1293.6	1371.5	877.1	907.3
Median	1029.3	1269.7	1271.4	760.1	835.9
Maximum	1780.9	1965.3	2210.6	1473.2	2339.0
Minimum	766.8	829.2	767.6	285.6	311.5
s	309.0	297.6	364.7	336.8	447.1
C.V. (%)	27.4	23.0	26.6	38.4	49.3

Table 6: Peak frequency observations recorded under muffler-C mounting on Tractor-2 at different RPM at 10 m distance

Sr. No.	**1000**	**1250**	**1500**	**1750**	**2000**
1	1641.9	146.9	1119.5	188.2	192.3
2	274.8	1408.7	1187.7	195.4	543.5
3	1607.6	1535.7	1691.7	1691.5	431.1
4	211.1	1507	1652.8	150.6	174.1

5	1964.3	1630.6	1064.8	996.3	153.1
6	1029.9	282.4	187.7	232.2	800.8
7	235.8	1922.6	229.6	264.3	220.2
8	285.3	294.7	611.5	192.8	797.4
9	292.2	1031.4	158.2	155	150.9
10	277	648.5	231.8	274.9	286.7
11	269.7	289	1866.6	328.8	296.4
12	218.7	275.6	1040.7	1683.1	195.4
13	1679.8	284.7	599.9	328.2	277
14	807.3	270.2	624.2	316.3	769
15	801.9	279.8	1694.1	255.5	219.4
16	1128.2	1810.7	607.2	277.3	278.6
17	227.5	153.8	1676.6	192.2	842.7
18	1437.1	275.8	147.5	295.4	215.9
19	198.4	1037.2	333.6	193.1	794
20	1960.7	231.2	1115.3	229.7	231.6
21	227.1	1258.4	329.8	286	284.9
22	202.3	238.7	336.7	241.8	220.5
23	295.7	193.8	1432.4	320.5	275.6
24	332.2	161.8	334.5	234.5	188.4
25	784	281.9	2002.4	331	223.5
26	278.1	151.4	1227.1	231.9	290.1
27	1260.6	792.9	229.1	1694.4	188.8
28	220.9	160.3	828.8	250.5	273.5
29	795.4	1256.9	278.9	314.6	183
30	1686.9	976.2	242.9	291.2	312.5
31	808.1	167.3	1262.7	327.2	283.8
32	1373.2	1393.4	178	229	183.9
33	247.8	1249	1265.9	1547.2	816.4
34	260.7	156.3	1393	1444.2	150.8
35	246.5	316.6	1254.8	261.4	180.9
36	1499.7	191.3	1308.8	244.1	283.1
37	290.8	176.2	1361.6	238.3	151.2
38	322.8	168	758	332.7	201
39	226.7	147.2	347.5	337.5	833.8
40	314.6	275.5	804.6	1460.1	266.7
41	329.7	1536.9	361	1498.4	239.9
42	298.1	835.7	343	236	316.3
43	1277.2	285	324.2	240.6	184.8
44	1974.2	227.3	334.7	1296.8	336.5
45	795	1281.4	182.6	1407.1	171.5
46	241.8	147.6	137.4	318.7	840.2
47	1362.4	649.3	158.6	223.4	237.9
48	797	248.6	1971.4	202.1	851.7
49	1682.3	1031.8	170.5	288.2	334.8
50	225.5	275.6	1510.2	152.3	205.7
Mean	744.1	631.0	810.2	498.5	347.6
Median	326.3	283.6	617.9	276.1	270.1
Maximum	1974.2	1922.6	2002.4	1694.4	851.7
Minimum	198.4	146.9	137.4	150.6	150.8
s	600.1	552.5	589.4	502.5	233.0
C.V. (%)	80.6	87.6	72.7	100.8	67.0

APPENDIX-V

Frequency Range Decibel, Amplitude Ratio and Percent Amplitude under Different Muffler Mounting on Tractor-1 at Different RPM

Table 1: Frequency range wise decibels, amplitude ratios and percent amplitudes under no muffler on Tractor-1 at 1000 RPM at ear level

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-10	0.3162	53.6
2.5 – 5.0	-17.5	0.13335	22.6
5.0 – 7.5	-17.5	0.13335	22.6
7.5 – 10.0	-45	0.0056	0.9
10.0 – 12.5	-60	0.001	0.2
12.5 – 15.0	-80	0.0001	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.58965	100.0

Table 2: Frequency range wise decibels, amplitude ratios and percent amplitudes under no muffler on Tractor-1 at 1000 RPM at 10 m distance

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-20	0.10	83.0
2.5 – 5.0	-40	0.01	8.3
5.0 – 7.5	-40	0.01	8.3
7.5 – 10.0	-70	0.0003162	0.3
10.0 – 12.5	-86	0.00005	0.0
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.12044	100.0

Table 3: Frequency range wise decibels, amplitude ratios and percent amplitudes under no muffler on Tractor-1 at 1250 RPM at ear level

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-12.5	0.237	39.6
2.5 – 5.0	-15	0.1778	29.7
5.0 – 7.5	-15	0.1778	29.7
7.5 – 10.0	-50	0.003162	0.5
10.0 – 12.5	-50	0.003162	0.5
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.59899	100.0

Table 4: Frequency range wise decibels, amplitude ratios and percent amplitudes under no muffler on Tractor-1 at 1250 RPM at 10 m distance

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-20	0.1	61.2
2.5 – 5.0	-30	0.03162	19.3
5.0 – 7.5	-30	0.03162	19.3
7.5 – 10.0	-84	0.000063	0.0
10.0 – 12.5	-86	0.00005	0.0
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.163428	100.0

Table 5: Frequency range wise decibels, amplitude ratios and percent amplitudes under no muffler on Tractor-1 at 1500 RPM at ear level

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-10	0.3162	44.7
2.5 – 5.0	-15	0.1778	25.1
5.0 – 7.5	-15	0.1778	25.1
7.5 – 10.0	-35	0.01778	2.5
10.0 – 12.5	-35	0.01778	2.5
12.5 – 15.0	-86	0.00005	0.0
15.0 – 17.5	-86	0.00005	0.0
17.5 – 20.0	-86	0.00005	0.0
Sum		0.70751	100.0

Table 6: Frequency range wise decibels, amplitude ratios and percent amplitudes under no muffler on Tractor-1 at 1500 RPM at 10 m distance

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-15	0.1778	61.2
2.5 – 5.0	-25	0.056	19.3
5.0 – 7.5	-25	0.056	19.3
7.5 – 10.0	-70	0.000316	0.1
10.0 – 12.5	-75	0.0001778	0.1
12.5 – 15.0	-86	0.00005	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.29039	100.0

Table 7: Frequency range wise decibels, amplitude ratios and percent amplitudes under no muffler on Tractor-1 at 1750 RPM at ear level

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-10	0.3162	39.3
2.5 – 5.0	-15	0.1778	22.1
5.0 – 7.5	-15	0.1778	22.1
7.5 – 10.0	-20	0.1	12.4
10.0 – 12.5	-30	0.03162	3.9
12.5 – 15.0	-65	0.00056	0.1
15.0 – 17.5	-75	0.0001778	0.0
17.5 – 20.0	-75	0.0001778	0.0
Sum		0.804336	100.0

Table 8: Frequency range wise decibels, amplitude ratios and percent amplitudes under no muffler on Tractor-1 at 1750 RPM at 10 m distance

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-15	0.1778	43.2
2.5 – 5.0	-17.5	0.13335	32.4
5.0 – 7.5	-20	0.1	24.3
7.5 – 10.0	-70	0.000316	0.1
10.0 – 12.5	-86	0.00005	0.0
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.41159	100.0

Table 9: Frequency range wise decibels, amplitude ratios and percent amplitudes under no muffler on Tractor-1 at 2000 RPM at ear level

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-10	0.3162	43.0
2.5 – 5.0	-15	0.1778	24.2
5.0 – 7.5	-15	0.1778	24.2
7.5 – 10.0	-30	0.03162	4.3
10.0 – 12.5	-30	0.03162	4.3
12.5 – 15.0	-75	0.0001778	0.0
15.0 – 17.5	-85	0.000056	0.0
17.5 – 20.0	-85	0.000056	0.0
Sum		0.73533	100.0

Table 10: Frequency range wise decibels, amplitude ratios and percent amplitudes under no muffler on Tractor-1 at 2000 RPM at 10 m distance

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-20	0.1	53.1
2.5 – 5.0	-25	0.056	29.7
5.0 – 7.5	-30	0.03162	16.8
7.5 – 10.0	-65	0.00056	0.3
10.0 – 12.5	-80	0.0001	0.1
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.188355	100.0

Table 11: Frequency range wise decibels, amplitude ratios and percent amplitudes under standard muffler (muffler-S) on tractor-1 at 1000 RPM at ear level

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-10	0.3162	44.5
2.5 – 5.0	-15	0.1778	25.0
5.0 – 7.5	-15	0.1778	25.0
7.5 – 10.0	-30	0.03162	4.5
10.0 – 12.5	-50	0.003162	0.4
12.5 – 15.0	-50	0.003162	0.4
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.709794	100.0

Table 12: Frequency range wise decibels, amplitude ratios and percent amplitudes under standard muffler (muffler-S) on tractor-1 at 1000 RPM at 10 m distance

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-30	0.03162	43.3
2.5 – 5.0	-30	0.03162	43.3
5.0 – 7.5	-40	0.01	13.7
7.5 – 10.0	-70	0.000316	0.4
10.0 – 12.5	-80	0.0001	0.1
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.073731	100.0

Table 13: Frequency range wise decibels, amplitude ratios and percent amplitudes under standard muffler (muffler-S) on tractor-1 at 1250 RPM at ear level

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-10	0.3162	38.6
2.5 – 5.0	-15	0.1778	21.7
5.0 – 7.5	-10	0.3162	38.6
7.5 – 10.0	-45	0.0056	0.7
10.0 – 12.5	-50	0.003162	0.4
12.5 – 15.0	-90	0.000031	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.819043	100.0

Table 14: Frequency range wise decibels, amplitude ratios and percent amplitudes under standard muffler (muffler-S) on tractor-1 at 1250 RPM at 10 m distance

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-15	0.1778	57.5
2.5 – 5.0	-20	0.1	32.4
5.0 – 7.5	-30	0.03162	10.2
7.5 – 10.0	-70	0.000316	0.1
10.0 – 12.5	-90	0.000031	0.0
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.309842	100.0

Table 15: Frequency range wise decibels, amplitude ratios and percent amplitudes under standard muffler (muffler-S) on tractor-1 at 1500 RPM at ear level

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-5	0.5623	46.9
2.5 – 5.0	-10	0.3162	26.4
5.0 – 7.5	-10	0.3162	26.4
7.5 – 10.0	-50	0.003162	0.3
10.0 – 12.5	-50	0.003162	0.3
12.5 – 15.0	-90	0.000031	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		1.201105	100.0

Table 16: Frequency range wise decibels, amplitude ratios and percent amplitudes under standard muffler (muffler-S) on tractor-1 at 1500 RPM at 10 m distance

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-20	0.1	43.1
2.5 – 5.0	-20	0.1	43.1
5.0 – 7.5	-30	0.03162	13.6
7.5 – 10.0	-70	0.000316	0.1
10.0 – 12.5	-80	0.0001	0.0
12.5 – 15.0	-90	0.000031	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.232117	100.0

Table 17: Frequency range wise decibels, amplitude ratios and percent amplitudes under standard muffler (muffler-S) on tractor-1 at 1750 RPM at ear level

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-5	0.5623	46.9
2.5 – 5.0	-10	0.3162	26.4
5.0 – 7.5	-10	0.3162	26.4
7.5 – 10.0	-50	0.003162	0.3
10.0 – 12.5	-50	0.003162	0.3
12.5 – 15.0	-90	0.000031	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		1.201105	100.0

Table 18: Frequency range wise decibels, amplitude ratios and percent amplitudes under standard muffler (muffler-S) on tractor-1 at 1750 RPM at 10 m distance

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-20	0.1	42.6
2.5 – 5.0	-20	0.1	42.6
5.0 – 7.5	-30	0.03162	13.5
7.5 – 10.0	-50	0.003162	1.3
10.0 – 12.5	-70	0.000316	0.1
12.5 – 15.0	-90	0.000031	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.235179	100.0

Table 19: Frequency range wise decibels, amplitude ratios and percent amplitudes under standard muffler (muffler-S) on tractor-1 at 2000 RPM at ear level

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-5	0.5623	46.1
2.5 – 5.0	-10	0.3162	25.9
5.0 – 7.5	-10	0.3162	25.9
7.5 – 10.0	-35	0.01778	1.5
10.0 – 12.5	-40	0.01	0.8
12.5 – 15.0	-90	0.000031	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		1.222561	100.0

Table 20: Frequency range wise decibels, amplitude ratios and percent amplitudes under standard muffler (muffler-S) on tractor-1 at 2000 RPM at 10 m distance

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-15	0.1778	45.7
2.5 – 5.0	-15	0.1778	45.7
5.0 – 7.5	-30	0.03162	8.1
7.5 – 10.0	-55	0.001778	0.5
10.0 – 12.5	-85	0.000056	0.0
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.389129	100.0

Table 21: Frequency range wise decibels, amplitude ratios and percent amplitudes under muffler-C on tractor-1 at 1000 RPM at ear level

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-10	0.3162	41.3
2.5 – 5.0	-20	0.1	13.1
5.0 – 7.5	-10	0.3162	41.3
7.5 – 10.0	-30	0.03162	4.1
10.0 – 12.5	-60	0.001	0.1
12.5 – 15.0	-90	0.000031	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.765101	100.0

Table 22: Frequency range wise decibels, amplitude ratios and percent amplitudes under muffler-C on tractor-1 at 1000 RPM at 10 m

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-25	0.056	57.2
2.5 – 5.0	-30	0.03162	32.3
5.0 – 7.5	-40	0.01	10.2
7.5 – 10.0	-80	0.0001	0.1
10.0 – 12.5	-90	0.000031	0.0
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.097826	100.0

Table 23: Frequency range wise decibels, amplitude ratios and percent amplitudes under muffler-C on tractor-1 at 1250 RPM at ear level

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-7.5	0.42169	51.9
2.5 – 5.0	-15	0.1778	21.9
5.0 – 7.5	-15	0.1778	21.9
7.5 – 10.0	-30	0.03162	3.9
10.0 – 12.5	-50	0.003162	0.4
12.5 – 15.0	-80	0.0001	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.812222	100.0

Table 24: Frequency range wise decibels, amplitude ratios and percent amplitudes under muffler-C on tractor-1 at 1250 RPM at 10 m

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-20	0.1	53.2
2.5 – 5.0	-25	0.056	29.8
5.0 – 7.5	-30	0.03162	16.8
7.5 – 10.0	-70	0.000316	0.2
10.0 – 12.5	-80	0.0001	0.1
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.188111	100.0

Table 25: Frequency range wise decibels, amplitude ratios and percent amplitudes under muffler-C on tractor-1 at 1500 RPM at ear level

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-10	0.3162	46.6
2.5 – 5.0	-15	0.1778	26.2
5.0 – 7.5	-15	0.1778	26.2
7.5 – 10.0	-50	0.003162	0.5
10.0 – 12.5	-50	0.003162	0.5
12.5 – 15.0	-90	0.000031	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.678205	100.0

Table 26: Frequency range wise decibels, amplitude ratios and percent amplitudes under muffler-C on tractor-1 at 1500 RPM at 10 m distance

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-17.5	0.1333	60.2
2.5 – 5.0	-25	0.056	25.3
5.0 – 7.5	-30	0.03162	14.3
7.5 – 10.0	-70	0.000316	0.1
10.0 – 12.5	-80	0.0001	0.0
12.5 – 15.0	-90	0.000031	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.221417	100.0

Table 27: Frequency range wise decibels, amplitude ratios and percent amplitudes under muffler-C on tractor-1 at 1750 RPM at ear level

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-10	0.3162	42.4
2.5 – 5.0	-20	0.1	13.4
5.0 – 7.5	-10	0.3162	42.4
7.5 – 10.0	-40	0.01	1.3
10.0 – 12.5	-50	0.003162	0.4
12.5 – 15.0	-90	0.000031	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.745643	100.0

Table 28: Frequency range wise decibels, amplitude ratios and percent amplitudes under muffler-C on tractor-1 at 1750 RPM at 10 m

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-15	0.1778	66.1
2.5 – 5.0	-25	0.056	20.8
5.0 – 7.5	-30	0.03162	11.8
7.5 – 10.0	-50	0.003162	1.2
10.0 – 12.5	-70	0.000316	0.1
12.5 – 15.0	-80	0.0001	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.269048	100.0

Table 29: Frequency range wise decibels, amplitude ratios and percent amplitudes under muffler-C on tractor-1 at 2000 RPM at ear level

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-10	0.3162	46.6
2.5 – 5.0	-15	0.1778	26.2
5.0 – 7.5	-15	0.1778	26.2
7.5 – 10.0	-50	0.003162	0.5
10.0 – 12.5	-50	0.003162	0.5
12.5 – 15.0	-80	0.0001	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.678274	100.0

Table 30: Frequency range wise decibels, amplitude ratios and percent amplitudes under muffler-C on tractor-1 at 2000 RPM at 10 m

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-15	0.1778	42.1
2.5 – 5.0	-15	0.1778	42.1
5.0 – 7.5	-25	0.056	13.3
7.5 – 10.0	-40	0.01	2.4
10.0 – 12.5	-70	0.000316	0.1
12.5 – 15.0	-80	0.0001	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.422066	100.0

APPENDIX-VI

Frequency Range Decibel, Amplitude Ratio and Percent Amplitude under Different Muffler Mounting on Tractor-2 at Different RPM

Table 1: Frequency range wise decibels, amplitude ratios and percent amplitudes under no muffler on Tractor-2 at 1000 RPM at ear level

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-10	0.3162	43.3
2.5 – 5.0	-15	0.1778	24.3
5.0 – 7.5	-15	0.1778	24.3
7.5 – 10.0	-25	0.056	7.7
10.0 – 12.5	-50	0.003162	0.4
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.73104	100.0

Table 2: Frequency range wise decibels, amplitude ratios and percent amplitudes under no muffler on Tractor-2 at 1000 RPM at 10 m distance

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-20	0.1	56.5
2.5 – 5.0	-27.5	0.042	23.7
5.0 – 7.5	-30	0.03162	17.9
7.5 – 10.0	-50	0.003162	1.8
10.0 – 12.5	-85	0.000056	0.0
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.1769	100.0

Table 3: Frequency range wise decibels, amplitude ratios and percent amplitudes under no muffler on Tractor-2 at 1250 RPM at ear level

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-7.5	0.42	44.3
2.5 – 5.0	-15	0.1778	18.7
5.0 – 7.5	-10	0.3162	33.3
7.5 – 10.0	-30	0.03162	3.3
10.0 – 12.5	-50	0.003162	0.3
12.5 – 15.0	-86	0.00005	0.0
15.0 – 17.5	-86	0.00005	0.0
17.5 – 20.0	-86	0.00005	0.0
Sum		0.9489	100.0

Table 4: Frequency range wise decibels, amplitude ratios and percent amplitudes under no muffler on Tractor-2 at 1250 RPM at 10 m distance

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-20	0.1	50.6
2.5 – 5.0	-25	0.056	28.3
5.0 – 7.5	-30	0.03162	16.0
7.5 – 10.0	-40	0.01	5.1
10.0 – 12.5	-80 (70+90)	0.0001	0.1
12.5 – 15.0	-90	0.00003162	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.1978	100.0

Table 5: Frequency range wise decibels, amplitude ratios and percent amplitudes under no muffler on Tractor-2 at 1500 RPM at ear level

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-10	0.3162	33.0
2.5 – 5.0	-15	0.1778	18.6
5.0 – 7.5	-10	0.3162	33.0
7.5 – 10.0	-20	0.1	10.4
10.0 – 12.5	-30	0.03162	3.3
12.5 – 15.0	-40	0.01	1.0
15.0 – 17.5	-50	0.003162	0.3
17.5 – 20.0	-50	0.003162	0.3
Sum		0.958144	100.0

Table 6: Frequency range wise decibels, amplitude ratios and percent amplitudes under no muffler on Tractor-2 at 1500 RPM at 10 m distance

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-15	0.1778	35.8
2.5 – 5.0	-15	0.1778	35.8
5.0 – 7.5	-20	0.1	20.1
7.5 – 10.0	-30	0.03162	6.4
10.0 – 12.5	-40	0.01	2.0
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.497295	100.0

Table 7: Frequency range wise decibels, amplitude ratios and percent amplitudes under no muffler on Tractor-2 at 1750 RPM at ear level

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-7.5	0.42	26.8
2.5 – 5.0	-10	0.3162	20.2
5.0 – 7.5	-7.5	0.42	26.8
7.5 – 10.0	-10	0.3162	20.2
10.0 – 12.5	-25	0.056	3.6
12.5 – 15.0	-35	0.01778	1.1
15.0 – 17.5	-40	0.01	0.6
17.5 – 20.0	-40	0.01	0.6
Sum		1.56618	100.0

Table 8: Frequency range wise decibels, amplitude ratios and percent amplitudes under no muffler on Tractor-2 at 1750 RPM at 10 m distance

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-12.5	0.237	39.1
2.5 – 5.0	-15	0.1778	29.3
5.0 – 7.5	-15	0.1778	29.3
7.5 – 10.0	-40	0.01	1.7
10.0 – 12.5	-50	0.003162	0.5
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.605837	100.0

Table 9: Frequency range wise decibels, amplitude ratios and percent amplitudes under no muffler on Tractor-2 at 2000 RPM at ear level

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-5	0.56	33.5
2.5 – 5.0	-15	0.1778	10.6
5.0 – 7.5	-5	0.56	33.5
7.5 – 10.0	-15	0.1778	10.6
10.0 – 12.5	-22.5	0.075	4.5
12.5 – 15.0	-30	0.03162	1.9
15.0 – 17.5	-30	0.03162	1.9
17.5 – 20.0	-25	0.056	3.4
Sum		1.66984	100.0

Table 10: Frequency range wise decibels, amplitude ratios and percent amplitudes under no muffler on Tractor-2 at 2000 RPM at 10 m distance

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-17.5	0.13335	27.8
2.5 – 5.0	-17.5	0.13335	27.8
5.0 – 7.5	-15	0.1778	37.1
7.5 – 10.0	-30	0.03162	6.6
10.0 – 12.5	-50	0.003162	0.7
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.479357	100.0

Table 11: Frequency range wise decibels, amplitude ratios and percent amplitudes under standard muffler (muffler-S) on tractor-2 at 1000 RPM at ear level

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-10	0.3162	50.5
2.5 – 5.0	-15	0.1778	28.4
5.0 – 7.5	-20	0.1	15.9
7.5 – 10.0	-30	0.03162	5.1
10.0 – 12.5	-70	0.0003162	0.1
12.5 – 15.0	-85	0.00005623	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.6260	100.0

Table 12: Frequency range wise decibels, amplitude ratios and percent amplitudes under standard muffler (muffler-S) on tractor-2 at 1000 RPM at 10 m

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-20	0.1	61.2
2.5 – 5.0	-30	0.03162	19.4
5.0 – 7.5	-30	0.03162	19.3
7.5 – 10.0	-80	0.0001	0.1
10.0 – 12.5	-92	0.000025	0.0
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.16344	100.0

Table 13: Frequency range wise decibels, amplitude ratios and percent amplitudes under standard muffler (muffler-S) on tractor-2 at 1250 RPM at ear level

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-10	0.3162	44.9
2.5 – 5.0	-15	0.1778	25.3
5.0 – 7.5	-15	0.1778	25.3
7.5 – 10.0	-30	0.03162	4.5
10.0 – 12.5	-70	0.0003162	0.1
12.5 – 15.0	-85	0.00005623	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.70384	100.0

Table 14: Frequency range wise decibels, amplitude ratios and percent amplitudes under standard muffler (muffler-S) on tractor-2 at 1250 RPM at 10 m

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-15	0.1778	60.6
2.5 – 5.0	-25	0.056	19.1
5.0 – 7.5	-25	0.056	19.1
7.5 – 10.0	-50	0.003162	1.1
10.0 – 12.5	-75	0.000178	0.1
12.5 – 15.0	-85	5.62E-05	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.2932	100.0

Table 15: Frequency range wise decibels, amplitude ratios and percent amplitudes under standard muffler (muffler-S) on tractor-2 at 1500 RPM at ear level

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-10	0.3162	44.9
2.5 – 5.0	-15	0.1778	25.3
5.0 – 7.5	-15	0.1778	25.3
7.5 – 10.0	-30	0.03162	4.5
10.0 – 12.5	-70	0.0003162	0.0
12.5 – 15.0	-85	0.00005623	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.7038	100.0

Table 16: Frequency range wise decibels, amplitude ratios and percent amplitudes under standard muffler (muffler-S) on tractor-2 at 1500 RPM at 10 m

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-15	0.1778	57.0
2.5 – 5.0	-23.5	0.0668	21.4
5.0 – 7.5	-23.5	0.0668	21.4
7.5 – 10.0	-70	0.000316	0.1
10.0 – 12.5	-80	0.0001	0.0
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.31189	100.0

Table 17: Frequency range wise decibels, amplitude ratios and percent amplitudes under standard muffler (muffler-S) on tractor-2 at 1750 RPM at ear level

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-10	0.3162	38.3
2.5 – 5.0	-12.5	0.2371	28.7
5.0 – 7.5	-12.5	0.2371	28.7
7.5 – 10.0	-30	0.03162	3.8
10.0 – 12.5	-50	0.003162	0.4
12.5 – 15.0	-90	0.000031	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.825263	100.0

Table 18: Frequency range wise decibels, amplitude ratios and percent amplitudes under standard muffler (muffler-S) on tractor-2 at 1750 RPM at 10 m

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-15	0.1778	54.1
2.5 – 5.0	-22.5	0.07498	22.8
5.0 – 7.5	-22.5	0.07498	22.8
7.5 – 10.0	-60	0.001	0.3
10.0 – 12.5	-80	0.0001	0.0
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.328935	100.0

Table 19: Frequency range wise decibels, amplitude ratios and percent amplitudes under standard muffler (muffler-S) on tractor-2 at 2000 RPM at ear level

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-10	0.3162	38.3
2.5 – 5.0	-12.5	0.2371	28.7
5.0 – 7.5	-12.5	0.2371	28.7
7.5 – 10.0	-30	0.03162	3.8
10.0 – 12.5	-50	0.003162	0.4
12.5 – 15.0	-90	0.000031	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.825263	100.0

Table 20: Frequency range wise decibels, amplitude ratios and percent amplitudes under standard muffler (muffler-S) on tractor-2 at 2000 RPM at 10 m

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-15	0.1778	48.9
2.5 – 5.0	-22.5	0.07498	20.7
5.0 – 7.5	-20	0.1	27.6
7.5 – 10.0	-40	0.01	2.8
10.0 – 12.5	-80	0.0001	0.0
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.362955	100.0

Table 21: Frequency range wise decibels, amplitude ratios and percent amplitudes under muffler-C on tractor-2 at 1000 RPM at ear level

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-10	0.3162	41.2
2.5 – 5.0	-12.5	0.2371	30.9
5.0 – 7.5	-13.5	0.21134	27.5
7.5 – 10.0	-50	0.003162	0.4
10.0 – 12.5	-85	0.00005623	0.0
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.767933	

Table 22: Frequency range wise decibels, amplitude ratios and percent amplitudes under muffler-C on tractor-2 at 1000 RPM at 10 m

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-20	0.1	61.1
2.5 – 5.0	-30	0.03162	19.3
5.0 – 7.5	-30	0.03162	19.3
7.5 – 10.0	-70	0.0003162	0.2
10.0 – 12.5	-92	0.000025	0.0
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.163656	

Table 23: Frequency range wise decibels, amplitude ratios and percent amplitudes under muffler-C on tractor-2 at 1250 RPM at ear level

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-10	0.3162	39.8
2.5 – 5.0	-12.5	0.2371	29.9
5.0 – 7.5	-12.5	0.2371	29.9
7.5 – 10.0	-50	0.003162	0.4
10.0 – 12.5	-80	0.0001	0.0
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.793737	

Table 24: Frequency range wise decibels, amplitude ratios and percent amplitudes under muffler-C on tractor-2 at 1250 RPM at 10 m

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-20	0.1	47.0
2.5 – 5.0	-25	0.056	26.3
5.0 – 7.5	-25	0.056	26.3
7.5 – 10.0	-65	0.00056	0.3
10.0 – 12.5	-92	0.000025	0.0
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.21266	

Table 25: Frequency range wise decibels, amplitude ratios and percent amplitudes under muffler-C on tractor-2 at 1500 RPM at ear level

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-10	0.3162	39.3
2.5 – 5.0	-12.5	0.2371	29.5
5.0 – 7.5	-12.5	0.2371	29.5
7.5 – 10.0	-40	0.01	1.2
10.0 – 12.5	-50	0.003162	0.4
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.803637	

Table 26: Frequency range wise decibels, amplitude ratios and percent amplitudes under muffler-C on tractor-2 at 1500 RPM at 10 m

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-17.5	0.1333	49.4
2.5 – 5.0	-23.5	0.0668	24.7
5.0 – 7.5	-23.5	0.0668	24.7
7.5 – 10.0	-50	0.003162	1.2
10.0 – 12.5	-85	0.00005623	0.0
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.27019	

Table 27: Frequency range wise decibels, amplitude ratios and percent amplitudes under muffler-C on tractor-2 at 1750 RPM at ear level

Frequency Range (kHz)	dB (SPL)	Amplitude Ratio	Percent Amplitudes
0.0 – 2.5	-10	0.3162	38.3
2.5 – 5.0	-12.5	0.2371	28.7
5.0 – 7.5	-12.5	0.2371	28.7
7.5 – 10.0	-30	0.03162	3.8
10.0 – 12.5	-50	0.003162	0.4
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.825257	

Table 28: Frequency range wise decibels, amplitude ratios and percent amplitudes under muffler-C on tractor-2 at 1750 RPM at 10 m

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-17.5	0.1333	39.3
2.5 – 5.0	-20	0.1	29.5
5.0 – 7.5	-20	0.1	29.5
7.5 – 10.0	-45	0.0056	1.6
10.0 – 12.5	-85	0.00005623	0.0
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.3390	

Table 29: Frequency range wise decibels, amplitude ratios and percent amplitudes under muffler-C on tractor-2 at 2000 RPM at ear level

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-10	0.3162	35.1
2.5 – 5.0	-12.5	0.2371	26.3
5.0 – 7.5	-12.5	0.2371	26.3
7.5 – 10.0	-20	0.1	11.1
10.0 – 12.5	-40	0.01	1.1
12.5 – 15.0	-85	0.00005623	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.90050	

Table 30: Frequency range wise decibels, amplitude ratios and percent amplitudes under muffler-C on tractor-2 at 2000 RPM at 10 m

Frequency Range (kHz)	**dB (SPL)**	**Amplitude Ratio**	**Percent Amplitudes**
0.0 – 2.5	-17.5	0.1333	39.6
2.5 – 5.0	-20	0.1	29.7
5.0 – 7.5	-20	0.1	29.7
7.5 – 10.0	-50	0.00316	0.9
10.0 – 12.5	-80	0.0001	0.0
12.5 – 15.0	-92	0.000025	0.0
15.0 – 17.5	-92	0.000025	0.0
17.5 – 20.0	-92	0.000025	0.0
Sum		0.336635	

APPENDIX-VII

Vibration Velocity Levels (mm/s) Recorded at Different RPM on Different Surfaces of Tractor-1 (Mini Tractor) & Tractor-2

Table 1: Vibration velocity levels (mm/s) recorded at different RPM over different surfaces of Tractor-1 (Mini Tractor) parts

Front Axle									
Replication	1000 RPM			1500 RPM			2000 RPM		
	X	Y	Z	X	Y	Z	X	Y	Z
1	80.2	9.1	9.8	94.8	23.0	65.3	176.5	27.9	56.2
2	15.5	7.7	10.3	136.0	69.1	136.2	100.5	20.5	63.0
3	130.3	8.1	6.5	178.4	40.5	102.0	87.7	34.7	151.4
Bonnet									
Replication	1000 RPM			1500 RPM			2000 RPM		
	X	Y	Z	X	Y	Z	X	Y	Z
1	53.4	16.3	43.6	53.1	50.7	42.5	22.9	54.0	60.6
2	25.2	18.6	25.0	57.4	77.9	64.6	78.7	63.4	42.7
3	22.3	17.3	31.0	94.6	71.1	99.7	63.7	14.2	48.4
Foot Rest									
Replication	1000 RPM			1500 RPM			2000 RPM		
	X	Y	Z	X	Y	Z	X	Y	Z
1	23.3	22.6	44.4	22.8	46.0	17.5	92.2	66.1	57.5
2	86.8	67.6	31.0	48.9	56.9	40.2	68.9	61.3	54.0
3	22.9	33.8	30.2	21.3	36.8	26.0	58.6	87.1	65.2

Table 2: Vibration velocity levels (mm/s) recorded at different RPM over different surfaces of Tractor-2 parts

Front Axle									
Replication	1000 RPM			1500 RPM			2000 RPM		
	X	Y	Z	X	Y	Z	X	Y	Z
1	2.87	6.96	0.99	59.25	65.52	62.58	67.8	95.7	86.5
2	2.92	14.44	1.35	33.77	55.27	46.59	13.18	76.48	73.86
3	2.93	8.82	2.38	19.05	34.89	62.58	67.8	95.7	86.5
Bonnet									
Replication	1000 RPM			1500 RPM			2000 RPM		
	X	Y	Z	X	Y	Z	X	Y	Z
1	12.28	9.34	6	92.51	57.42	15.71	72.69	46.16	45.8
2	14.64	22.04	12.9	23.06	20.43	19.25	83.73	45.85	82.4
3	21.24	10.97	11.95	74.69	39.43	10	88.9	50.1	37.13
Foot Rest									
Replication	1000 RPM			1500 RPM			2000 RPM		
	X	Y	Z	X	Y	Z	X	Y	Z
1	0.71	5.55	5.98	2.3	17.41	22.99	39.15	77.44	39.75
2	0.75	3.98	5.76	2.11	12.59	13.64	31	89.85	129.74
3	0.59	2.3	1.97	2.27	10.3	4.46	43.88	45.28	76.22

APPENDIX-VIII

Vibration Acceleration Levels (m/s^2) Recorded at Different RPM on Different Surfaces of Tractor-1 (Mini Tractor) & Tractor-2

Table 1: Vibration acceleration levels (m/s^2) recorded at different RPM over different surfaces of Tractor-1 (Mini Tractor) parts

Front Axle									
Replication	1000 RPM			1500 RPM			2000 RPM		
	X	Y	Z	X	Y	Z	X	Y	Z
1	11.2	5.5	6.2	14.6	6.9	9.1	34.9	8.7	9.9
2	10.1	5.0	5.6	19.9	11.8	18.9	19.6	11.0	12.7
3	25.2	5.5	6.6	33.5	8.4	14.1	15.9	7.8	17.2
Bonnet									
Replication	1000 RPM			1500 RPM			2000 RPM		
	X	Y	Z	X	Y	Z	X	Y	Z
1	11.1	11.1	12.5	14.9	19.5	22.0	14.2	19.7	21.4
2	10.7	11.2	13.3	20.0	24.8	18.6	23.2	26.4	23.5
3	10.5	10.3	14.4	34.4	22.9	24.7	25.7	9.6	26.2
Foot Rest									
Replication	1000 RPM			1500 RPM			2000 RPM		
	X	Y	Z	X	Y	Z	X	Y	Z
1	10.2	10.3	10.8	9.4	13.6	7.7	17.4	19.3	16.2
2	12.9	14.6	8.7	10.5	14.5	10.2	15.5	18.3	15.7
3	10.7	12.8	8.4	10.0	11.6	7.5	20.0	18.9	20.0

Table 2: Vibration acceleration levels (m/s^2) recorded at different RPM over different surfaces of Tractor-2 parts

Front Axle									
Replication	1000 RPM			1500 RPM			2000 RPM		
	X	Y	Z	X	Y	Z	X	Y	Z
1	5.51	4.63	2.06	13.54	11.96	25.27	10.4	22.17	19.03
2	5.59	6.94	4.53	8.64	10.97	12.58	8.25	17.2	17.3
3	4.9	6.5	2.45	7.45	10.17	25.27	10.41	22.3	19.03
Bonnet									
Replication	1000 RPM			1500 RPM			2000 RPM		
	X	Y	Z	X	Y	Z	X	Y	Z
1	10.96	7.13	6.24	26.92	24.42	10.02	27.79	18.2	19.77
2	7.85	8.37	9.27	13.9	10.68	11.21	32.96	18.57	29.96
3	14.3	6.55	7.41	22.85	13.22	8.7	36.41	18.65	15.68
Foot Rest									
Replication	1000 RPM			1500 RPM			2000 RPM		
	X	Y	Z	X	Y	Z	X	Y	Z
1	2.89	8.69	9.3	6.12	13.53	14.74	14.38	17.91	18.15
2	2.85	8.69	9.4	5.94	12.62	13.54	12.61	26.54	28.39
3	3.03	5.62	6.54	6.13	7.84	10.23	9.89	17.46	14.87