Reduction of the Car Toxic Emissions by using Double Catalytic Converter

By

Mohammed Othman Aljamal

Supervisor:

Dr. Zuhdi Salhab

Submitted to the College of Engineering

in partial fulfillment of the requirements for the degree of

Bachelor degree in Automotive Engineering

Palestine Polytechnic University

Jan 2016

Palestine polytechnic University

Hebron – Palestine

College of Engineering

Mechanical Engineering Department

Reduction of the Car Toxic Emissions by using Double Catalytic Converter

Project Team:

Mohammed O. Aljamal

By the guidance of our supervisor , and by the acceptance of all members in the testing committee, this project is delivered to Mechanical Engineering Department in the college of Engineering, to be as a partial fulfillment of the requirement of the department for the degree of B.sc .

Supervisor signature

Testing committee signature

-- --

The head of department signature

جامعة بوليتكنك فلسطين

الخليل – فلسطين

كلية الهندسة

دائرة الهندسة الميكانيكية

Reduction of the Car Toxic Emissions by using Double Catalytic Converter

فريق المشروع:

محمد عثمان الجمل

بناء على نظام كلية الهندسة وإشراف ومتابعة المشرف المباشر على المشروع ومواففة أعضاء اللجنة المناقشة , تم تقديم هذا العمل إلى دائرة الهندسة الميكانيكية . وذلك للوفاء بمتطلبات درجة البكالوريوس في هندسة السيارات.

توقيع المشرف

توقيع اللجنة المناقشة

--   --

توقيع رئيس الدائرة

Dedication (الإهداء)

إلى وطني المُشرد الذي لطالما كان مصدراً لإلهامي بالقوة والمنعة

إلى فِلسطين الأرض والإنسان

إلى التربةِ المَقدسية التي أنبَتت القطوف الهَندسية الدانية من رحمِ الأمِّ الغالية وروح الأبِ العالية

إلى عائلتي أصحاب القلوب الراقية

إلى الأبُوة والأخوةُ .. إلى اللذين لولاهم ما كنا

إلى دائرة الهندسة الميكانيكية في جامعة بوليتكنك فلسطين

إلى تلك التي تَعَرقت جبهتها لتقديم اليد التي زرعت هذه البذرة فأنبتت هذه الفكرة

إلى رفيقتي الغالية

إلى من قدم لي الكثير الكثير

إلى مشرفي المخلص الدكتور زهدي سلهب

إلى من ساندني وزرع حب العلم في نفسي

إلى الدكتور مؤمن صغير

إلى من ساندني ووقف بجانبي يداً بيد

إلى رفاقي المخلصين

Abstract

Exhaust gas pollutants emitted to the atmosphere are seriously considered to be hygienic and environmental risk. This project responds to environmental and humanity needs to reduce the concentration of the toxic emissions by using double Catalytic Converter. In order to achieve these goals, a new exhaust system was designed. The project Confirms the validity of modifying the exhaust system by using SolidWorks program. Experimental Results show that using double catalytic converter has a good effect in reducing the toxic emission, the estimated reduction percentage of these gases (without catalytic converters, after the first one and after the second one) as shown in following table

	Reduction of exhaust gases		
	%CO	%HC	%NOx
First catalytic converter	25.13	53.35	33.75
Second catalytic converter	16.24	45.38	35.27

الملخص

تصدر المركبات التي تحتوي على محركات احتراق داخلي مجموعة من الانبعاثات السامة والضارة بالبيئة وعناصرها, يُركز هذا المشروع على تصميم نظام عادم جديد يحتوي على صندوقي بيئة من أجل تقليل هذه الانبعاثات , بحيث تحصل تنقية غازات العادم على مرحلتين أساسية وثانوية.

حيث أظهرت النتائج العملية بأن إضافة صندوق بيئة ثانوي إلى صندوق البيئة الأساسي يسهم في تقليل نسبة الغازات الضارة بالبيئة وعناصرها وتكون نسبه تخفيض تراكيز الغازات الضارة أكبر من الطريقة التقليدية والتي تستخدم صندوق بيئة واحد.

والجدول التالي يوضح نسبة تحويل الغازات داخل المحولات الحفازة :

	نسبة تحويل الغازات		
	% أكاسيد النيتروجين	% الهيدروكربونات	% أول أكسيد الكربون
المحول الحفاز الاول	33.75	53.35	25.13
المحول الحفاز الثاني	32.27	48.38	16.24

Table of Contents

Chapter One

Chapter Two

Chapter Three

Chapter Four

Chapter Five

Abbreviations

Abbreviations	**Description**
CO	Carbon Monoxide
UHC	Unburned Hydrocarbon
NO_X	Nitrogen Oxides
NO	Nitric Oxide
SIE	Spark Ignition Engines
CIE	Compression Ignition Engines
SCR	Selective Catalytic Reduction
H_2O	Water
EGR	Exhaust Gas Recirculation
N_2	Nitrogen
Pb	Lead
ICE	Internal Combustion Engines
CH_4	Methane
SO_2	Sulfur Dioxide
NMVOC	Non-Methane Volatile Organic Compounds
PM	Particulate Matters
ICEV	Internal Combustion Engine Vehicles

O_2	Oxygen
C_8H_{18}	Gasoline
C	Carbon
H_2	Hydrogen
$\emptyset$	Fuel/Air Equivalent Ratio
λ	Ratio of Actual A/F to Stoichiometry
N_2	Nitrogen
CO_x	Oxides of Carbon
NO_x	Oxides of Nitrogen
SO_x	Oxides of Sulphur
EPA	Environmental Protection Agency
TDC	Top Dead Center
EVAP	Evaporation Emission Control System

List of Figures

List of Tables

Chapter One

Introduction

1.1 Introduction

1.2 Background

1.3 Problem of statement

1.4 Research Hypothesis

1.5 Aims and Objectives

1.6 Literature Review

1.7 Project Scope

1.8 Significance of Study

1.9 Methodology

1.10 Implementation Plan Time Table

1.11 Project Budget

1.1 Introduction

The world today suffers from different kinds of pollutions that affects the environment such as air and water pollution. All of that can be recognized everywhere like global warming, acid rain, smog and particles in the air, the effect of pollution is apparent at most for air.

The major causes of pollution are:

- Industrial factories
- Increasing in the world population
- Increasing in human needs and the transportation sector -the emissions of automotive engines- as a source of pollution

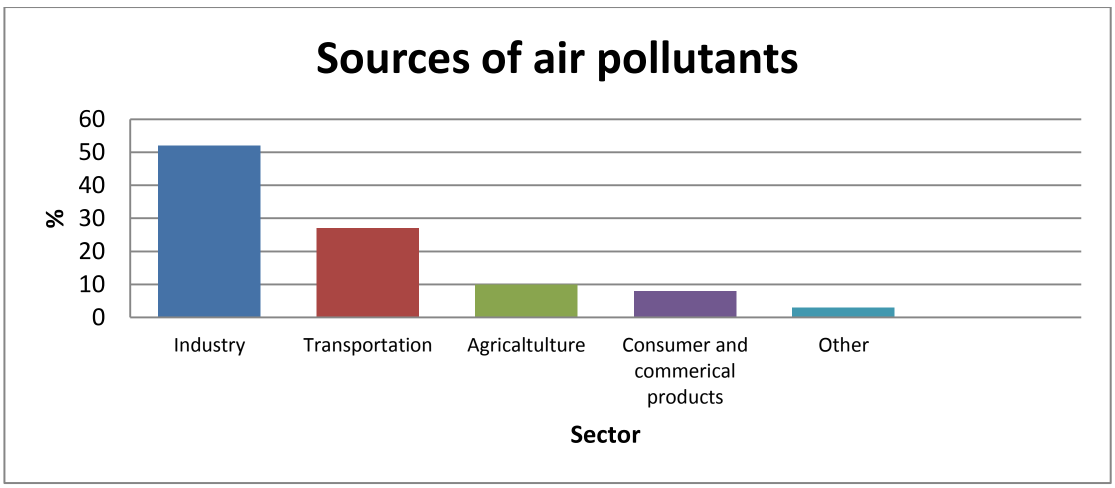


Figure 1.1: Sources of air pollutants[1]

The development of automotive technology in the last years and competition between the companies is to make the vehicle more powerful and more comfortable for the driver and passengers with suitable cost for all the people. All of that made the marketing of vehicles easier for customers which lead to increase the number of cars around the world which in return lead to increase the emissions from the vehicles and the negative effect on the environment. The automotive engineers made a lot of researches about the emissions to find suitable solutions that can convert the harmful pollutants into less toxic compounds. One of these solutions was the catalytic converter. This project are going to find the benefits of adding secondary catalytic converter to the primary catalytic converter with some calculations for that.

1.2 Background

Emissions of the combustion of the fuel inside the engine are one of the greatest challenges that face the automotive engineers and the automotive companies. Most of the studies today head to reduce the effect of pollution that can be recognized everywhere like global warming, acid rain, smog and particles in air. Lots of researches have been established to focus on this purpose.

Emissions of burning the fuel inside the engine contains four major kinds of elements which are the high percentage of the automotive emissions and they are:

1. Carbon monoxide (CO);this element is produced during incomplete combustion (insufficient amount of air).
2. Unburned hydrocarbon (UHC); this element is produced during incomplete combustion or unsuitable mixing (partial combustion).
3. Nitrogen oxides ($NO_{x;}$) include Nitric oxide (NO), Nitrogen dioxide($NO_{2)}$ and Nitric oxide (NO) are produced during combustion in the hot burned gases, NO = f (T).
4. Particulate matters PM; this elements produced during the compression ignition engines (CIE) more than spark ignition engines (SIE).

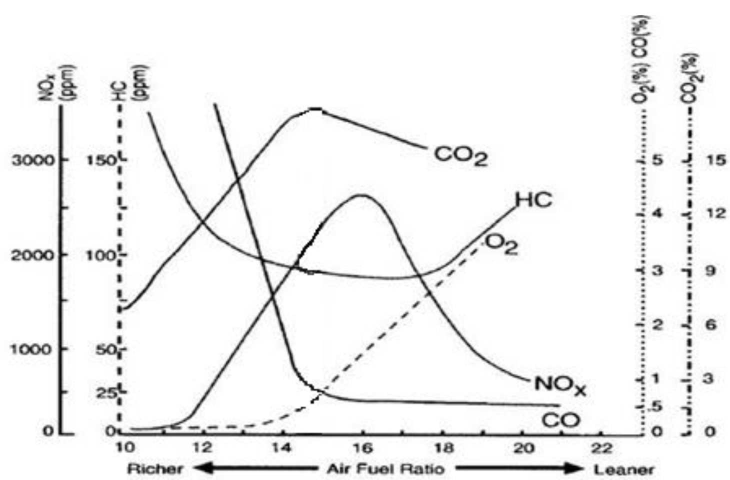


Figure 1.2: The relation between engine emissions and air fuel ratio

1.3 Problem statement

- Main problem

Experimental study for investigation the effects of using double catalytic converter for reducing concentration of toxic emission from SIE in vehicle.

- Sub problems

1. Confirming the validity of modifying the exhaust system by using SolidWorks program.
2. Studying the effect of using double catalytic converter on reducing of toxic emission.

1.4 Research Hypothesis:

- Adding a secondary three-way catalytic converter to the primary catalytic converter in series will decrease the harmful emissions of the exhaust system (reduce the NO_x, CO and UHC).
- Building and Designing exhaust system for the best flow distribution of the exhaust emissions along the system will solve a raising of the back pressure in the exhaust pipes as a result of adding a second catalytic converter in series.

1.5 Aims and Objectives

The main aim is to convert the harmful pollutants into less toxic compounds from the engine by using double three-way catalytic converter and to prove that the benefits of this way is greater than the common way.

The project targets the following specific objectives:

- Designing and measuring the experiment in automotive workshop.
- Showing the results of the experiment as a comparison of the exhaust system before and after the experiment.

1.6 Literature Review

Many studies about emission reduction had been investigated; the following studies was introduced in that field.

1.6.1 Controlling Toxic Emission Exhaust in vehicle Using Chemically Modified Catalytic Converter

H.AL-sarsour, and M Nairoukh; under supervision of Z.Salhab, and M.Jabari introduced this study, study description as the following:

This study responds to environmental and humanity needs to reduce the concentration of toxic emissions by injection an optimum amount of urea into the exhaust manifold to react with NO_x and CO emissions inside catalytic converter. In order to achieve these goals, a new system was designed and implemented. The designed system is composed of mechanical and electronic parts such as sensors. Sensors are located before and after catalytic converter for measuring removal efficiency of catalytic converter. The effect of operational parameters was investigated for reducing the emission concentration. Experiments with new system were performed on a diesel engine. The effect of operational parameters such as (engine speed, diesel injection timing, A/F ratio and urea injection quantity) on the efficiency of the catalytic converter before and after urea injection. they observed that the concentrations of NO_x and CO emissions reduced with injection urea in the exhaust, and the removal efficiency of catalytic converter is enhanced.

Figure 1.3: Project shape layout.

They see that it affect by engine operating parameters, they observed that the NO_x rate is increased with engine speed, advancing injection timing and decreased with A/F. the rate of CO increased with engine speed and reach its maximum value at 2000RPM, and it increased steadily with A/F to reach about 18:1 then it decreased. Advancing injection timing increases the rate of CO.

The concentration of NO_x and CO emissions decreased with injection urea, and the removal efficiency of catalytic converter is increased. There is an optimum amount of urea injection, that not mean excess amount make the concentration on both CO and NO_x still decrease. There is a point of chemical equilibrium and the excess amount leave the exhaust pipe without reacting in the form of ammonia.

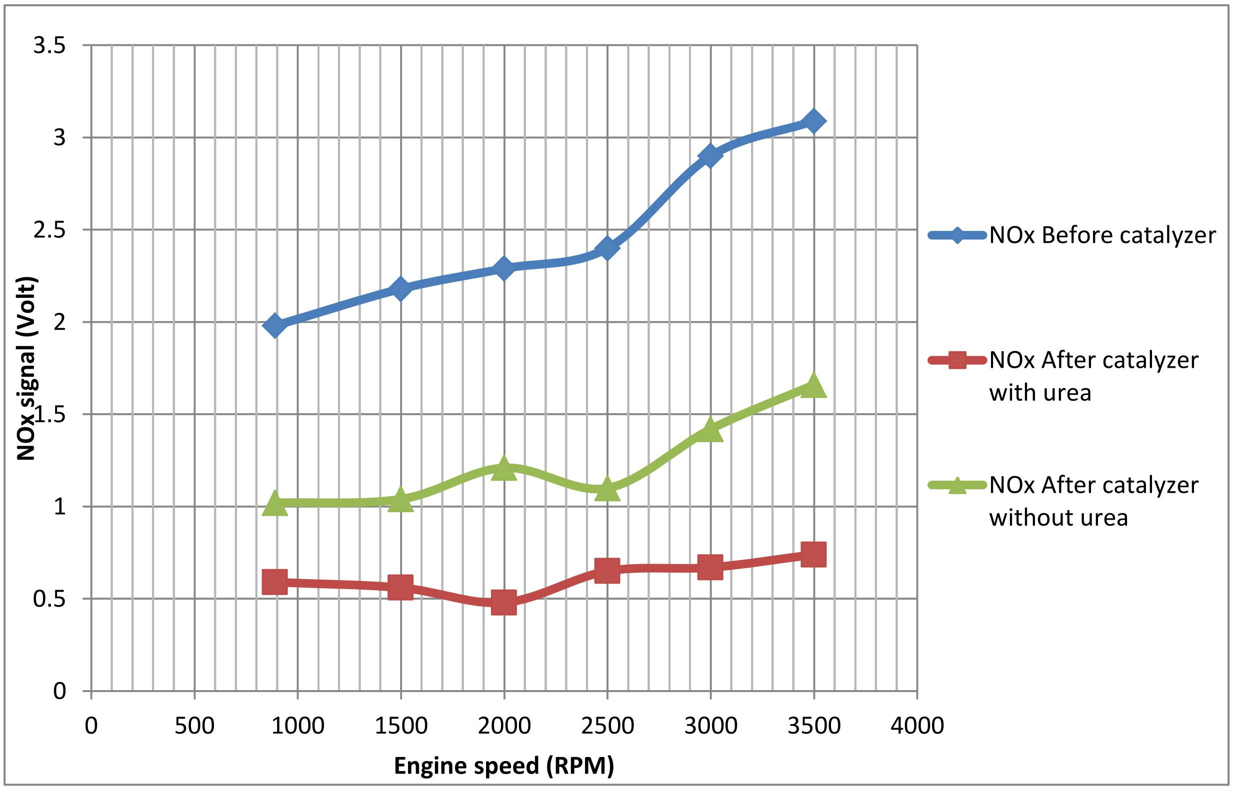


Figure 1.4 : Effect of engine speed on the output NOx signal before and after catalytic converter.

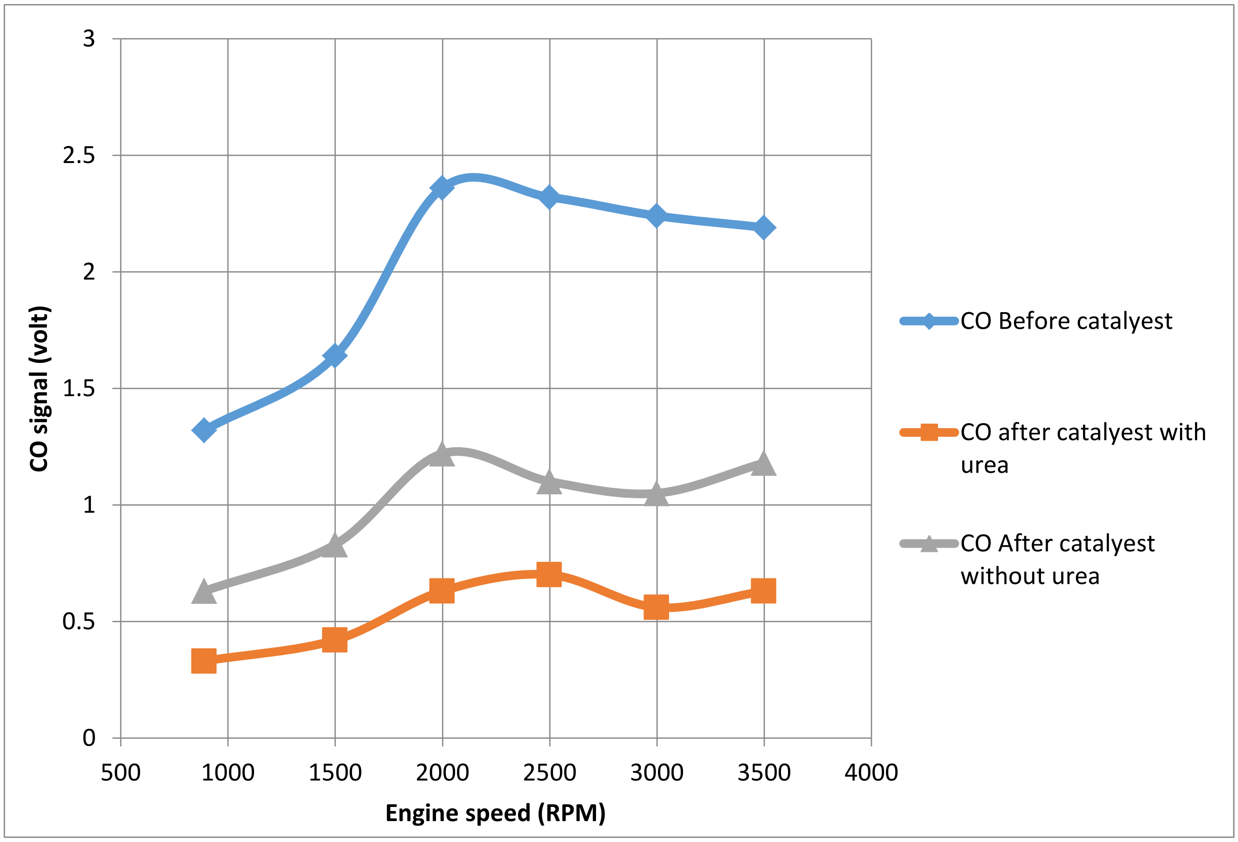


Figure 1.5 : Effect of engine speed on the output CO signal before and after catalytic converter.

1.6.2 Optimum Design of Manganese-Coated Copper Catalytic Converter to Reduce Carbon Monoxide Emissions on Gasoline Motor

B. Irawan, P. Purwanto, and H. Hadiyanto; introduced this study, study description as the following:

One of the engineering technologies that can be used to reduce air pollution is the use of catalytic converter mounted on vehicle gas exhaust duct. Unfortunately, these tools are very expensive in the market and not all motor vehicles use these technologies, because the catalyst was made from expensive metals and rarely available in the market, such as: Palladium, Platinum and Rhodium. Besides, the catalyst is susceptible to premium fuel with low levels of lead (Pb) which results in the damage of the function of the catalyst due to blockage in the honeycomb catalytic converter. The research done in laboratory to test the other substrate materials as a catalyst, to study the ability of the catalyst in a catalytic converter to reduce exhaust emissions of carbon monoxide. This research studied the performance capabilities and assess the effectiveness of manganese-coated copper catalysts which are designed in such a way to obtain the appropriate shape and type of catalytic converter catalyst and suitable for premium fuel motor vehicles [3]. The result showed that:

(1) Catalytic Converter design and modification of catalytic materials can be an alternative to overcome the high air pollution problem from the transportation sector, especially particular carbon monoxide exhaust emissions from gasoline motors.

(2) The use of Manganese-Coated Copper as a catalyst in the catalytic converter was significantly able to increase the reduction of Carbon Monoxide exhaust emissions.

(3) The increase of catalyst cells amount decreased the concentration of carbon monoxide exhaust emissions.

(4) Optimum Design of Model 2 Catalytic Converter was able to reduce exhaust emissions of carbon monoxide.

The previous studies focused on finding a new ways in order to reduce the toxic emitted gases from a cars .This project differs from its predecessors in Evaluating the effect of adding secondary catalytic converter on the performance of the exhaust system by reducing the effect of the toxic emissions on the environment and public health by designing and building new exhaust system includes two catalytic converters in series (primary and secondary).

1.7 Project Scope:

The scope of the project includes the following main topics:

- Evaluation of the effect of adding a secondary catalytic converter on the performance of the exhaust system by reducing the effect of the toxic emissions on the environment and public health.
- Designing and building new exhaust system includes two catalytic converters in series (primary and secondary).

1.8 Significance of Study:

Internal combustion engine vehicles are responsible for the vast majority of pollutants that plague urban areas today. Studies of the sources of air pollution have shown that transportation accounts for the majority of nitrogen oxide (54%) and carbon monoxide (89%) emissions in urban areas. Furthermore, internal combustion engines are also considered to be one of the largest sources of carbon dioxide. Internal combustion engine vehicles also generate other types of pollutants including sulfur oxides and hydrocarbons.

These emissions are directly responsible for many of the air quality and human health problems, therefore the scientists focused on finding a solution for reducing these emissions, then they found many solutions for control of these emissions such as using catalytic converter. A catalytic converter is a vehicle emissions control device that converts toxic pollutants in exhaust gas to less toxic pollutants by catalyzing a redox reaction (oxidation or reduction).Due to the effectiveness of catalytic converter in reduction of the exhaust gas pollutants, this project introduces studying and evaluating the effect of adding secondary catalytic converter on emissions performance by designing and building a new exhaust system by using double catalytic converters.

1.9 Methodology

The project uses applied research aimed to find a solution for the toxic exhaust emission from a car, by using the tools of research to satisfy the objectives.

1.10 Implementation Plan Time Table

The project is divided into two stages (semesters). In first stage, the following tasks are implemented.

- Planning and setting project concepts and aims
- Establishing scientific background
- Literature review is being introduced
- Choosing suitable requirements for implementation
- Proposition suitable experimental setup design

In the second stage (semester), the following tasks will be implemented

- Preparing the system parts
- Building experimental setup
- Checking the project parts and perform initial experiments
- Performing final experiments
- Analyzing the experimental results

The time table for the first semester is illustrated in Table 1.1.

Table 1.1: The time table for the first semester.

TASKS	1st Month				2nd Month				3rd Month				4th Month			
	WK_1	WK_2	WK_3	WK_4	WK_1	WK_2	WK_3	WK_4	WK_1	WK_2	WK_3	WK_4	WK_1	WK_2	WK_3	WK_4
Identification of project idea	■	■														
Drafting a preliminary project proposal			■	■												
Establishing scientific background					■	■	■									
Documentation of literature review						■	■	■								
Choosing suitable requirements for implementation								■	■	■	■					
Suggestion a setup project design										■	■	■	■			
Writing first draft report									■	■	■	■	■	■	■	
Presentation of first semester																■

The time table for the first semester is illustrated in Table 1.2.

Table 1.2: The time table for the second semester.

TASKS	1^{st} Month				2^{nd} Month				3^{rd} Month				4^{th} Month			
	WK_1	WK_2	WK_3	WK_4	WK_1	WK_2	WK_3	WK_4	WK_1	WK_2	WK_3	WK_4	WK_1	WK_2	WK_3	WK_4
Preparing a system parts																
Building experimental setup																
Checking the project parts and perform initial experiments																
Performing final experiment																
Taking and analyzing the experimental result																
Writing a second report																
Presentation of second semester																

1.10 Project Budget

The total cost for implementing this project is estimated at 1260 JD as detailed in Table 1.3.

Table 1.3**:** The total estimated cost for implementing the project

NO.	**Item**	**Quantity**	**Unit Cost (JD)**	**Total Cost (JD)**
1	Catalytic Converter	2	520	1040
2	Other Costs		200	200
3	Cost of Printing and Imaging		20	20
	Total Cost			1260

Chapter Two

Combustion in Internal Combustion Engines

2.1 Introduction

Internal combustion engines (ICE) operate by burning fossil fuel. Exhaust emissions are their major contribution to environmental pollution. Typical emissions contain carbon dioxide (CO_2), methane (CH_4), nitrous oxides (NO_x). carbon monoxide (CO), sulfur dioxide (SO_2), non-methane volatile organic compounds (NMVOC) and particulate matters (PM).

Environmental pollution from internal combustion engine vehicles (ICEV) is not only limited to air pollution. If all activities related to transportation are considered, many other pollution sources and pollutants have to be added to those described above. Pollutants are emitted to air, water and soil.

This chapter presents pollution from transportation, outlines the impact of ICEV on the environment and introduces the main features of ICE; the formation of pollutants. The options for control of exhaust emissions through engine modification and fuel composition will be discussed in details.

2.2 Internal Combustion Engine

The internal combustion engine (ICE) is a heat engine that converts chemical energy in a fuel into mechanical energy, usually made available on a rotating output shaft. Chemical energy of the fuel is first converted to thermal energy by means of combustion or oxidation with air inside the engine. This thermal energy raises the temperature and pressure of the gases within the engine, and the high-pressure gas then expands against the mechanical mechanisms of the engine. This expansion is converted by the mechanical linkages of the engine to a rotating crankshaft, which is the output of the engine[4].

Engine vehicles are a major source of air pollution worldwide. In many urban areas, motor vehicles collectively produce 50 to 90 percent of local air pollution, depending upon the pollutants. Vehicles can also produce a significant amount of the toxic or hazardous pollutants found in our air.

Engine which use in this Project is Spark Ignition Engine which works as reciprocating engine, this Engine has four cylinders in which pistons reciprocate back and forth. The combustion chamber is located in the closed end of each cylinder. Power is delivered to a rotating output crankshaft by mechanical linkage with the pistons.

2.2.1 The Four-Stroke Combustion Cycle for a Spark Ignition Engines

During the Intake Stroke, air and fuel moves into the low pressure area created by the piston moving down inside the cylinder. The fuel injection system has calculated and delivered the precise amount of fuel to the cylinder to achieve a 14.7 to 1 ideally ratio with the air fuel mixture entering the combustion chamber respectively [4].

As the piston moves upwards during the Compression Stroke, a rapid pressure increase occurs inside the cylinder, causing the air/fuel mixture to superheat. This precise superheated mixture is ignited when the piston approaches Top Dead Center.

Just before the piston reaches top dead center to start the Power Stroke, the spark plug ignites the air/fuel mixture in the combustion chamber, causing a flame-front to begin to spread through the mixture. During combustion, hydrocarbons and oxygen react, creating heat and pressure. Combustion by products will consist primarily of water vapor and carbon dioxide if the mixture and spark timing are precise.

After the mixture has burned and the piston reaches bottom dead center, the Exhaust Stroke begins as the exhaust valve opens and the piston begins its return to top dead center. The water vapor, carbon dioxide, nitrogen, and a certain amount of unwanted pollutants are pushed out of the cylinder into the exhaust system.

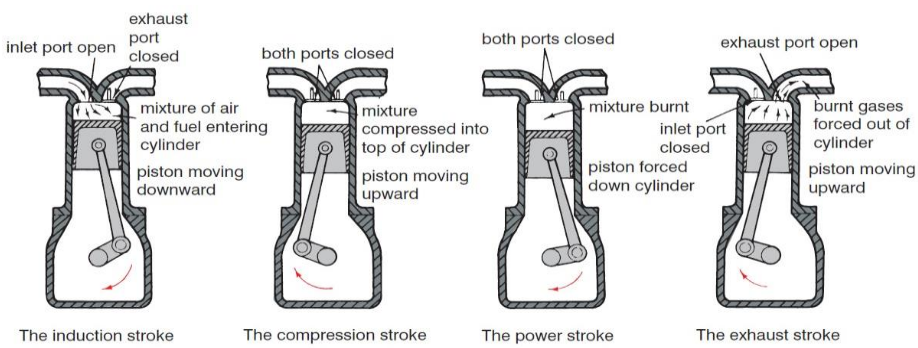


Figure 2.1: Four-Stroke Combustion Cycle

2.3 Combustion Reaction

Internal Combustion Engines obtain their energy from combustion of hydrocarbon fuel with air. In a “perfect” engine, oxygen in the air would convert all of the hydrogen in fuel to water and all of the carbon in the fuel to carbon dioxide (carbon mixed with oxygen). Nitrogen in the air would remain unaffected. In reality, the combustion process is not “perfect” and automotive engines emit several types of pollutants. Combustion Reaction can occur as :

1) “Perfect” Combustion Process:

Fuel (hydrocarbons) + Air (oxygen and nitrogen) = Carbon Dioxide (CO_2) + Water (H_2O) + Nitrogen (2.1)

2) Typical Real-World Engine Combustion Process:

Fuel (hydrocarbons) + Air (oxygen and nitrogen) = Unburned or partially burned Hydrocarbons (VOCs) + Nitrogen Oxides (NO_x) + Carbon Monoxide (CO) + Carbon Dioxide (CO_2) + Water (H_2O) + Oxygen (O_2) (2.2)

Fuel which is used in this project is Gasoline (C_8H_{18}), the stoichiometric combustion of Gasoline with air is shown in equation (2.1):

$$C_8H_{18} + 12.5O_2 + 12.5(3.76)\ N_2 \rightarrow 8\ CO_2 + 9\ H_2O + 1.25\ (3.76)\ N_2 \qquad (2.3)$$

Fuel/air mixture with more or less than the stoichiometric air requirement can be burned. With excess air or fuel-lean combustion, the extra air appears in the products in unchanged form. For example the combustion of octane with 25 percent excess air, or 1.25 times the stoichiometric air requirement gives:

$$C_8H_{18} + 1.25 * 12.5(O_2 + 3.76)\ N_2 \rightarrow 8\ CO_2 + 9\ H_2O + 3.13\ O_2 + 58.95\ N_2 \qquad (2.4)$$

With less than the stoichiometric air requirement, i.e, with fuel-rich combustion, there is insufficient oxygen to oxidize fully the fuel C and H to CO_2 and H_2O. The products are a mixture of CO_2 and H_2O with carbon monoxide CO and nitrogen oxides NO_x. The product composition cannot be determined from an element balance alone and an additional assumption about the chemical composition of the product species must be made [5] .

The composition of working fluid, which changes during the engine operation cycle, is indicated in Table 2.1[5].

Table 2.1 : Working Fluid constituents

Process	Working Fluid constituents
Intake	Air Fuel* Recycled Exhaust** Residual gases❦
Compression	Air Fuel Recycled Exhaust Residual gases
Expansion	Combustion products(mixture of N_2, H_2O, CO_2, CO, H_2, O_2, NO, OH, O, H, NO_2,..)
Exhaust	Combustion products (mainly N_2, CO_2, H_2O, O_2($\phi < 1$) or CO and H_2 ($\phi > 1$))

* Liquid and vapor in the intake; mainly vapor within the cylinder.

** Sometime used to control NO_x emissions

* Within the cylinder

2.3 Exhaust Gas Composition

Dry exhaust gas composition data, as a function of fuel/air equivalence ratio, for several different multi- and single- cylinder automotive spark-ignition engine over a range of engine speed and loads are shown in Figure 2.2 [5].

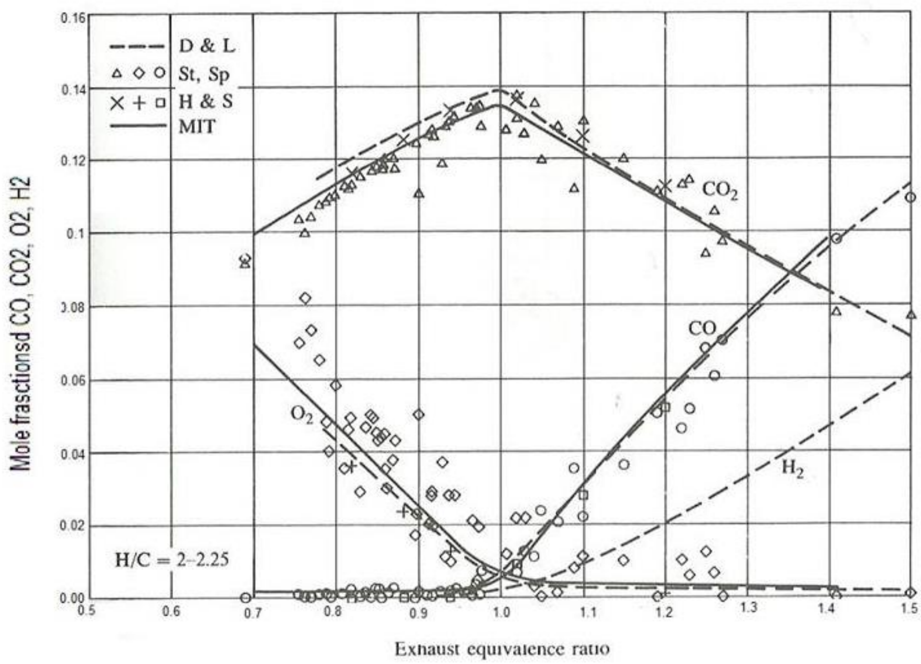


Figure 2.2: Spark-ignition engine exhaust gas composition data in mole fractions as a fuel/air equivalence ratio. Fuels: gasoline and isooctane.

2.4 Exhaust Gases Emissions

Internal combustion engine generate undesirable emissions during the combustion process. In this, both SI and CI engines are equally responsible for the same. The emissions exhausted into the surrounding pollute the Atmosphere and causes the following problems:

- Global warming
- Acid rain
- Smog
- Odors
- Respiratory and other health hazards

The major causes of these emissions are non-stoichiometric combustion dissociation of nitrogen, and impurities in the fuel and air, the emissions of concern are unburnt hydrocarbons (HC), oxides of carbon (CO_x), oxides of nitrogen (NO_x), and oxides of Sulphur (SO_x). And solid carbon particulates [6].

It is the dream of engineers and scientists to develop engines and fuels such that very few quantity of harmful emissions are generated, and these could be let into the surroundings without major impact on the However, with the present technology this is environment. not possible, and after-treatment of the exhaust gases as well reduction of emissions are very important. In case of in-cylinder after-treatment it consists mainly of the use of thermal or catalytic converter and particulate traps.

For in-cylinder reduction NO_x , exhaust gas recirculation (EGR) and some fuel additives are being tried. In addition to exhaust emissions non-exhaust emissions also play a part. In this part of chapter we will look into the details of these emissions and their control.

The power that propels automobiles comes from the combustion chamber. That is where hydrocarbons in fuel meet air. Ideally, oxygen in the air should convert all the hydrocarbons in the fuel in to water and carbon dioxide. But, in reality, combustion also produces unburned hydrocarbons, oxides of nitrogen, carbon monoxide and water.

The gasoline burned in an engine contains many chemicals, however, it is primarily made up of hydrocarbons (also referred to as HC). Hydrocarbons are chemical compounds made up of hydrogen atoms which chemically bond with carbon atoms. There are many different types of hydrocarbon compounds found in gasoline, depending on the number of hydrogen and carbon atoms present, and the way that these atoms are bonded.

Inside an engine, the hydrocarbons in gasoline will not burn unless they are mixed with air. This is where the chemistry of combustion begins. Air is composed of approximately 20.95% oxygen (O_2), 78.09% nitrogen (N_2), and minute amounts of other inert gasses [7].

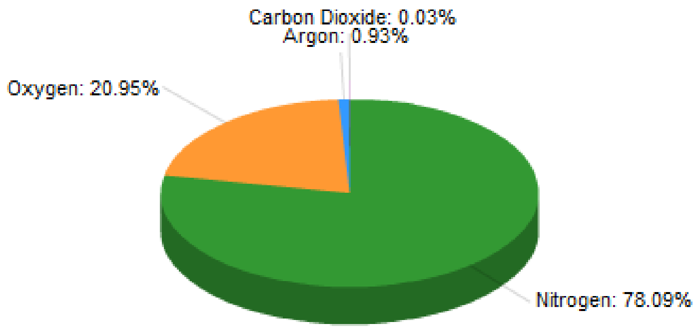


Figure 2.3: Air Components

The hydrocarbons in fuel normally react only with the oxygen during the combustion process to form water vapor (H_2O) and carbon dioxide (CO_2), creating the desirable effect of heat and pressure within the cylinder. Unfortunately, under certain engine operating conditions, the nitrogen also reacts with the oxygen to form nitrogen oxides (NO_x), a criteria air pollutant. The ratio of air to fuel plays an important role in the efficiency of the combustion process.

2.4.1 Harmful Exhaust Emissions

As previously mentioned, even the most modern, technologically advanced automobile engines are not "perfect"; they still inherently produce some level of harmful emission output. There are several conditions in the combustion chamber which prevent perfect combustion and cause unwanted chemical reactions to occur. The following are examples of harmful exhaust emissions and their causes.

2.4.1.1 Hydrocarbon (HC) Emission

Hydrocarbons are, quite simply, raw unburned fuel. When combustion does not take place at all, as with a misfire, large amounts of hydrocarbons are emitted from the combustion chamber. A small amount of hydrocarbon is created by a gasoline engine due to its design. A normal process called wall quenching occurs as the combustion flame front burns to the relatively cool walls of the combustion chamber. This cooling extinguishes the flame before all of the fuel is fully burned, leaving a small amount of hydrocarbon to be pushed out the exhaust valve. Another cause of excessive hydrocarbon emissions is related to combustion chamber deposits. Because these carbon deposits are porous, hydrocarbon is forced into these pores as the air/fuel mixture is compressed. When combustion takes place, this fuel does not burn, however, as the piston begins its exhaust stroke, these hydrocarbons are released into the exhaust stream [8].

The most common cause of excessive hydrocarbon emissions is misfire which occurs due to ignition, fuel delivery, or air induction problems. Depending on how severe the misfire, inadequate spark or a noncombustible mixture (either too rich or too lean) will cause hydrocarbons to increase to varying ranges. For example, a total misfire due to a shorted spark plug wire will cause hydrocarbons to increase dramatically. Conversely, a slight lean misfire due to a false air entering the engine, may cause hydrocarbons to increase only slightly. Excess hydrocarbon can also be influenced by the temperature of the air/ fuel mixture as it enters the combustion chamber. Excessively low intake air temperatures can cause poor mixing of fuel and air, resulting in partial misfire [8].

2.4.1.2 Carbon Monoxide (CO) Emission

Carbon monoxide is a colorless, odorless, poisonous gas formed when carbon in fuels are not burned completely. It is a byproduct of highway vehicle exhaust, which contributes about 60 percent of all CO emissions. In cities, automobile exhaust can cause as much as 95 percent of all CO emissions. These emissions can result in high concentrations of CO, particularly in local areas with heavy traffic congestion.

Carbon monoxide (CO) is a byproduct of incomplete combustion and is essentially partially burned fuel. If the air/fuel mixture does not have enough oxygen present during combustion, it will not bum completely. When combustion takes place in an oxygen starved environment, there is insufficient oxygen present to fully oxidize the carbon atoms into carbon dioxide (CO_2). When carbon atoms bond with only one oxygen atom carbon monoxide (CO) forms [8].

An oxygen starved combustion environment occurs as a result of air/fuel ratios which are richer than stoichiometry (14.7 to 1). There are several engine operating conditions when this occurs normally. For example, during cold operation-warm up-, and power enrichment. It is, therefore, normal for higher concentrations of carbon monoxide to be produced under these operating conditions. Causes of excessive carbon monoxide includes leaky injectors, high fuel pressure, improper closed loop control, etc.

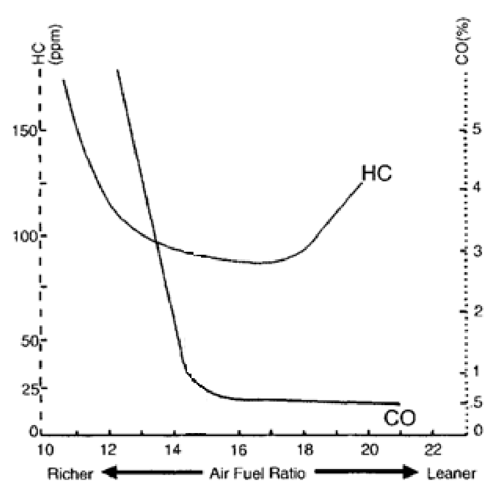


Figure 2.4: The relationship between the rates of HC and CO, concentration

with air/fuel ratio

When the engine is at warm idle or cruise, very little carbon monoxide is produced because there is sufficient oxygen available during combustion to fully oxidize the carbon atoms. This results in higher levels of carbon dioxide (CO_2) the principal by-product of efficient combustion.

2.4.1.3 Oxides of Nitrogen (NO_x) Emissions

Oxides of nitrogen are produced by combustion of all fossil fuels including coal- and gas fired power stations and motor vehicles. The two main nitrogen oxides are nitric oxide (NO), or nitrogen monoxide, and nitrogen dioxide (NO_2) the sum of which is equal to NO_x. But almost 90% of the NO_x combustion product is in the form of NO which is then oxidized to nitrogen dioxide (NO_2) in the air [8].

High cylinder temperature and pressure which occur during the combustion process can cause nitrogen to react with oxygen to form Oxides of Nitrogen (NO_x). Although there are various forms of nitrogen-based emissions that comprise Oxides of Nitrogen (NO_x), nitric oxide (NO) makes up the majority, about 98% of all NO_x emissions produced by the engine.

Generally speaking, the largest amount of NO_x is produced during moderate to heavy load conditions when combustion pressures and temperatures are their highest. However, small amounts of NO_x can also be produced during cruise and light load, light throttle operation.

Common causes of excessive NO_x include faulty EGR system operation, lean air/fuel mixture, high temperature intake air, overheated engine, excessive spark advance, etc. Nitrogen oxides, particularly nitrogen dioxide, are expelled from high temperature [8]:

$$O + N_2 \rightarrow NO + N \qquad (2.7)$$

$$N + O_2 \rightarrow NO + O \qquad (2.8)$$

$$N + OH \rightarrow NO + H \qquad (2.9)$$

$$NO + H_2O \rightarrow NO_2 + H_2 \qquad (2.10)$$

$$NO + O_2 \rightarrow NO_2 + O \qquad (2.11)$$

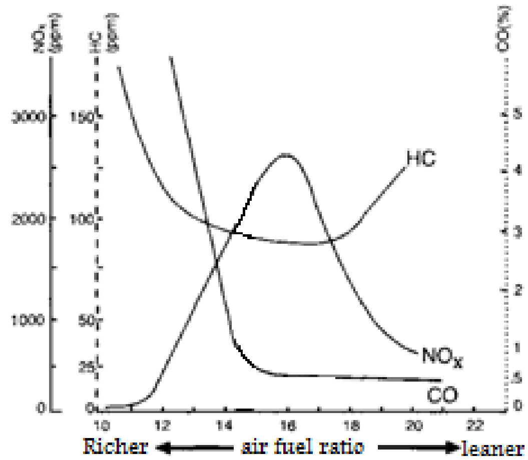


Figure 2.5: The relationship between the rates of NO_x, HC and CO, concentration with air/fuel ratio.

2.4.2 Air/Fuel Mixture Impact on Exhaust Emissions

As you can see in Figure 2.5, HC and CO levels are relatively low near the theoretically ideal 14.7 to 1 air/fuel ratio. This reinforces the need to maintain strict air/fuel mixture control. However, NO_x production is very high just slightly leaner than this ideal mixture range. This inverse relationship between HC/CO production and NO_x production poses a problem when controlling total emission output. Because of this relationship, you can understand the complexity in reducing all three emissions at the same time.

2.4.3 Impact on Health

Emissions have a variety of negative effects on public health and the environment. For understanding the impact of vehicle exhausts on human health, Table 2.2 summarizes the impact of toxic emission on human health

Table 2.2 : Impact on Health [9]

Name	**Physiological Effects On Human**	
	Acute Effects	**Chronic Effects**
1.Carbon Monoxide (CO)	Asphyxiation, heat and brain damage	Increased red blood cells (polycythemia) in blood, leading to increased resistance to blood to flow, weakness fatigue, and headaches.
2.Carbon Dioxide (CO_2)	Carbon Dioxide reduces the volume of oxygen enters the blood stream and can slow reflexes.	Cause drowsiness, impair judgment and vision and even cause death.
3.Nitrogen Dioxide (NO_2)	Incompletely understood, although cell membrane disruption appears to be the principal reason for respiratory tract edema.	Cell membrane damage and acid- induced irritation Leading to or contributing to diminished pulmonary function and right-heart stress.
4.Sulfur Dioxide (SO_2)	Give rise to irritation reactions, which cause capillaries to dilate and exude fluid accumulation and swelling (edema).	Contributes to and aggravates lung diseases like chronic bronchitis, pulmonary fibrosis via irritation leading to decrease pulmonary function and increase in stress on the heart.
5.Hydrocarbons(C_xH_y)	The primary harm of hydrocarbons is in their participation in ozone production	Cancer is one direct primary effect of some organic compounds.
6.Particulate Matters (PM)	Effect varies depending on nature and size of particles. Can cause irritation, altered immune, or systematic toxicity.	Depending on the nature and size of the particles can cause decreased pulmonary function and stress on the heart.

2.5 Exhaust Emission Control

The exhaust system is used to reduce the pollutants of the exhaust gas generated by combustion in the engine and to damp its sound waves. The engine power should decrease as little as possible during the process.

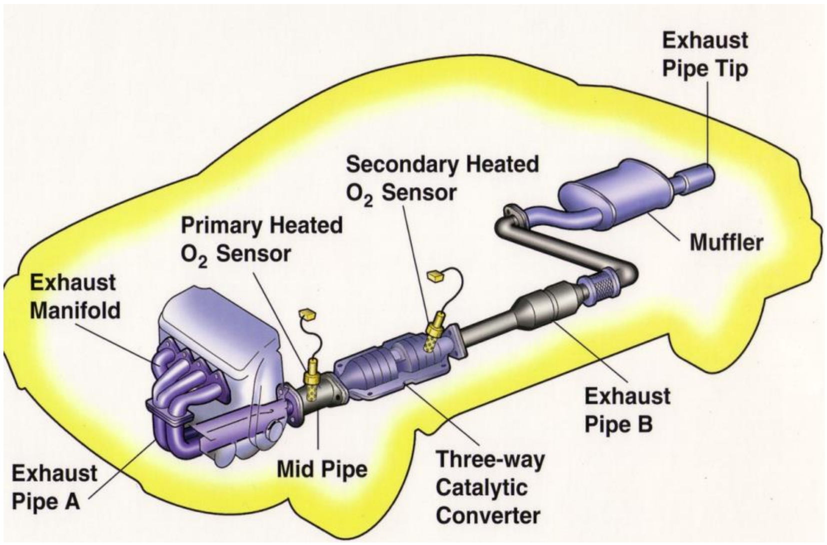


Figure 2.6: Exhaust system components

Exhaust system consists basically of three main components:

- The exhaust pipes combine the exhaust gas outlets in the cylinder head into one or more pipes (manifolds), and also connect the catalytic converter and the mufflers to each other. The length and cross section of the pipes, as well as the type of junction used, influence the vehicle's performance charcteristics and acoustic behavior.
- The muffler consists of chambers from different sizes. The major function of muffler is damp the sound waves.
- The catalytic converter serves as an exhaust gas cleaning device for internal combustion engines . It is mounted as close as possible to the engine so that it can quickly reach its operating temperature.

2.5.1 Catalytic Converters:

Catalytic converters were first widely introduced in American production cars in 1975 due to EPA regulations on toxic emissions reductions. The United States Clean Air Act required a 75% decrease in emissions in all new model vehicles after 1975, a decrease to be carried out with the use of catalytic converters. Without catalytic converters, vehicles release hydrocarbons, carbon monoxide, and nitrogen oxide. These gases are the largest source of ground level ozone, which causes smog and is harmful to plant life. catalytic converters can also be found in generators, buses, trucks, and trains, almost everything with an internal combustion engine has a form of catalytic converter attached to its exhaust system [10].

A catalytic converter is a device used to reduce the emissions from an internal combustion engine (used in most modern day automobiles and vehicles). Not enough oxygen is available to oxidize the carbon fuel in these engines completely into carbon dioxide and water; thus toxic by-products are produced. Catalytic converters are used in exhaust systems to provide a site for the oxidation and reduction of toxic by-products (like nitrogen oxides, carbon monoxide, and hydrocarbons) of fuel into less hazardous substances such as carbon dioxide , water vapor, and nitrogen gas.

2.5.1.1 How it Works

A catalytic converter is a simple device that uses basic redox reactions to reduce the pollutants a car makes. It converts around 98% of the harmful fumes produced by a car engine into less harmful gases. It is composed of a metal housing with a ceramic honeycomb-like interior with insulating layers. This honeycomb interior has thin wall channels that are coated with a wash coat of aluminum oxide. This coating is porous and increases the surface area, allowing more reactions to take place and containing precious metals such as platinum, rhodium, and palladium. No more than 4-9 grams of these precious metals are used in a single converter [10].

The converter uses simple oxidation and reduction reactions to convert the unwanted fumes. Recall that oxidation is the loss of electrons and that reduction is the gaining of electrons. The precious metals mentioned earlier promote the transfer of electrons and, in turn, the conversion of toxic fumes [10].

The last section of the converter controls the fuel-injection system. This control system is aided by an oxygen sensor that monitors how much oxygen is in the exhaust stream, and in turn tells the engine computer to adjust the air-to-fuel ratio, keeping the Catalytic Converter running at the stoichiometric point and near 100% efficiency [10].

2.5.1.2 Catalytic Converter Parts:

The figure 2.7 shows the main parts of catalytic converter [11] :

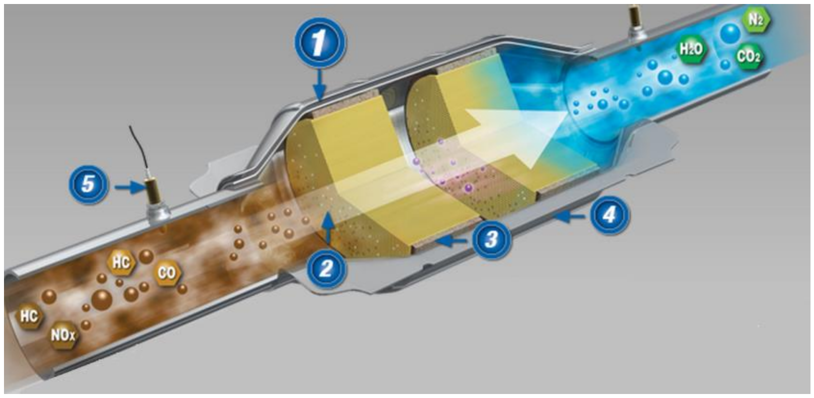


Figure 2.7: Main parts of Catalytic Converter

1. Stainless Steel Body.

For long life and durability. The ribbed body minimizes expansion and distortion, as well as forming channels that protect the cushioning mat from direct exposure to exhaust gases.

2. Monolithic Free-Flowing Substrate

The substrates are the backbone of the converter. This is where the proprietary mix of precious metal(s) and the washcoat formulated to store O2 allow the conversion process to take place. Converters are available in single- or multiple-substrate designs.

3. Catalyst cushioning Mat

The mat cushions the converter substrate, holding the ceramic catalyst in proper alignment. Creates a seal between the substrate and body, making sure all exhaust goes through the catalyst. Allows for thermal expansion of the body.

4. Body And Pipe Heat Shields

Deflects heat created by the converter away from the vehicle's undercarriage

5. O_2(Oxygen) Sensors

Another vital part of an emissions control system. These sensors are placed before and after the Catalytic Converter on an OBDII vehicle. They are designed to monitor the O_2 storage efficiency of the converter. This information also allows the PCM to adjust fuel controls.

2.5.1.3 Catalytic Converter Types

First-generation catalytic converters, called “two-way converters,” only controlled carbon monoxide (CO) and hydrocarbon (HC) emissions. In the early 1980s, catalysts were introduced that could control nitrogen oxides (NO_x), in addition to controlling CO and HC, called a “three-way converter.”

2.5.1.3.1 Two-Way Catalytic Converters

- Allows oxidation of CO (Carbon Monoxide) to less-harmful CO_2 (Carbon Dioxide)

$$2CO + O_2 \rightarrow 2CO_2 \qquad (2.12)$$

- Allows oxidation of HC (Unburned Hydrocarbons) to CO_2 (Carbon Dioxide) and H_2O (Water)

$$C_xH_{2x+2} + [(3x+1)/2]\ O_2 \rightarrow xCO_2 + (x+1)\ H_2O \qquad (2.13)$$

In this design, exhaust gases are directed to flow through the substrate containing precious metals platinum and palladium, which allow the chemical reaction to occur. The exhaust gases increase in temperature as the conversion process takes place [12].

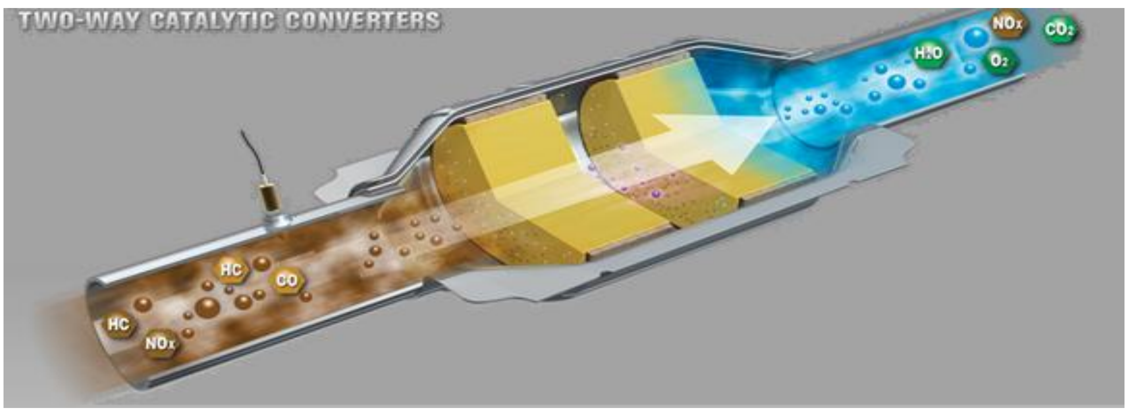


Figure 2.8: Two-Way Catalytic converter

Because of the intense heat created by this process, exhaust gases leaving the converter should be hotter than the gases entering the converter. This also explains why heat shields are required on most units. Two-way converters operate relatively efficiently with a lean fuel mixture. Ineffectiveness in controlling NO_x led to the introduction of three-way converters [12].

2.5.1.3.2 Three-Way Plus Air Catalytic Converters

- Allows reduction of NO_x (Nitrogen Oxides) to N_2 (Nitrogen) and O_2 (Oxygen)

- Allows oxidation of CO (Carbon Monoxide) to less-harmful CO_2 (Carbon Dioxide)

- Allows oxidation of HC (Unburned Hydrocarbons) to CO_2 (Carbon Dioxide) and H_2O (Water)

Inside this converter there are two substrates. The front, coated with the precious metal rhodium, is used to reduce NO_x emissions into simple N_2 and O_2. This process is most effective when little O_2 is present (rich mixture). That is why it is located upstream of the air tube [12].

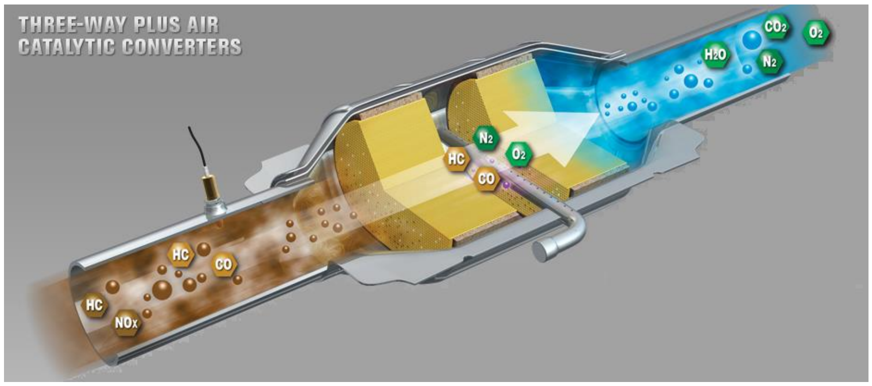


Figure 2.9: Three-Way Plus Air Catalytic Converters

Since a rich mixture is high in HC and CO, an air pump and tube supply additional O_2 to this mixture before it enters the second substrate. The second substrate, coated with the precious metals palladium and platinum, allows oxidation of HC and CO to less harmful emissions CO_2 and H_2O. This system was not very efficient and was phased out in the early '80s, when the current three-way converter was introduced [12].

2.5.1.3.3 Three-Way Catalytic Converters

- Allows reduction of NO_x (Nitrogen Oxides) to N_2 (Nitrogen) and O_2 (Oxygen)

$$2NO_x \rightarrow xO_2 + N_2 \quad (2.14)$$

- Allows oxidation of CO (Carbon Monoxide) to less-harmful CO_2 (Carbon Dioxide)

$$2CO + O_2 \rightarrow 2CO_2 \quad (2.15)$$

- Allows oxidation of HC (Unburned Hydrocarbons) to CO_2 (Carbon Dioxide) and H_2O (Water)

$$C_xH_{2x+2} + [(3x+1)/2]O_2 \rightarrow xCO_2 + (x+1)H_2O \quad (2.16)$$

Three-way converters have been used in vehicle emissions control systems in North America - and many other countries - since 1981. The three-way without air uses advanced catalyst chemistry to store and release O_2, in conjunction with an O_2 monitoring and control system [12].

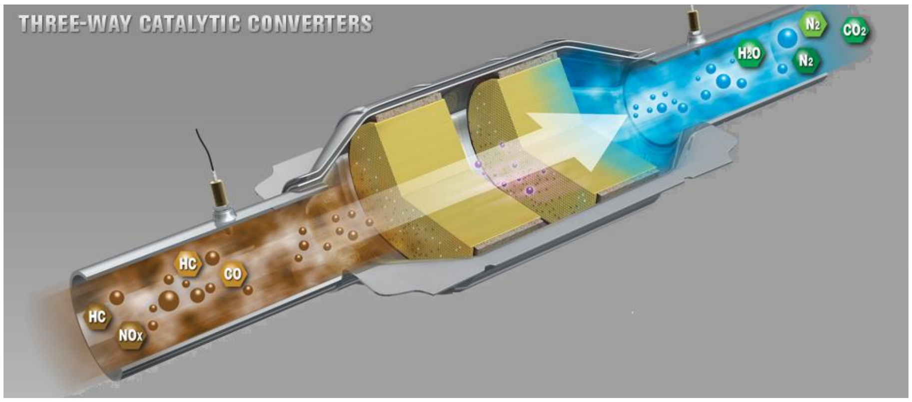


Figure 2.10: Three-Way Catalytic Converters

This system utilizes one or more O_2 sensors to oscillate the fuel mixture between lean and rich conditions. This oscillation, combined with the O_2 storage and release on the catalyst surface, allows for optimum reduction of all three emissions [12].
The following tables show the exhaust emission before and after three-way catalytic converter

Table 2.3: Exhaust emission before catalytic converter [12]

Harmful Emissions(Product of incomplete combustion)		
HC	Hydrocarbons	Unburnt fuel
CO	Carbon Monoxide	Partially burnt fuel or oil
NO_x	Oxides of Nitrogen	Extreme Combustion Temperature

Table 2.4: Emissions after Catalytic Converter [12]

Emissions after Catalytic Converter	
H_2O	Water
CO_2	Carbon Dioxide
N_2	Nitrogen

2.5.1.3.4 Reason of Choosing Three-way Catalytic Converter

The three-way Catalytic Converter is currently the safest, most efficient, and most reliable form of exhaust emission control available for Gasoline engines. The three-way Catalytic Converter converts three pollutants - hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxides (NO_x), into less harmful gases.

2.5.1.4 Catalytic Converter Efficiency:

The conversion efficiency of a catalyst is the ratio of the rate of mass removal in the catalyst of the particular constituent of interest to the mass flow rate of that constituent into the catalyst: e.g., for HC,

$$\eta_{cat} = (\dot{m}_{HC,in} - \dot{m}_{HC,out}) / \dot{m}_{HC,in}$$

The variation of conversion efficiency of a typical oxidizing Catalytic Converter with temperature is shown in Figure 2.11. At high enough temperature, the steady-state conversion efficiencies of a new oxidation catalyst are typically 98 to 99 percent for CO and 95 percent or above for HC. However, the catalyst is ineffective until its temperature has risen above 250 to 300° C. The term ligh-off temperature is often used to describe the temperature at which the catalyst becomes more than 50 percent effective [5].

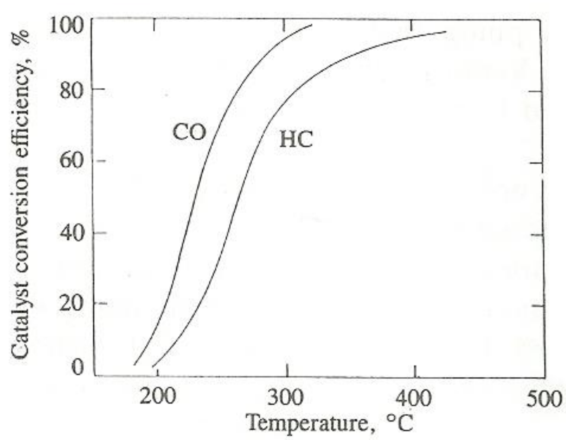


Figure 2.11 : Conversion efficiency for CO and HC as a function of temperature for typical oxidizing catalytic converter.

If an engine is operated at all times with an air/fuel ratio at or close to stoichiometric, then both NO reduction and CO and HC oxidation can be done in a single catalyst bed. The catalyst effectively brings the exhaust gas composition to a near-equilibrium state at these exhaust conditions; i.e., a composition of CO_2, H_2O, and N_2 . Enough reduction gases will be present to reduce NO and enough O_2 to oxidize the CO and hydrocarbons. Such a catalyst is called three-way catalyst since it removes all three pollutants simultaneously. Figure 2.12 shows the conversion efficiency for NO, CO, and HC as a function of the air/fuel ratio. There is a narrow range of air/fuel ratios near stoichiometric in which high conversion efficiencies for all three pollutants are achieved. The width of this window is narrow, about 0.1 fuel/air ratios ($7d10^{-3}$ in equivalence ratio unit) for catalyst with high mileage use, and depends on catalyst formulation and engine operating conditions.

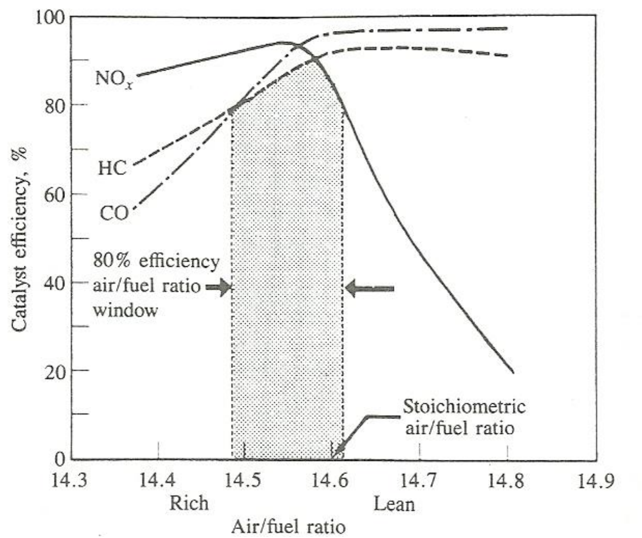


Figure 2.12 : Conversion efficiency for NO, CO, and HC for a three-way catalyst as a function of exhaust gas air/fuel ratio.

2.5.2 Exhaust Gas Recirculation

Exhaust Gas Recirculation (EGR) is a nitrogen oxide (NO_x) emissions reduction technique used in petrol and diesel engines. EGR works by recirculating a portion of an engine's exhaust gas back to the engine cylinders. Exhaust gas is routed back into the combustion chamber because the exhausted air is much hotter than the intake air. EGR works by diluting the N_2 and providing gases inert to combustion (CO_2 primarily) to act as an absorbent of combustion heat to reduce peak in cylinder temperatures. NO_x is produced in a narrow band of high cylinder temperatures and pressures [13].

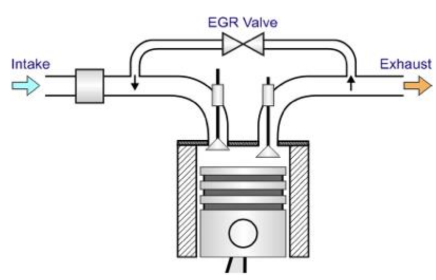


Figure 2.13: Principle Operation of EGR

The exhaust gas, added to the fuel, oxygen, and combustion products, increases the specific heat capacity of the cylinder contents, which lowers the adiabatic flame temperature.

2.5.3 Injection Timing

The NO_x emission is reduced, when delaying the injection timing from the original fuel optimized injection timing. The injection timing has two effects on NOx formation. When the combustion process is delayed, the rate of heat release is changed slightly, but more importantly, the maximum pressure and thereby the cylinder bulk temperature is changed during the combustion process. The delayed "end of combustion" may affect different emission components, whereas NO_x is related more closely to the early combustion phase around TDC, where the temperature are high [14].

2.5.4 Evaporation Emission Control System (EVAP)

The EVAP is design to store and dispose of fuel vapor normally is created in the fuel system. The EVAP system prevents Hydrocarbons in the form of fuel vapors from entering the atmosphere even when the vehicle is not running. The EVAP system delivers these vapors to the intake manifold to be burned with the normal air/fuel mixture. This fuel charged is added during periods of closed loop fuel control system.

The EVAP system is fully closed system designed to maintain stable fuel tank pressure without allowing fuel vapors to escape to the atmosphere. Fuel vapor is normally created in fuel tank as a result of evaporation. It is then transfer to the EVAP system charcoal canister when tank vapor pressure become excessive [15].

2.5.5 Secondary Air Injection System

Combustion gases that enter the exhaust manifold are not completely burned and would continue to burn if not limited by the amount of oxygen in the exhaust system. To decrease the level of emission from the tailpipe, the secondary air injection system as shown in Figure 2.14 is used to introduced air into the exhaust flow, thereby allowing combustion period help to lower the level of UHC and CO emission that forwarded to the catalytic converter, addition air in the exhaust system also ensure that an adequate supply of oxygen is provided to Catalytic Converter for catalytic oxidation [16].

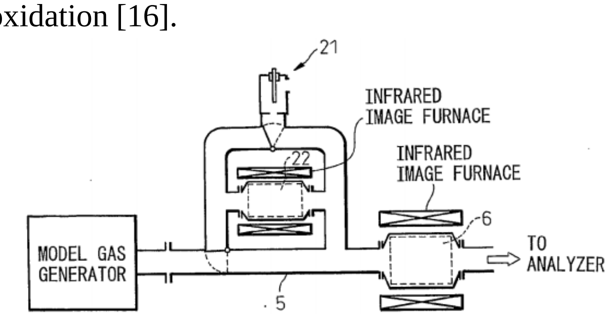


Figure 2.14 :Principle of Secondary Air Injection System

.

Chapter Three

System Design

3.1 Introduction

3.2 Design Concept

3.1 Introduction

Toxic Emissions of the combustion of the fuel are one of the greatest challenges that face the automotive engineers and the automotive companies. The main aim of this project is to convert the harmful pollutants into less toxic compounds emitted from the engine by using double three-way catalytic converter and to prove that the benefits of this way is greater than using single catalytic converter, by doing experimental study for investigation the effects of using double catalytic converter for reducing concentration of toxic emission from SIE in vehicle, and confirming the validity of modifying the exhaust system by using SolidWorks program.

The system involves double catalytic converter ,the exhaust gases are emitted from internal combustion engine then enters to a primary catalytic converter, then they pass into a secondary catalytic converter for purpose of producing a new exhaust system capable of reducing the percentage of toxic exhaust gases, the project targets the following specific objectives:

- Designing and building the exhaust system in automotive workshop.
- Analyzing and comparing the results of the experiment
- Measuring the exhaust gases concentration

3.2 Design Concept:

In this project the system is designed to reduce the toxic emitted gases by using double catalytic converter. The project focuses on a design which is includes the best specification for creating a new exhaust system, taking into consideration that the back pressure, purposed designed system is shown in figure 3.1.

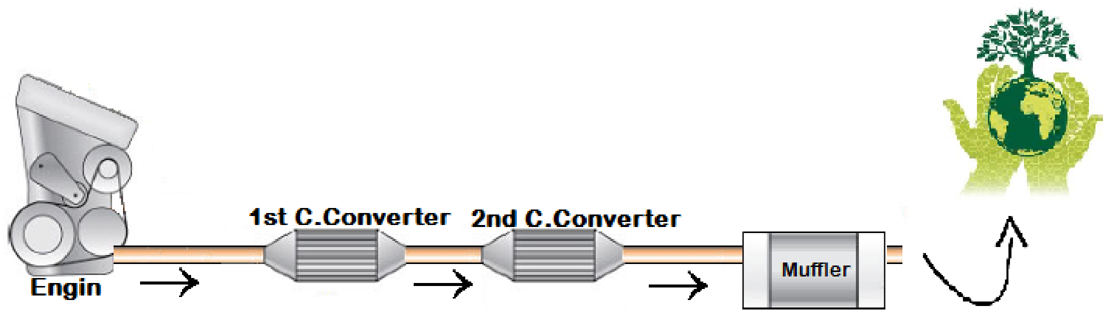


Figure 3.1: Purposed designed system.

And its components as the following :

1. Engine
2. First catalytic converter
3. Second catalytic converter
4. Muffler

3.2.1 Exhaust back pressure

Engine exhaust back pressure is defined as the exhaust gas pressure that is produced by the engine to overcome the hydraulic resistance of the exhaust system in order to discharge the gases into the atmosphere so the exhaust back pressure is the gage pressure in the exhaust system at the outlet of the exhaust manifold [17].

pressure losses in the exhaust system result of the exhaust port and manifold having and the pressure at the exit of manifold have average levels that are higher than atmospheric . Figure 3.2 shows the time- averaged exhaust manifold gauge pressure sure as a function of inlet manifold vacuum (which varies inversely to load) and speed for a four- cylinder automobile spark-ignition engine. At high speeds and loads the exhaust manifold operates at pressure substantially above atmospheric [5].

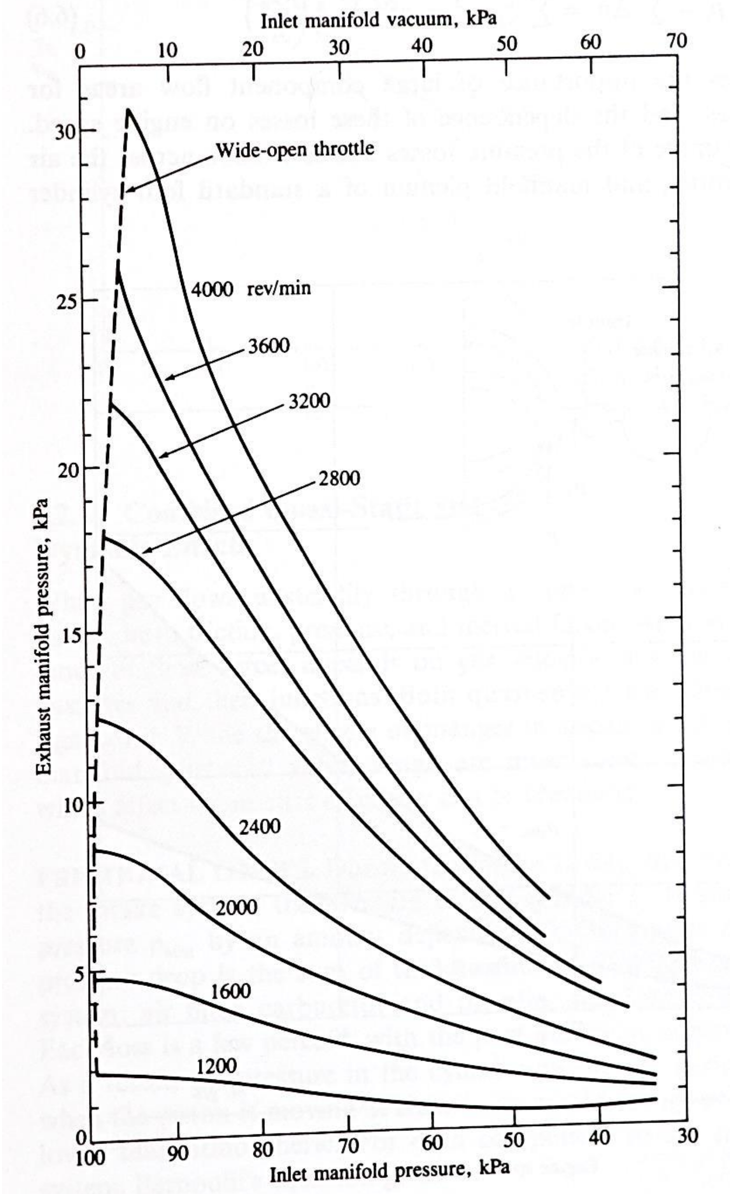


Figure 3.2: Exhaust manifold pressure as a function of load (define by inlet manifold vacuum) and speed, four-stroke cycle four cylinder spark- ignition engine.

The pulsating flow from each cylinder`s exhaust process sets up pressure waves in the exhaust system. These pressure waves propagate at the local sound speed relative to the moving exhaust gas. The pressure waves interact with the pipe junction and ends in the exhaust manifold and pipe. These interactions cause pressure waves to be reflected back toward the engine cylinder. In multicylinder engines, the pressure waves set up by each cylinder, transmitted through the exhaust and reflected from the end, can interact with the each other. These pressure waves may aid or inhibit the gas exchange processes. When they aid the exhaust process, the exhaust system is said to be tuned [5].

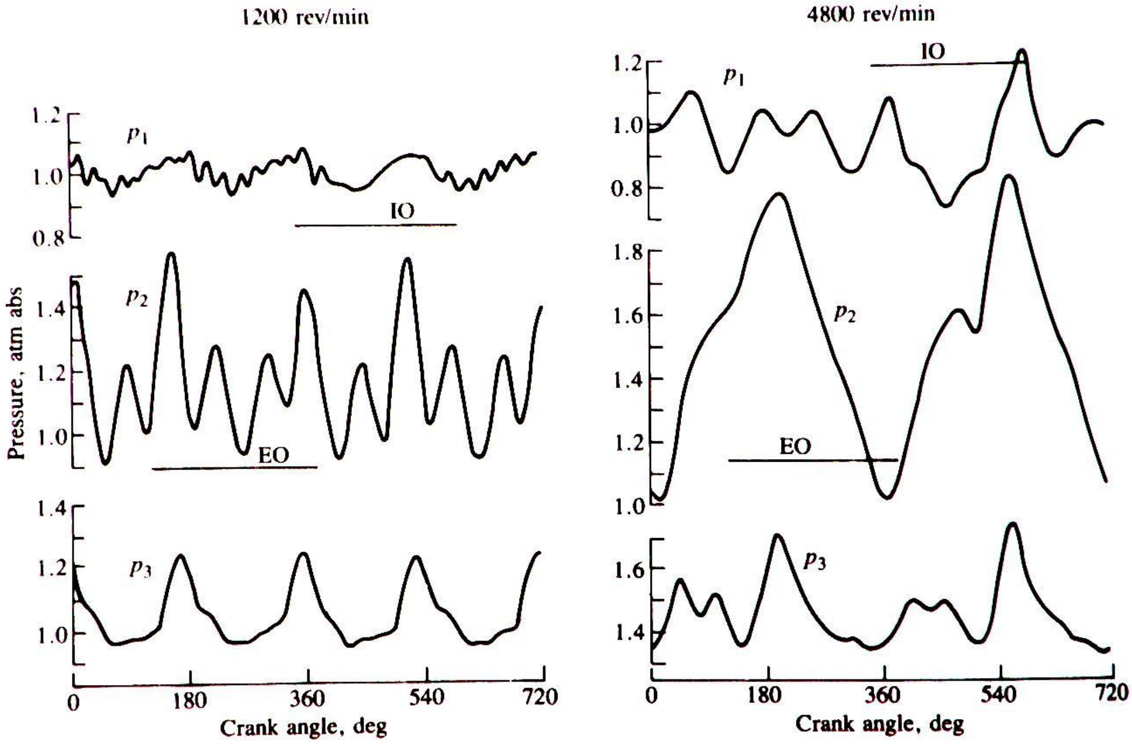


Figure 3.3: Instantaneous pressure in the intake and exhaust manifold for a four-stroke four cylinder spark- ignition engine, at wide open throttle [5].

Examples of the pressure variations in the exhaust system of four- cylinder automobile spark-ignition engine at wide- open throttle are shown in figure 3.3 . The complexity of the phenomena that occur is apparent. The amplitude of the pressure fluctuation increases substantially with increasing engine speed. The primary frequency in the exhaust corresponds to the frequency of the individual cylinder exhaust processes. Higher harmonics that result from pressure waves in exhaust is important also.

Increasing of exhaust back pressure above allowed level can have a number of effects on the engine, such as:

- Increasing of pumping work; as the engine gets rid of exhaust gases cylinder scavenging and combustion effects.
- Turbocharger problems.
- Exhaust restriction.
- Clogging of catalytic converter.

- Clogging or restricting of muffler.
- Damaging or defecting of exhaust pipe.

3.2.2 Computational fluid dynamics (CFD)

The transient catalytic converter performance is governed by complex interactions between exhaust gas flow and the monolithic structure of the catalytic converter. Therefore, during typical operating conditions of interest, one has to take into account the effect of pressure drop by catalytic converter. Computational fluid dynamics (CFD) is a powerful tool for calculating the flow field inside the catalytic converters.

A suitable design must take into consideration to ensure that the systems do well, for this purpose; the designed system had been tested by the following steps:

i) System geometry design
ii) Flow optimization of the catalytic converters under the given geometry.

3.2.2.1 System geometry design

The system geometry are designed by the following steps:

- Designing of the catalytic converters
- Designing of the pipes

3.2.2.1.1 Designing of the catalytic converters

When the system is designed; it was taking into consideration the availability of the catalytic converter in the same dimensions that the system is designed on it .

The 3D model of these catalytic converters is modeled by using solidworks program. Most catalytic converters are the ceramic monolith substance with square channels type and are usually coated with platinum , rhodium, and palladium.

The catalytic converters modeled here is shown in figure 3.4. The flow through the catalytic converters are passes through a ceramic monolith substrate with square shape channels, and then exit through the outlet, with a different uniform velocities like 25m/s , 28m/s , 32 m/s, .. etc. vary with the engine speed.

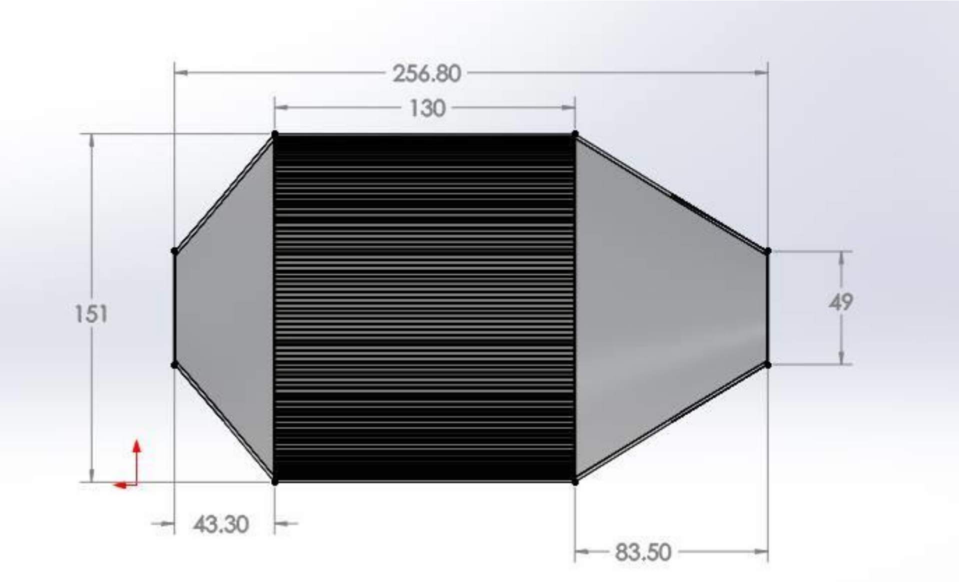


Figure 3.4: Dimensions of catalytic converter

While the flow in the inlet and outlet section is turbulent, the flow through the substrate is laminar and is characterized by inertial and viscous loss co-efficient in the flow(x) direction .

Computational fluid dynamics is applied to show the pressure distribution and velocity field in the inlet and outlet of the system . figure 3.5, and figure 3.6 show the arrangement of the catalytic converter considered in the study, the data of the catalytic converters are shown in table 3.1.

Table 3.1 : Data of catalytic converters

Substrate material	ceramic	Total volume of substrate	2296.125 cm^3
Catalytic substance	platinum, palladium, rhodium	Overall length of substrates	130 mm
Cell density	400 cpsi	Cell equivalent length	1.27 mm
Wall thickness	0.15 mm	Cell equivalent width	1.27 mm
Substrate cross-section	176.625 cm^2	Porosity	0.78

Figures 3.5, 3.6, set of cells of the catalytic converters

Figure 3.5: Geometry of catalytic converter

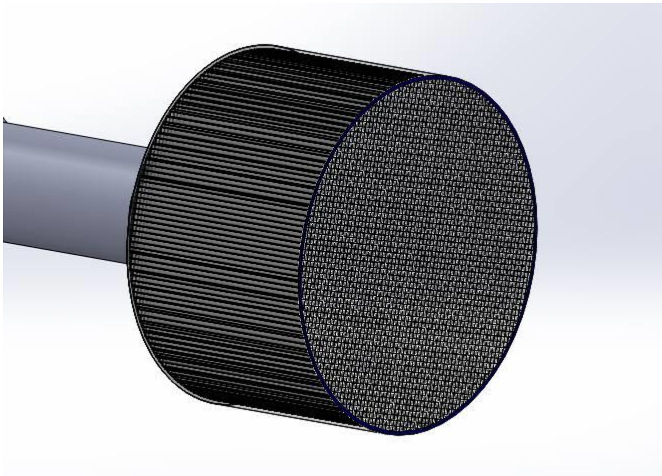


Figure 3.6: Frontal section of catalytic converter

The dimensions of a square cells are illustrated in the following figure.

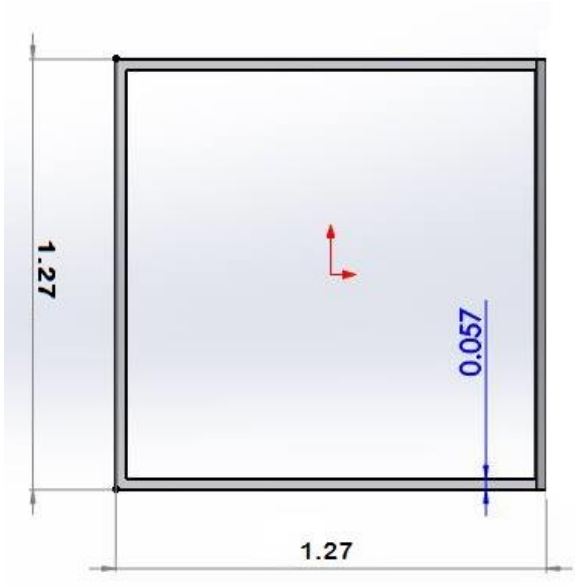


Figure 3.7: Dimensions of a catalytic converter cells

Figure 3.8 shows the geometry of a double catalytic converter that used in the project

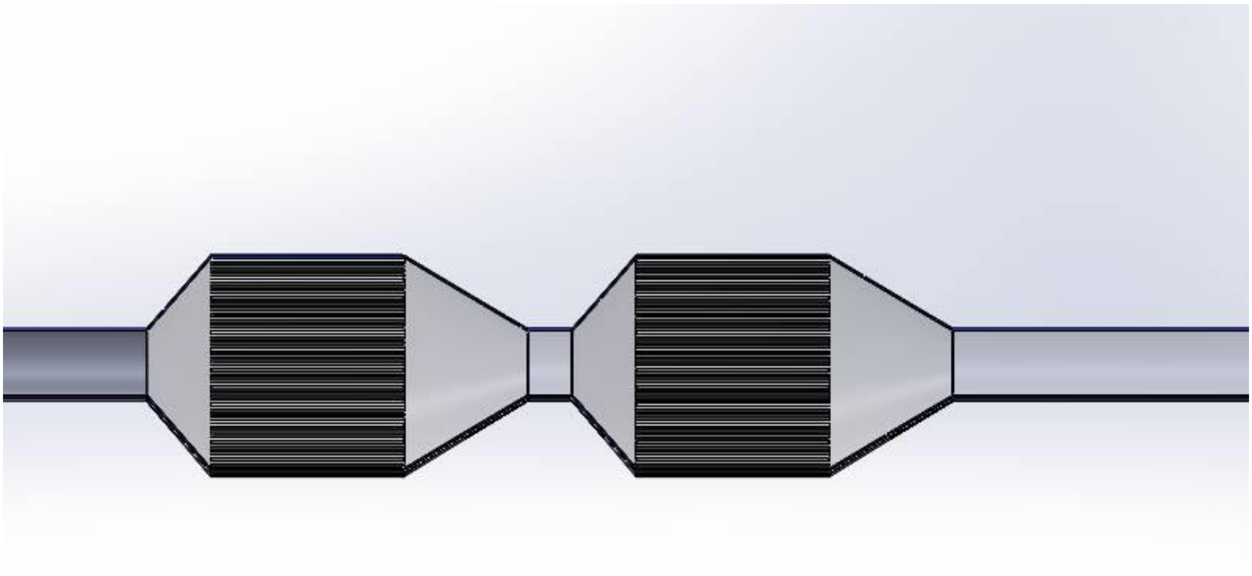


Figure 3.8: Geometry of a double catalytic converter

3.2.2.1.2 Pipes Design:

The dimensions of the exhaust system for a car used in this project are as the following:

- The total length from the exhaust manifold to the exit = 3380 mm
- Muffler dimensions: length = 240 mm / width = 300 mm
- Distance between the exhaust manifold and the main Catalytic Converter = 350 mm
- Inner Exhaust pipe diameter (D_{in}) = 46.5 mm
- Outer Exhaust pipe diameter (D_{out}) = 49 mm

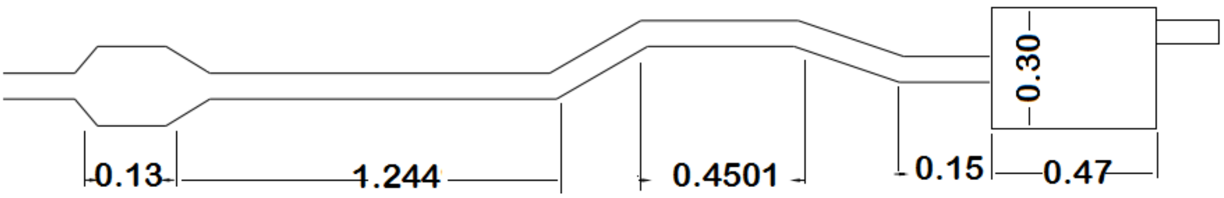


Figure 3.9: Dimensions of exhaust system for used car(all dimensions in m)

The previous dimensions are taken into consideration for designing and building a new exhaust system that has better performance in reducing the toxic exhaust gases.

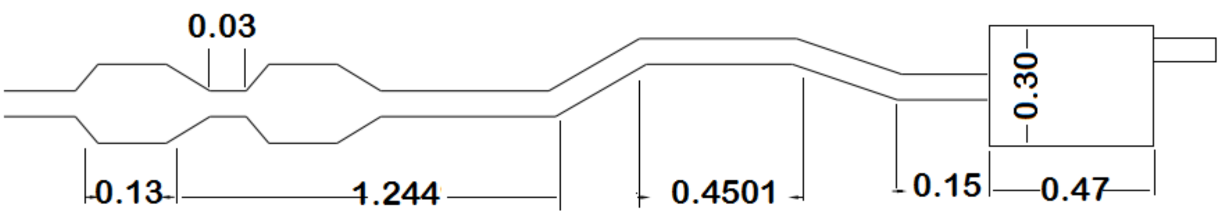


Figure 3.10: New Exhaust system dimensions(all dimensions in m)

The dimension between the two catalytic converter as shown in the figure 3.11. This dimension is selected to ensure that the temperature of the exhaust gases are enough to make the second catalytic converter working will, since the working of catalytic converter require to be the temperature of exhaust gases larger then 250 °C.

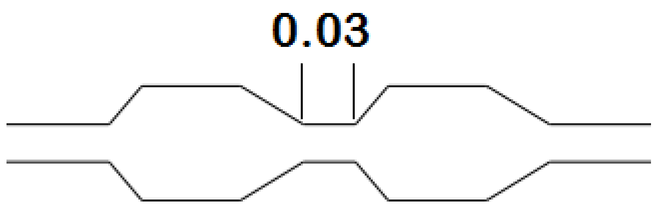


Figure 3.11: The dimension between catalytic converters

3.2.2.2 Flow optimization of the catalytic converters

Completion of solidworks test require adaptation of the input parameter .

Input parameters:

- Analysis type : steady state
- Fluids type : (CO, CO_2, NO_2, HC, H_2O)
- Outlet pressure: 100 kpa
- Inlet Temperature **:** 1000 k
- Inlet pressure:

To find the pressure equation of the inlet exhaust gases , assuming:

- Ideal system
- One cylinder
- Fully throttle open
- $\Delta t \rightarrow 0$

$the\ exhaust\ mass\ flow\ rate$

$$\dot{m} = \frac{Av\ Pc}{\sqrt{R\ T}} \left\{ \frac{2\gamma}{\gamma - 1} \left[\left(\frac{Pd}{Pc} \right)^{\frac{2}{\gamma}} - \left(\frac{Pd}{Pc} \right)^{\frac{\gamma+1}{\gamma}} \right] \right\}^{\frac{1}{2}} \tag{3.1}$$

γ : $ratio\ of\ specific\ heats$

Av : $Area\ of\ the\ valves$

Pd : $duct\ pressure$

$Pc : cylinder\ pressure$

The car used in the project has two exhaust valve

$Av = 0.3\ Bore$

The cylinder bore = 79 mm

$D = 0.3 * 79 = 23.7\ mm$

$$Av = \frac{\pi}{4} D^2 = \frac{\pi}{4}(23.7 * 10^{-3})^2$$

$Av = 4.411 * 10^{-4}\ m$

$Total\ Area\ for\ a\ two\ valves = 2 * Av$

$Avt = 8.823 * 10^{-4} m^2$

$$Cp\ at\ 1200\ k\ for\ a\ combustion\ products = 1.4324\ \frac{kj}{kg.k}$$

$$Cv\ at\ 1200\ k\ for\ a\ combustion\ products = 1.16 \frac{kj}{kg.k}$$

$$\gamma = \frac{Cp}{Cv} = \ 1.234827 \qquad (3.2)$$

This case are taken when the exhaust valve are totally open , assuming the exhaust gases temperature at that condition are equal to 1200 k

$T = 1200\ k$

$$Rtot = cp - cv = 1.4324 - 1.16 \qquad (3.3)$$

$$Rtot = 0.2724 \frac{kj}{kg.k}$$

By applying Otto cycle principle , the cylinder pressure at the condition of opining of the exhaust valve is equal to 402.087 kpa .

By applying :

$$\dot{m} = \frac{Av\ Pc}{\sqrt{R\ T}} \left\{ \frac{2\gamma}{\gamma - 1} \left[\left(\frac{Pd}{Pc}\right)^{\frac{2}{\gamma}} - \left(\frac{Pd}{Pc}\right)^{\frac{\gamma+1}{\gamma}} \right] \right\}^{\frac{1}{2}}$$

$\dot{m} = 38\frac{g}{s}$

$but,$

$m = PV/RT$

By assumption the cylinder Volume (V) is constant at the moment of opining the exhaust valves , and the cylinder temperature at that moment is constant and equal to 1200 k ,but the exhaust gases pressure are vary as shown in the fowling,

$$\dot{m} = \frac{V}{RT}\frac{dp}{dt} \quad (3.4)$$

Let the engine speed are equal to 4200 RPM , and $Vc\ is\ the\ monimum\ cylinder\ volume$

$$V = Vc\left\{1 + \frac{1}{2}(rc - 1)\left[R + 1 - \cos\theta - \ (R^2 - sin^2\theta)^{\frac{1}{2}}\right]\right\} \quad (3.5)$$

$\theta\ is\ the\ crank\ angle$

and for the used engine:

$rc\ is\ the\ compression\ ratio\ and\ its\ value\ is\ 10.5, and\ R\ are\ equal\ to\ 3$.

$\frac{dp}{dt} = \ \dot{m}\frac{RT}{V}$

$let\ us\ take\ a\ two\ crank\ revlutions\ \theta(0 - 720)°$

$the\ pressure\ vary\ as\ the\ figure\ 3.12\ shows\ and\ it`s\ equation$:

$$p(t) = 1.851 * 10^5 * [\sin(0.000994t + 1.191)] + 4.367 * 10^4 * [\sin(0.01759t - 1.605)] \quad (3.6)$$

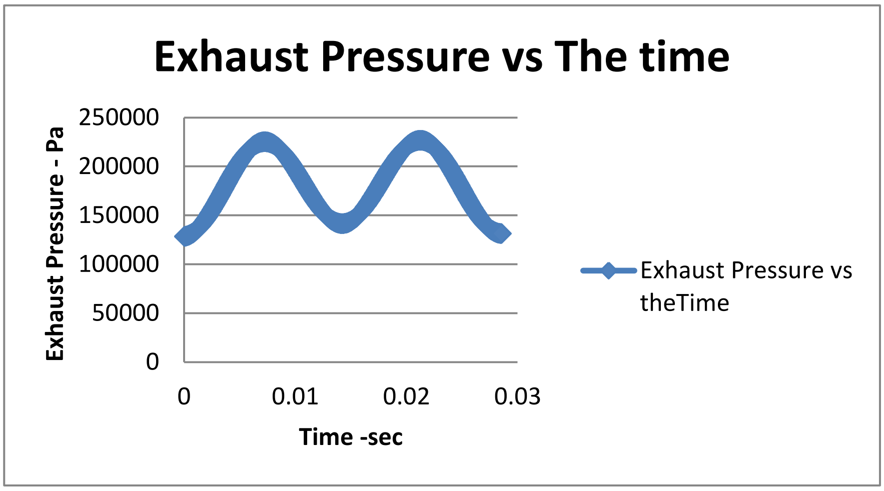


Figure 3.12: The relation between the exhaust pressure and the time

every single angle take about a 0.00003968 *s to a complestion , the pressure variation vs the crank angle shown in figure* 3.13 *and it`s equation of*:

$$p(\theta) = 1.851 * 10^5(sin25.05\theta + 1.191) + 4.367 * 10^4 \sin(443.3\theta - 1.605) \qquad (3.6)$$

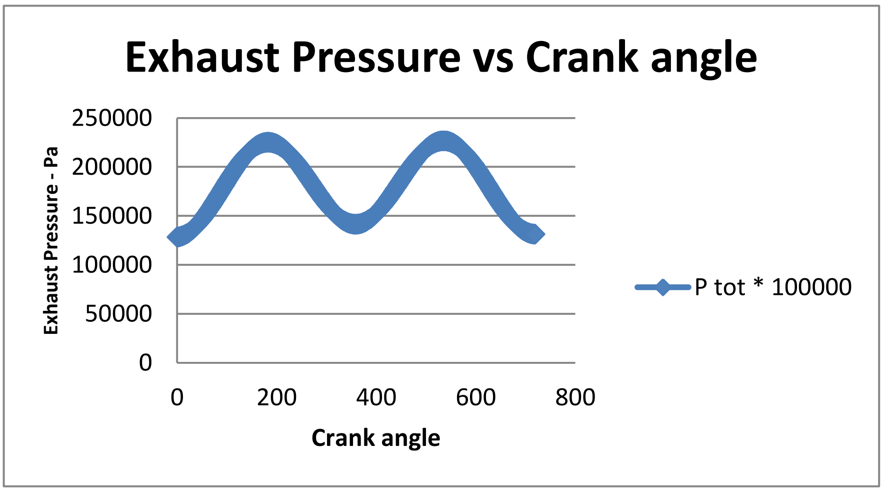


Figure 3.13: The relation between the exhaust pressure and the crank angle

The input pressure to the program as following:

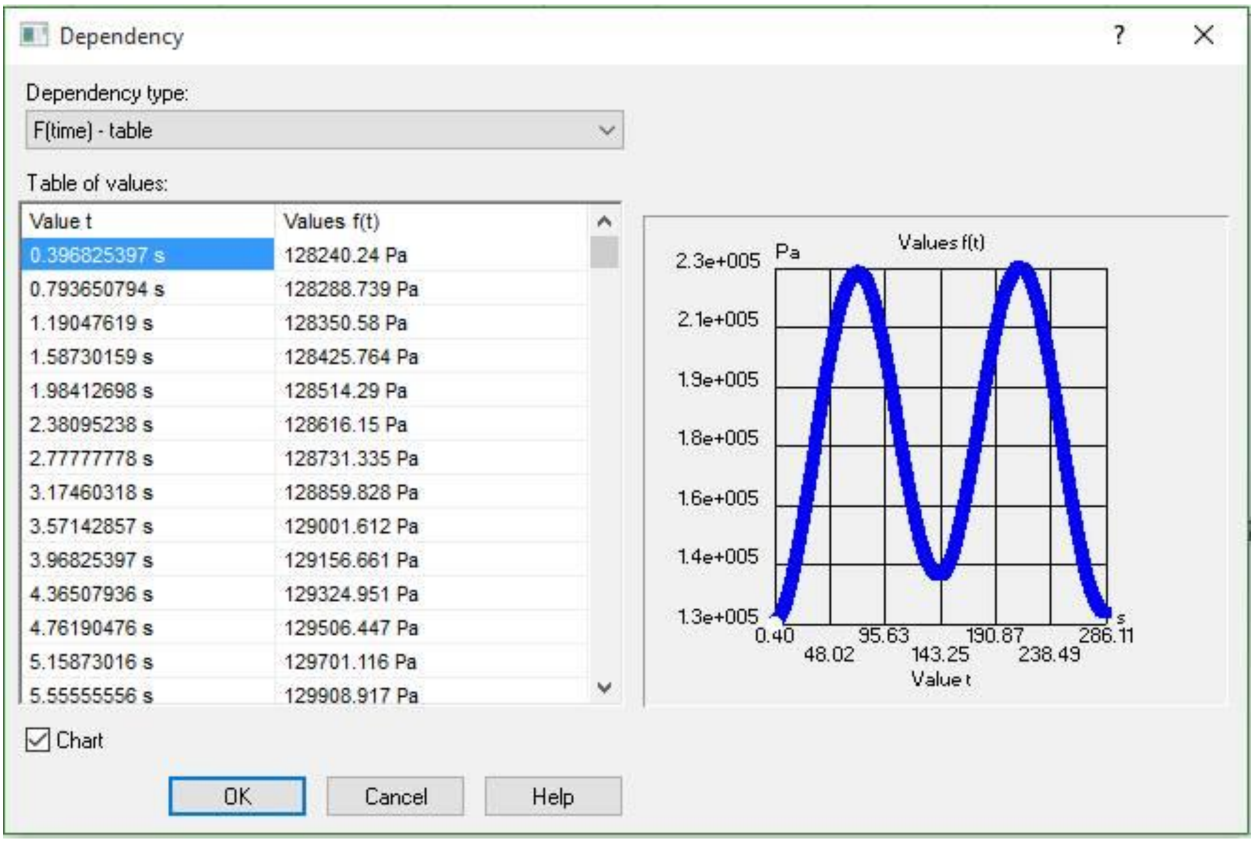


Figure 3.14: Input pressure

After running solidworks program. The exhaust gases flow through the system and pressure drop due to viscous resistance of the porous media are shown in the figure 3.15 , where the fluid velocity changes as it pass through the porous substrate.

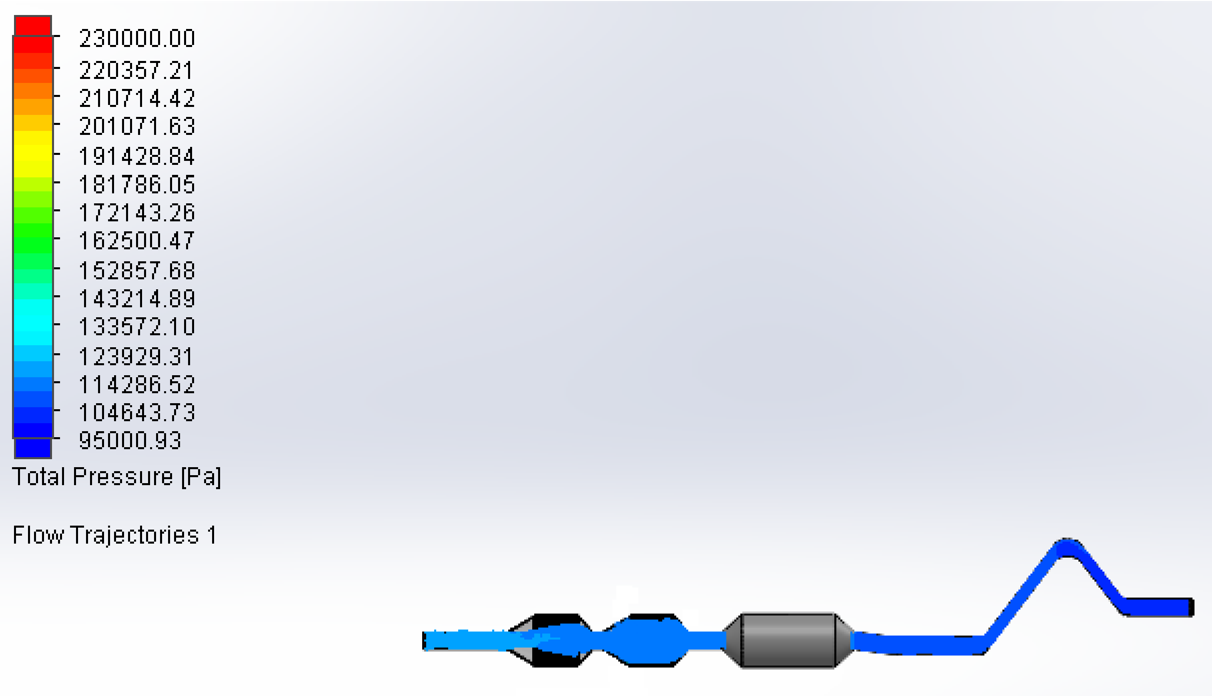


Figure 3.15: System pressure distribuion

The pressure fied distribuion is shown in the last figure , it can be observed the pressure distribution along the system .

The temperature distribution of the fluid along the system are showing in the figure 3.16.

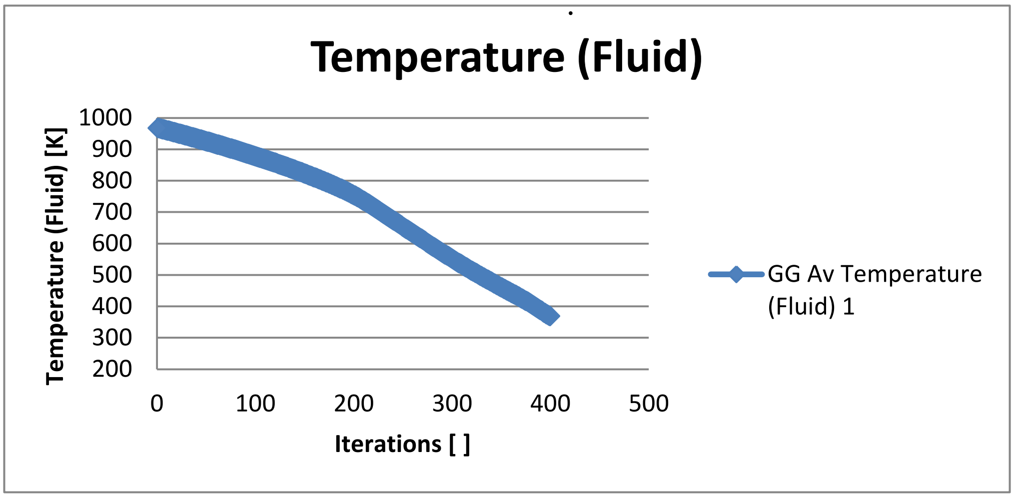


Figure 3.16: System temperature distribution

The velocity distribution of the fluid along the system are showing in the figure 3.17.

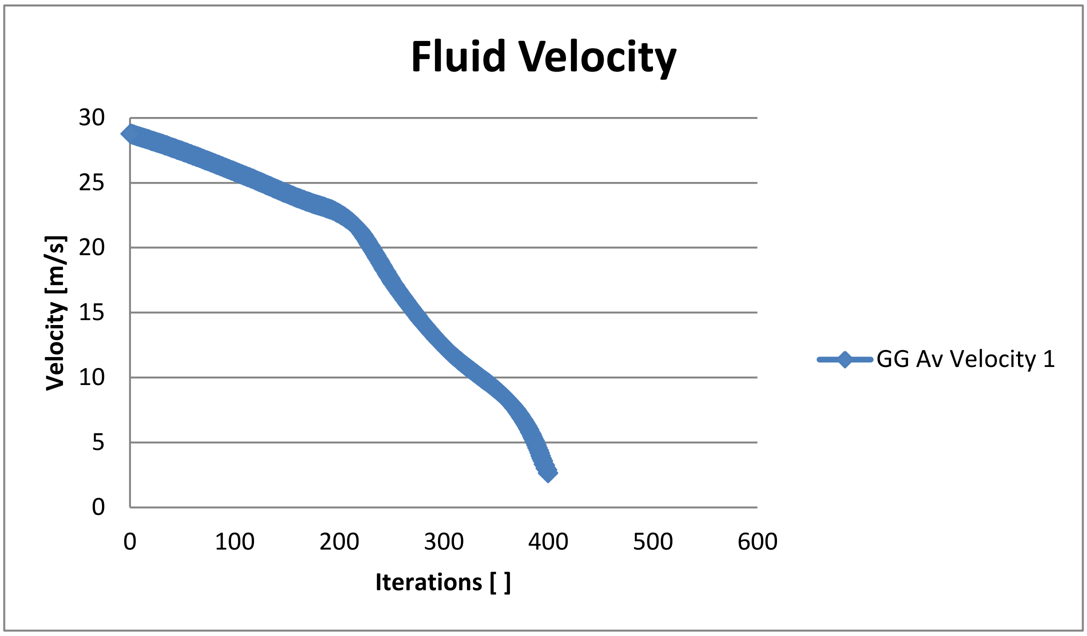


Figure 3.17: System velocity distribution

According to figures 3.16,3.17, the velocity and temperature of the exhaust gases are decreased through pass along the system.

Chapter Four

Project Implementation

4.1 Introduction

4.2 Project Implementation

4.1 Introduction

Developing the exhaust system treatment to reduce the concentration of the toxic emissions in gasoline engine by using double catalytic converter, and measuring the exhaust gases concentration to compare the project results.

After designing the system on the gasoline engine, many steps had been performed to build the system and many experiments had been performed to study the effect of using double catalytic converter .

This chapter focuses on the steps of implementation and building the system .

4.2 Project Implementation

A suitable design must be taken into consideration to ensure that the systems do as planned, a favorable shape layout as shown in figure 4.1.

Figure 4.1 shows the exhaust system contain double three- way catalytic converter, and the entrances of the gas analyzer device.

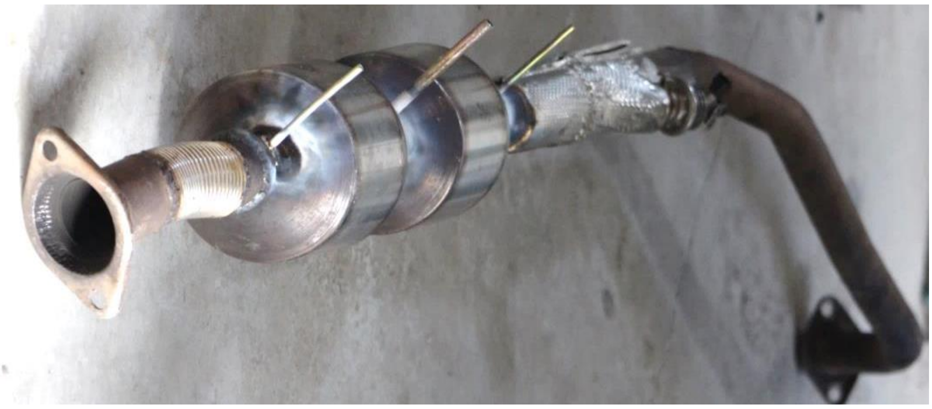


Figure 4.1: Shape layout of the system

4.2.1 Steps of system building

The system designed by using SolidWorks program, and the implementation was done in the workshops (Wilding workshop, and Automotive workshops) . The steps of implementation are as the following:

- Preparing a car for well running, figure 4.2 .

Figure 4.2: The car in which the project implemented on it

- Disassemble the old exhaust system, figure 4.3.

Figure 4.3: The old exhaust system

- Preparing a set of requirements in which the project need it, like as :
  - Double catalytic converter
  - Pipes

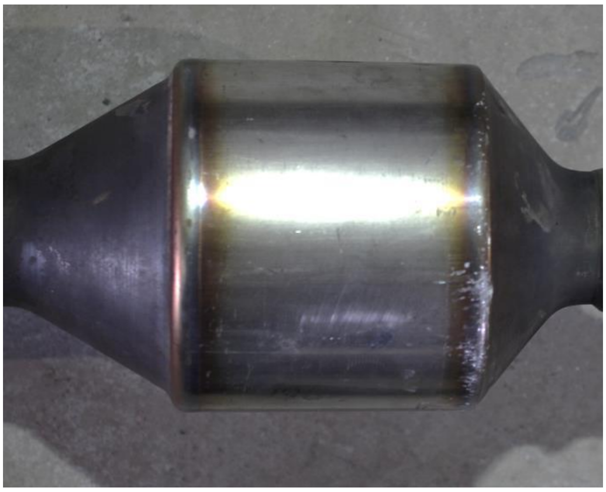


Figure 4.4: Primary catalytic converter

Figure 4.5: Secondary catalytic converter

- Assembling a Double three- way catalytic converter

The three-way catalytic converter is currently the safest, most efficient, and most reliable form of exhaust emission control available for gasoline engines. The double catalytic converter uses in the system are shown in the figure 4.6.

Figure 4.6: Double catalytic converter layout

- Assembling and installation of the system on the car, figure 4.7.

Figure 4.7: The new exhaust system on a car

Chapter Five

Experimental Results

5.1 Introduction

5.2 Engine Specification

5.3 Diagnostic Device

5.4 Emissions Measurements

5.1 Introduction

The aim of this project is to develop an exhaust treatment system to reduce the concentration of toxic emitted emission by using double catalytic converter. In this project the system has been designed and applied on a gasoline engine (Toyota corolla vehicle).

After mounting the system on the gasoline engine, the experiments were performed to study the effect of using double catalytic converter over the efficiency of the exhaust system on reducing the concentration of the toxic emission , and to study the effect of parameters such as engine speed, and A/F ratio on the concentration of emitted gases. experiments were done before the first catalytic converter and after the first catalytic converter, and after the second catalytic converter . All experiments were performed without applying load on the engine.

5.2 Engine Specifications

The car used in this project Toyota corolla (gasoline) engine as shown in figure (5.1) to perform the experiment. The technical specification for Toyota corolla 1.6 vvt 2003 illustrated in table (5.1)

Table 5.1: Car specifications

Key data about Toyota corolla 1.6 VVT-i

Engine of Toyota corolla 1.6 VVT-I

Engine type	naturally aspirated petrol
Engine code	3ZZ-FE
Cylinders	Straight 4
Capacity	1.6 liter / 1598 cc / 97.516 cu in
Engine properties	DOHC, 4 valves per cylinder 14 valves in total
Maximum Engine power	110ps/ 108 bhp / 81kW @6000 rpm
Compression ratio	10.5:1
Fuel system	EFi
Ron number	95

5.3 Diagnostic Device

The diagnostic device used in this project maha gasanalyzercas shown in figure (5.1) to perform the experiments, and the test was done in “Hebron municipality station dynamometer ”. A very good description and in detailed features of maha gas analyzer can be found in its respective datasheet. A copy of that maha Datasheet can be found in Appendices chapter.

Figure 5.1: Maha gas analyzer

The measurements were taken for four cases :

- Engine speed: 850 RPM
- Engine speed: 1500 RPM
- Engine speed: 2500 RPM
- Engine speed: 3500 RPM

The analysis of the results depend on the reduction and oxidation reactions in the catalytic converter and on the combustion geometry.

5.4 Emissions Measurements

The measurement test was done in "Hebron municipality station dynamometer" . A copy of Emissions Measurements Papers can be found in Appendices chapter.

All experiments were performed without applying load on the engine, and the measurement results are as follow:

5.4.1 CO Measurements:

Carbon monoxide (CO) emissions from internal combustion engines are controlled primarily by fuel/air equivalence ratio. For fuel-rich mixtures CO concentrations in the exhaust increase steadily with increasing equivalence ratio, as the amount of excess fuel increases. For fuel-lean mixture, CO concentrations in the exhaust vary little with equivalence ratio.

Table 5.2 shows the concentration of CO before and after the first catalytic converter, and after the second catalytic converter.

Table 5.2: Concentration of CO along the system

Engine Speed	CO concentration before catalytic converters (% Vol.)	CO concentration after the first catalytic converter (% Vol.)	CO concentration after the second catalytic converter (% Vol.)
850	0.73	0.62	0.47
1500	0.56	0.49	0.46
2500	0.28	0.21	0.19
3500	0.2	0.1	0.09

The following figures illustrate the CO concentration as a function of engine speed and lambda with three measurement cases.

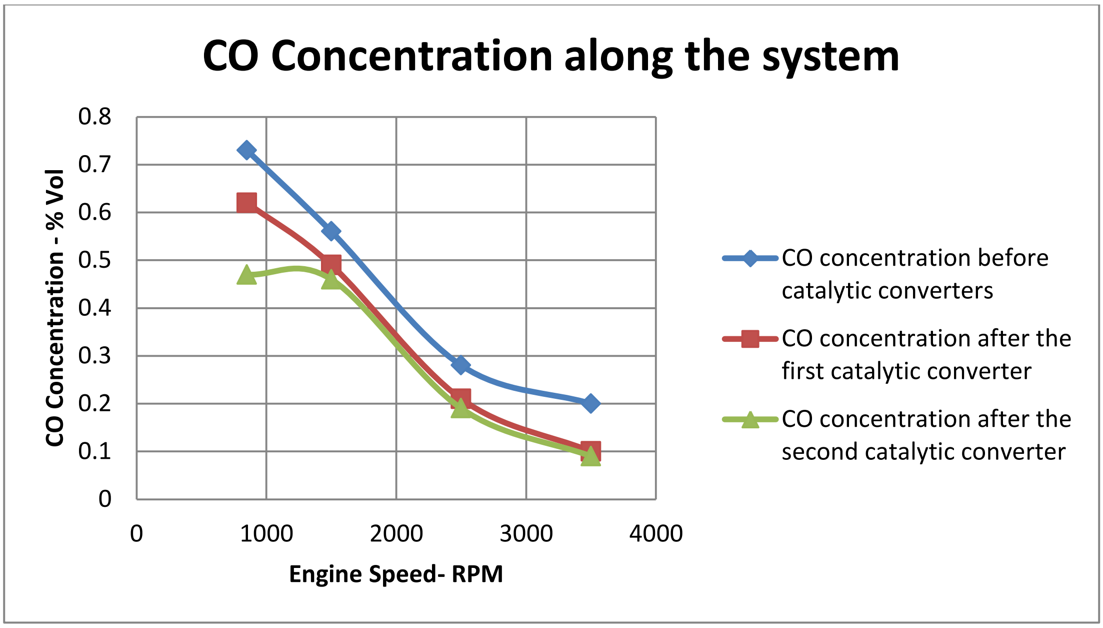


Figure 5.2: Concentration of CO along the system

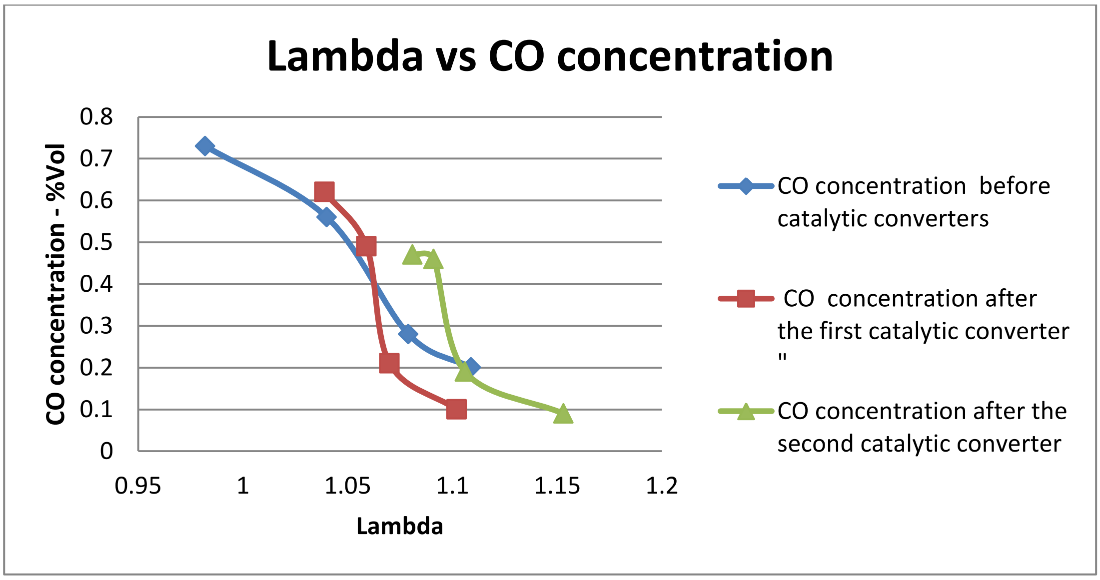


Figure 5.3: The relation between lambda and CO concentration

5.4.2 CO_2 Measurements

The concentration of CO_2 emission in gasoline engine is increased through pass in catalytic converters.

Table 5.3 shows the concentration of CO_2 before and after the first catalytic converter, and after the second catalytic converter.

Table 5.3: Concentration of CO_2 along the system

Engine Speed	CO_2 concentration before catalytic converters (% Vol.)	CO_2 concentration after the first catalytic converter (% Vol.)	CO_2 concentration after the second catalytic converter (% Vol.)
850	10.3	11.5	11.7
1500	12.1	13.6	14.3
2500	12.6	14.2	15.7
3500	12.9	14.9	16.1

The following figures illustrate the CO_2 concentration as a function of engine speed and lambda with three measurement cases.

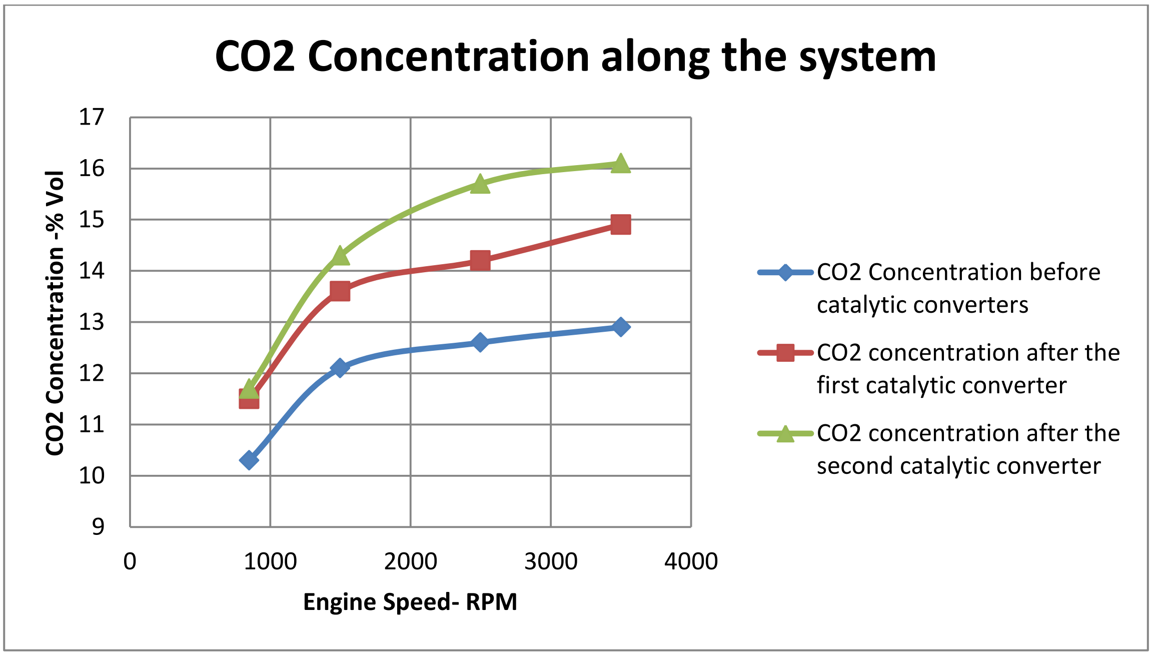


Figure 5.4: Concentration of CO_2 along the system

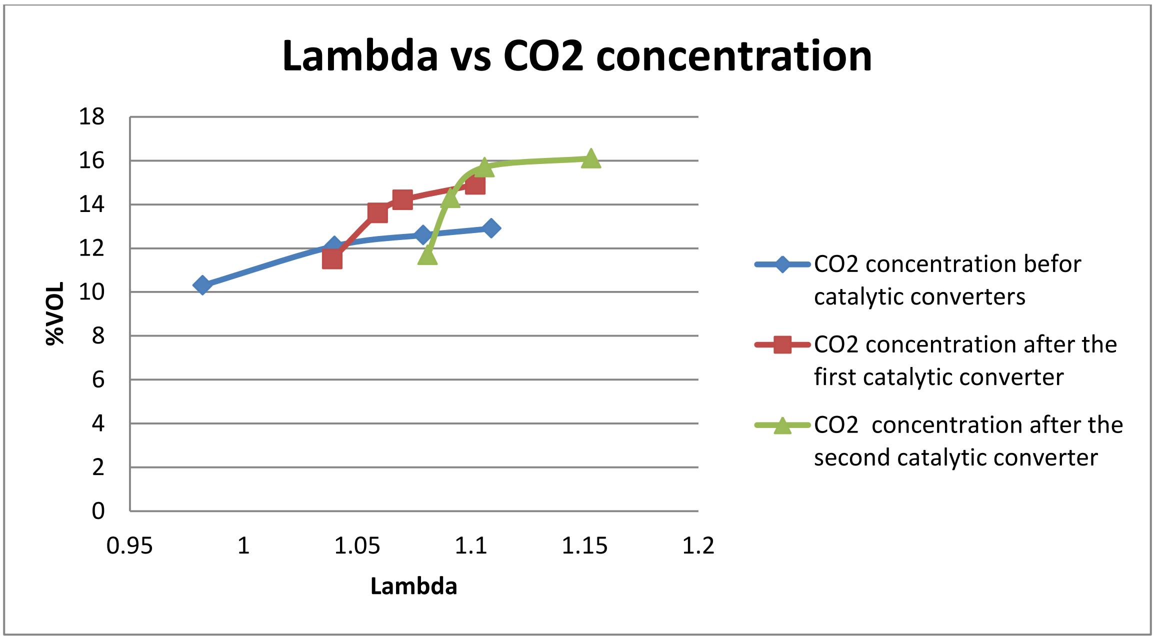


Figure 5.5: The relation between lambda and CO_2 concentration

5.4.3 HC Measurements

The concentration of HC emission in gasoline engine is reduced through pass in catalytic converters, since the catalytic converters activate the oxidation reaction, which leads to reduce the gas concentration.

Table 5.4 shows the concentration of HC before and after the first catalytic converter, and after the second catalytic converter.

Table 5.4: Concentration of HC along the system

Engine Speed	HC concentration before catalytic converters (ppm)	HC concentration after the first catalytic converter (ppm)	HC concentration after the second catalytic converter (ppm)
850	475	113	60
1500	144	98	59
2500	140	69	43
3500	125	57	25

The following figures illustrate the HC concentration as a function of engine speed and lambda with three measurement cases.

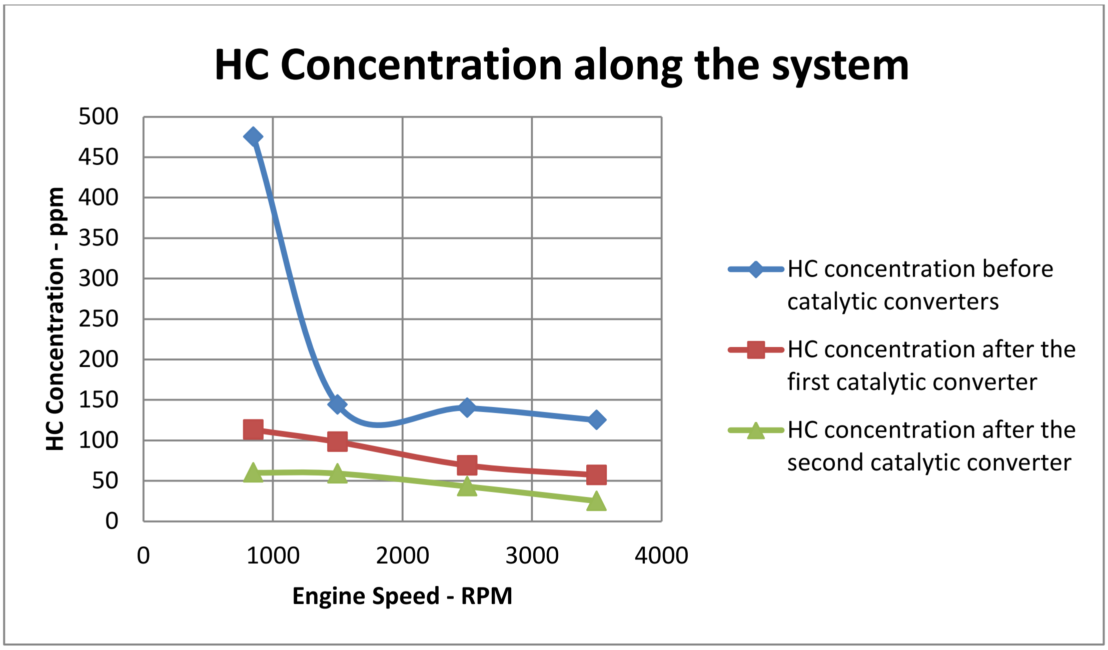


Figure 5.6: HC concentration along the system

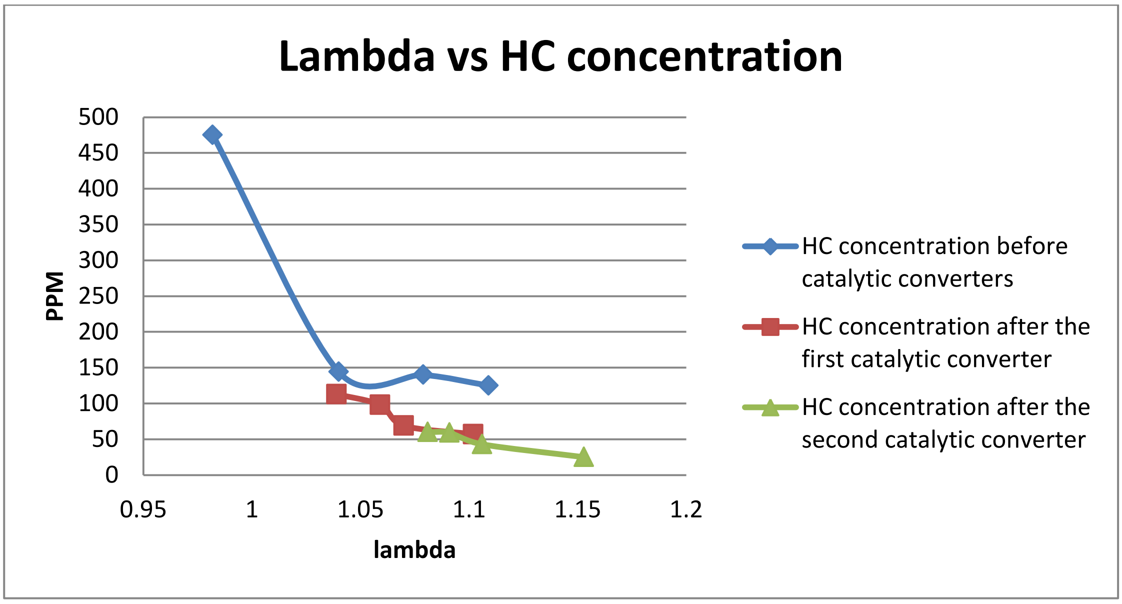


Figure 5.7: The relation between lambda and HC concentration

5.4.4 NOx Measurements

The concentration of NO_x reduces drastically with the attachment of catalytic converters. Table 5.5 shows the concentration of NO_x before and after the first catalytic converter, and after the second catalytic converter.

Table 5.5: The concentration of NO_x along the system

Engine Speed	NO_x concentration before catalytic converters (ppm)	NO_x concentration after the first catalytic converter (ppm)	NO_x concentration after the second catalytic converter (ppm)
850	22	10	6
1500	95	72	49
2500	276	201	146
3500	805	585	342

The following figures illustrate the NO_x concentration as a function of engine speed and lambda with three measurement cases.

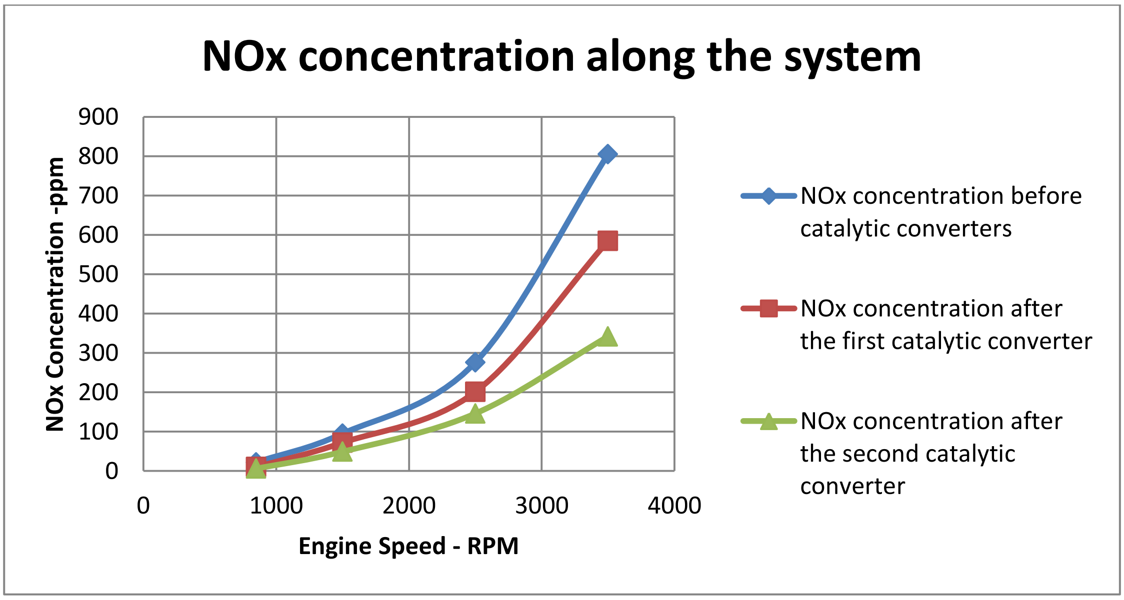


Figure 5.8: Concentration of NO_x along the system

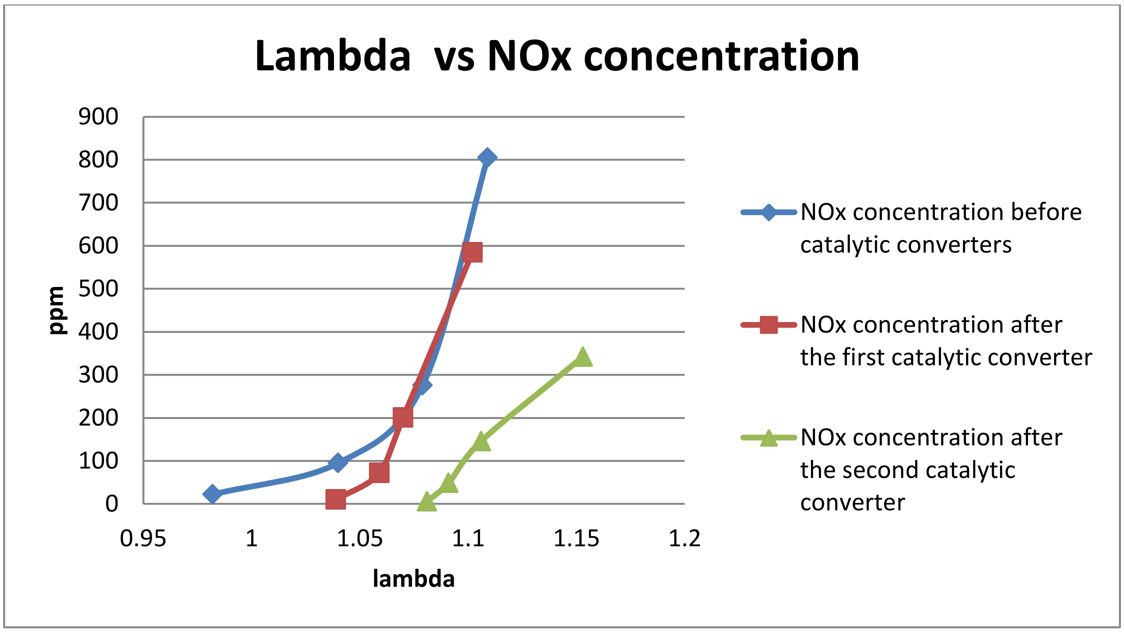


Figure 5.9: the relation between Lambda and NO_x concentration

5.4.5 O_2 Measurements

Table 5.6 shows the effect of catalytic converters on the amount of oxygen emitted from the engine. The amount of oxygen emitted from the engine is equipped with catalytic converters has been reduced significantly with the absence of catalytic converter.

Table 5.6: concentration of O_2 along the system

Engine Speed	O_2 concentration before catalytic converters (% Vol.)	O_2 concentration after the first catalytic converter (% Vol.)	O_2 concentration after the second catalytic converter (% Vol.)
850	0.86	0.56	0.31
1500	1.28	1.05	0.98
2500	2.04	1.7	1.52
3500	2.76	2.3	1.76

The following figures illustrate the NO_x concentration as a function of engine speed and lambda with three measurement cases.

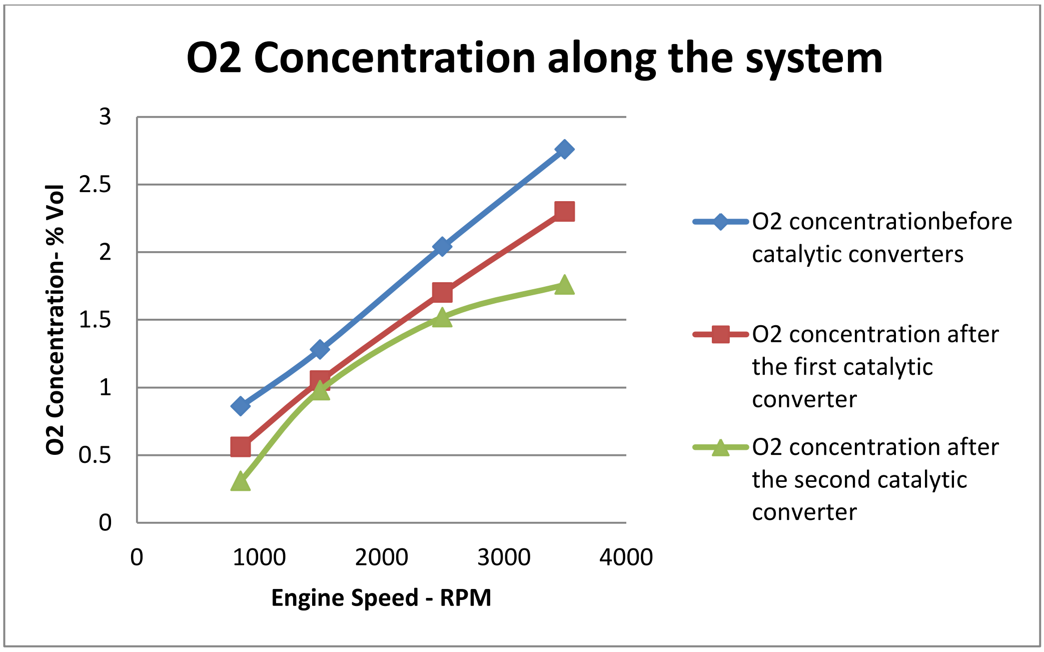


Figure 5.10: Concentration of O_2 concentration along the system

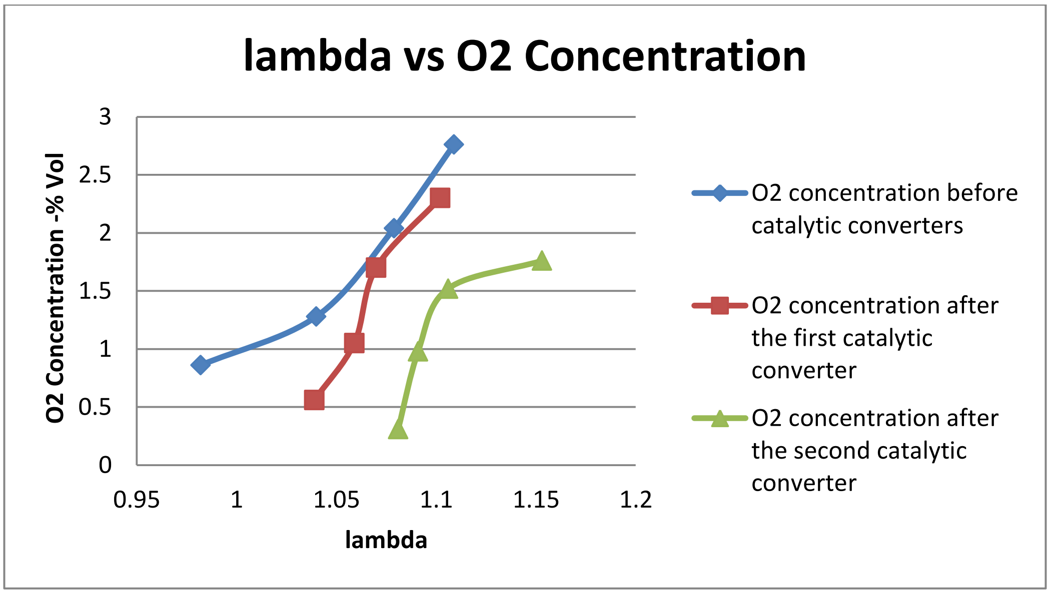


Figure 5.11: The relation between lambda and O_2 Concentration

5.5 Results Discussion

The analysis of the results depend on the reduction and oxidation reactions in the catalytic converter and the combustion geometry.

From the measured results it is clearly noticed that the emissions (CO, HC, and NO_x) are a strongly function of excess-air ratio (equivalence ratio).

It was also noticed that a rich mixture does not have enough oxygen to react with all the carbon and hydrogen , and both HC and CO emissions increase, where as lean mixture, HC emissions decrease until reach extreme lean , HC emissions increase due to poor combustion and misfire.

In the case of NO_x emissions, the generation is a function of the combustion temperature, highest near stoichiometric conditions when temperatures at the peak value, maximum NO_x emissions occur at slightly lean condition, where the combustion temperature is high and there is an excess oxygen to react with the nitrogen.

The results also confirm that exhaust emissions are a dependent parameter on engine speed.

It was also noticed that:

- The nitrogen oxides concentration is reduced through pass in catalytic converters, since the catalytic converters activate the reduction reaction, which leads to reduce the gas concentration according to the following equation

$$2NO_x \rightarrow xO_2 + N_2$$

- The concentration of CO gas decreased during catalytic converters , since the catalytic converters activate the oxidization interaction of CO to CO_2 according to the following equation :

$$2CO + O_2 \rightarrow 2CO_2$$

- Increasing in CO_2 concentration after each stage of oxidization reaction in catalytic converters, since the catalytic converters are active oxidization reactions as the following equations:

oxidation of CO $\quad 2CO + O_2 \rightarrow 2\ CO_2$

oxidation of HC $C_xH_{2x+2} + [(3x+1)/2]O_2 \rightarrow xCO_2 + (x+1)H_2O$

- Hydrocarbon concentration is reduced through pass in catalytic converters, since the catalytic converters activate the oxidation reaction, which leads to reduce the gas concentration according to the following equation

$$C_xH_{2x+2} + [(3x+1)/2]O_2 \rightarrow xCO_2 + (x+1)H_2O$$

- In the case of using catalytic converters, it is seen from figures (5.2 - 5.11) that there is a noticed reduction of gases (CO,HC,and NO_x).

The following table shows the estimated reduction percentage of these gases (without catalytic converters, after the first one and after the second one).

Table 5.7: Reduction of the toxic exhaust gases

	Reduction of exhaust gases		
	%CO	%HC	%NOx
First catalytic converter	25.13	53.35	33.75
Second catalytic converter	16.24	45.38	35.27

There is a deviation in the practical experiments results . Because of the bad condition of the engine, the mechanical components of the engine must repair to have a good results.

There is a deviation in the practical experiments results:

- Because of the bad condition of the engine, the mechanical components of the engine must repair to have a good results.
- The values also not significant since there is no load on the engine and the measurement values are taken only for a varies engine speed.

At idle speed , the engine working at a slightly rich mixture , when the speed of the engine increase the value of lambda will increase. This mean :

- Decreasing of CO concentration with increasing of engine speed, since at lean mixture there is excess air (sufficient oxygen) uses to form CO_2 , figure (5.2,5.3)

- Increasing of CO_2 Concentration with increasing of engine speed, since at lean mixture there is excess air (sufficient oxygen) uses to convert CO to CO_2 , figure (5.4,5.5)

- Decreasing of HC Concentration with increasing of engine speed, since there is a sufficient oxygen to react with the fuel and release the power . until reach the extreme lean , the concentration of HC will increase , due to poor combustion and misfire, figure (5.6,5.7)

- Increasing of NO_x Concentration with increasing of engine speed, since increase in engine speed leads to decrease in volumetric efficiency, there for increasing of the fraction of residual gases although heat transfer rate are decreasing with the speed, the transfer time per cycle decreases the average heat transfer per cycle, this leading to higher gas temperature, and increasing in NO_x formation, figure (5.8,5.9)

5.6 Conclusion

Relaying on the experiment results illustrated on the figures(5.2 - 5.11), it is included that using a catalytic converter is an efficient tool for vehicle emissions reduction.

References

[1] environmentpollution.0fees.net visited 2015

[2] H. Sinzenich, K. Wehler, and R. Müller, *Exhaust aftertreatment for reducing nitrogen oxide emissions*, mtu,Friedrichshafen,Germany,2014

[3] P. Purwanto, H. Hadiyanto, Optimum Design of Manganese-coated Copper Catalytic Converter to Reduce Carbon Monoxide Emissions on Gasoline Motor ,ELSIEVER , Volume 23 (2015), Pages 86–92 .

[4] Willard W. Pulkrabek , *Engineering Fundamentals of the Internal Combustion Engine,* University of Wisconsin , new jersey, 1991.

[5] John B .Haywood ,*INTERNAL COMPUSTION ENGINE FUNDAMENTALS* ,McGraw Book Company ,New York ,1988.

[6] V .Ganesan ,*INTERNAL COMBUSTION ENGINES , SECOND EDITTION* , Tata McGraw Company ,New York ,1999.

[7] en.wikipedia.org/wiki/Atmosphere_of_Earth visited 2015

[8] Toyota company ,*COMBUSTION CHEMISTRY & EMISSION ANALYSIS*, in *Advanced Emissions & Driveability Diagnosis* - Course 972 , Japan ,1992 , 31-54.

[9] Eugene O.Itua, "Vehicular Emission (Air Quality) Monitoring Study", Lagos, Nigeria, 2006

[10]chemwiki.ucdavis.edu/Physical_Chemistry/Kinetics/Case_Studies%3A_Kinetics/Catalytic_Converters visited 2015

[11] www.carid.com/walker/info/catalytic-converters.html visited 2015

[12] www.walkerexhaust.com/support/understanding-catalytic-converter/evolution-of-the-catalytic-converter visited 2015

[13] Zuhdi salhab, "Effect of Exhaust Gas Recirculation on the emission and Performance of Hydrogen Fueled Spark- Ignition Engine ", Global Journal of Researches in Engineering, Hebron, Palestine, 2012

[14] svendenningesen, "Air pollution from large two stroke diesel engine and technology to control it- svendhenningesen", Management of natural resource R&D department, Copenhangen, Denemark, 1998.

[15] Toyota motor sale, "Evaporation emission control system", New York, USA,2006

[16] Toyota motor sale, "Secondary air injection- Toyota motor sale", New York, USA,2007

[17] K. S. UMESH1, V. K. PRAVIN2 & K. RAJAGOPAL, CFD ANALYSIS OF EXHAUST MANIFOLD OF MULTI-CYLINDER SI ENGINE TO DETERMINE OPTIMAL GEOMETRY FOR REDUCING EMISSIONS ,International Journal of Automobile Engineering Research and Development , Vol. 3 (2013) , ISSN 2277-4785 .

[18] en.wikipedia.org/wiki/Atmospheric_pressure visited 2015

[19] M.Massoud, Engineering Thermofluids Thermodynamics, Fluid Mechanics, and Heat Transfer , springer ,2005

[20] learn.adafruit.com/all-about-stepper-motors/what-is-a-stepper-motor visited 2015

[21] www.technologystudent.com/prddes1/standard6.html visited 2015

[22] en.wikipedia.org/wiki/ULN2003A visited 2015

[23] en.wikipedia.org/wiki/Pressure_sensor visited 2015

[24]en.wikibooks.org/wiki/Introduction_to_Chemical_Engineering_Processes/What_is_a_mass_balance%3F visited 2015

Appendices

- Maha Gas Analyzer
- Measurement Readings

Maha Gas Analyzer Datasheet

Emission Testers
for Diesel, Gasoline and Gas Engines

Model: MET 6.3 • MET 6.1 • MET 6.2 • Export • MDO2 LON • MGT5
DITEST SPEED 2000 • RPM VC2

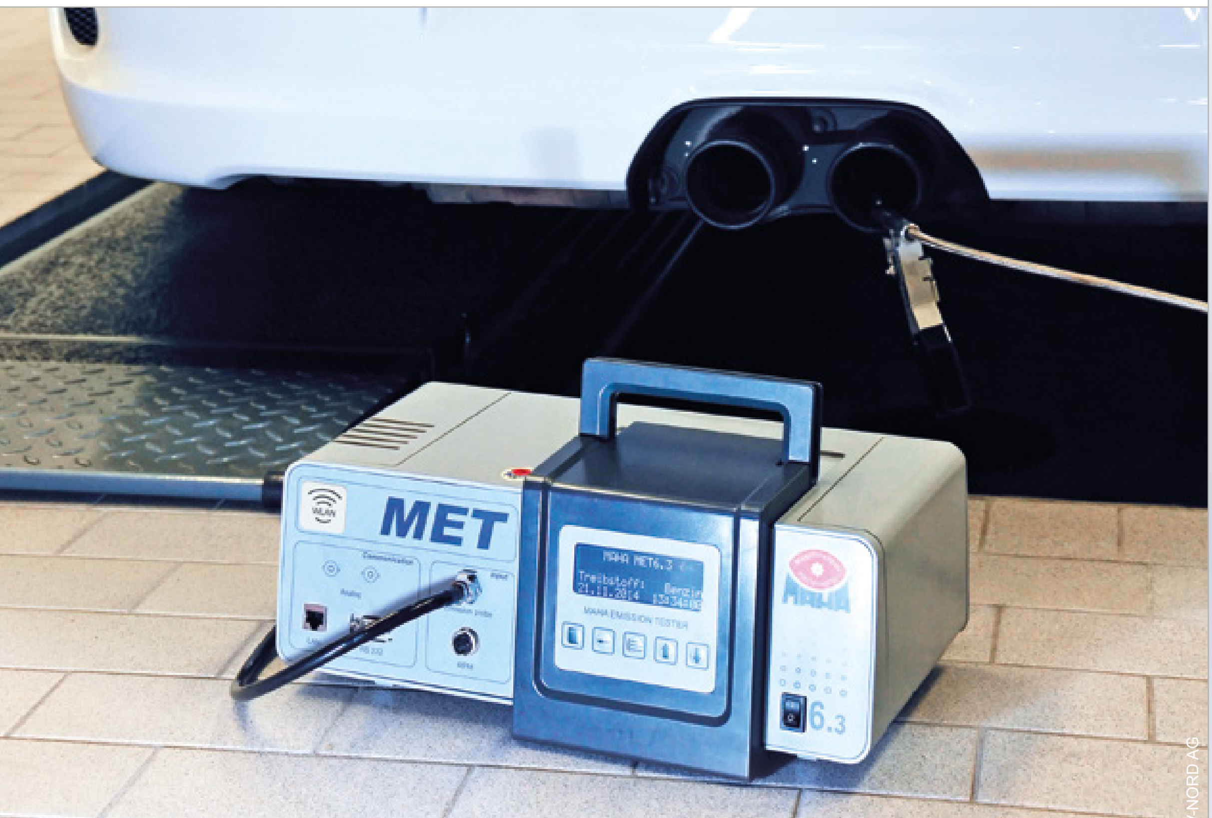


Image: TÜV-NORD AG

Dynamometers, Diagnostic Units, Emission Testers

- ► Emission Testers
- ► RPM Counter
- ► OBD-Scan Tools for Emission Testing

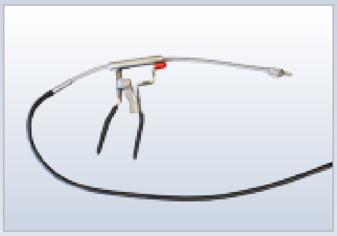
Premium Workshop Equipment

Combination emission tester for petrol/gas and diesel engines Model: MET 6.3

The MET 6.3 combination emission tester combines cutting-edge petrol and diesel emission measuring technology in one compact housing. The unique design offers the user extensive options for emission diagnostics, in addition to using the tester in the official exhaust emission inspection (AU). When the tester is fully equipped, it can simultaneously measure HC, CO, CO_2, O_2, NO, NO_2, NO_x, turbidity coefficient and particle mass concentration. With its PC-supported inspection workflow, which is well-organised and user-friendly, it is the perfect emission tester for the legally prescribed AU emission inspection. Thanks to its compact dimensions, low weight, wireless PC connection (optional) and OBD module, the MET 6.3 is particularly suitable for mobile applications. The optional heated 5.5 m probe hose for petrol and diesel measurement makes it easy to connect the emission probe to the vehicle being tested (e.g. to a lorry's vertical exhaust pipe). The MET 6.3 is backed up by a well-planned servicing scheme. When consumables (filters, O_2 sensors, etc.) need to be changed, the software displays the component change that is due in good time. Highly durable consumable parts and service hatches that are straightforward to access reduce the effort required for servicing work to a minimum.

- ► Analysis of the gas components HC, CO, CO_2, O_2, lambda (calculated), CO corrected (calculated), optionally NO, NO_2, NO_x
- ► Analysis of diesel emission turbidity coefficient (K value), particle mass concentration
- ► Small, lightweight (roughly 5 kg as combi-device), practical and durable
- ► The perfect device for mobile use: small, lightweight, power supply from vehicle, wireless connection to OBD and emission tester (optional), mobile carrying case (optional)
- ► Menu-driven control and easy-to-use inspection workflow (on PC)
- ► Just one probe, with patented rapid-action clamp, for all engine types
- ► 5 m probe hose (heated), also usable for diesel measurement (option)
- ► Large, easy-access service hatches for straightforward servicing
- ► Automatic notification when filters or O_2 sensors are due to be changed
- ► MAHA wireless OBD: wireless, lightweight and easy to use
- ► Wireless device communication via W-LAN (optional)
- ► Mains connection and power supply from on-board electrical system possible (10–30 V)
- ► Innovative patented water extractor
- ► Low power consumption thanks to intelligent energy management
- ► MAHA green line-certified thanks to its particularly low environmental impact
- ► Approval: to MID 2004/22/EC, PTB 18.9

Accesssories



Emission probe for petrol/gasoline and diesel with special clamping device

DITEST SPEED 2000, practice-oriented rpm measurement via magnet combo-sensor

Oil temperature sensor

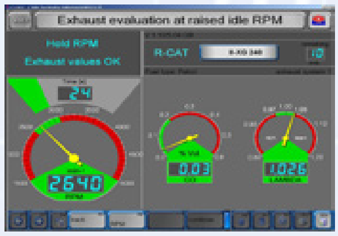
Trolley for single-, combo-tester and e.g. printer

MAHA wireless OBD

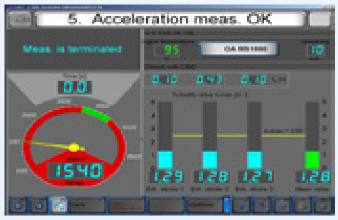
Emission probe, heated, 5 m

Mobility Kit for MET 6 Series

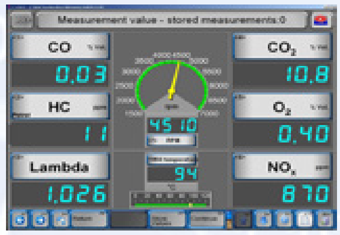
Partial flow emission tester with display unit in high-quality synthetic casing



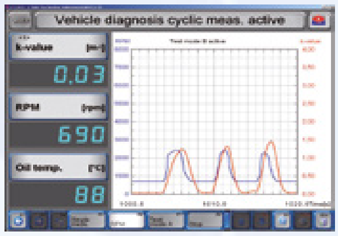
Inspection workflow, petrol



Inspection workflow, diesel

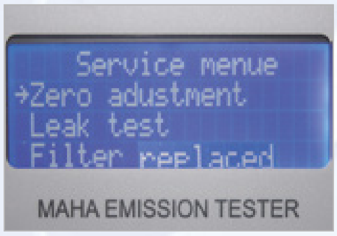


Measurement values, diagnostics mode petrol



Measurement values, diagnostics mode diesel

Easily accessible maintenance flap



Display: Servicing menu

Application

MET 6 measurement on CAR

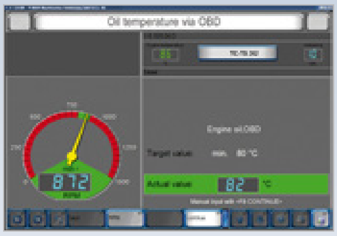
Mobile carrying case in use

Emission Tester for Gasoline and Gas Powered Otto Engines Model: MET 6.1

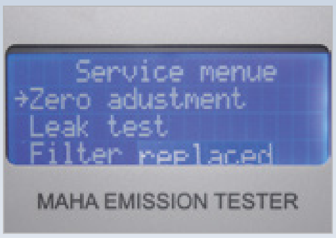
The MET 6.1 petrol/gas emission tester offers cutting-edge emission measuring technology in a compact housing. With its PC-supported inspection workflow, which is well-organised and user-friendly, it is the perfect emission tester for the legally prescribed AU emission inspection for petrol-driven and gas-driven vehicles. Extensive options for emission diagnostics (HC, CO, CO_2, O_2, NO, NO_2, NO_x, lambda, CO corrected) complete the MET 6.1's versatile range of applications. Thanks to its compact dimensions, low weight, wireless PC connection (optional) and OBD module, this emission tester is particularly suitable for mobile applications. The MET 6.1 is backed up by a well-planned servicing scheme. When consumables (filters, O_2 sensors, etc.) need to be changed, the software displays the component change that is due in good time. Highly durable consumable parts and service hatches that are straightforward to access reduce the effort required for servicing work to a minimum.

- ► Analysis of the gas components HC, CO, CO_2, O_2, lambda (calculated), CO corrected (calculated), optionally NO, NO_2, NO_x
- ► Small, lightweight (less than 5 kg), practical and durable
- ► The perfect device for mobile use: small, lightweight, power supply from vehicle, wireless connection to OBD and emission tester (optional), mobile carrying case (optional)
- ► Menu-driven control and easy-to-use inspection workflow (on PC)
- ► Probe with patented rapid-action clamp
- ► Large, easy-access service hatches for straightforward servicing
- ► Automatic notification when filters or O_2 sensors are due to be changed
- ► MAHA wireless OBD: wireless, lightweight and easy to use
- ► Wireless device communication via W-LAN (optional)
- ► Mains connection and power supply from on-board electrical system possible (10–30 V)
- ► Innovative patented water extractor
- ► Low power consumption thanks to intelligent energy management
- ► MAHA green line-certified thanks to its particularly low environmental impact
- ► Approval: to MID 2004/22/EC

Application

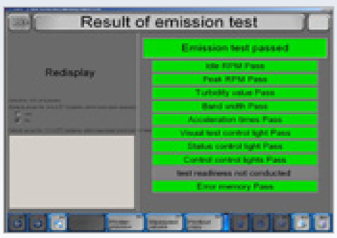


RPM, motor temperature via OBD



Display: Servicing menu

MET 6 measurement on motorcycle



Display of a measurement result (countryspecific)

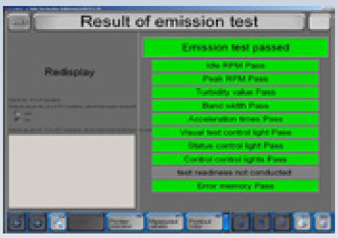
Main menu

Diesel Engine Emission Tester (Opacimeter) Model: MET 6.2

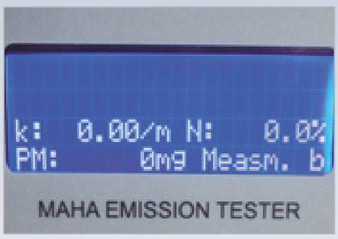
The MET 6.2 diesel emission tester offers cutting-edge emission measuring technology in a compact housing. With its PC-supported inspection workflow, which is well-organised and user-friendly, it is the perfect emission tester for the legally prescribed AU emission inspection for vehicles with diesel engines. Extensive options for emission diagnostics, turbidity coefficient (K value), particle mass concentration, NO, NO_2, NO_x complete the MET 6.2's versatile range of applications. Thanks to its compact dimensions, low weight, wireless PC connection (optional) and OBD module, this emission tester is particularly suitable for mobile applications. The MET 6.2 is backed up by a well-planned servicing scheme. When filters need to be changed, the software displays the component change that is due in good time. Highly durable consumable parts and service hatches that are straightforward to access reduce the effort required for servicing work to a minimum.

- ► Analysis of diesel emission turbidity coefficient (K value), particle mass concentration, optionally NO, NO_2, NO_x
- ► Small, lightweight (less than 5 kg), practical and durable
- ► The perfect device for mobile use: small, lightweight, power supply from vehicle, wireless connection to OBD and emission tester (optional), mobile carrying case (optional)
- ► Menu-driven control and easy-to-use inspection workflow (on PC)
- ► Probe with patented rapid-action clamp
- ► 5 m probe hose (heated), also usable for diesel measurement (option)
- ► Large, easy-access service hatches for straightforward servicing
- ► Automatic notification when filters are due to be changed
- ► MAHA wireless OBD: wireless, lightweight and easy to use
- ► Wireless device communication via W-LAN (optional)
- ► Mains connection and power supply from on-board electrical system possible (10–30 V)
- ► Innovative patented water extractor
- ► Low power consumption thanks to intelligent energy management
- ► MAHA green line-certified thanks to its particularly low environmental impact
- ► Approval: to PTB 18.9

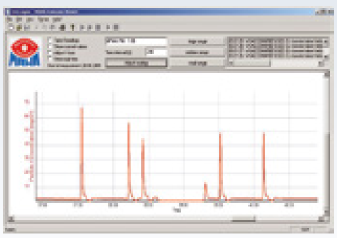
Application



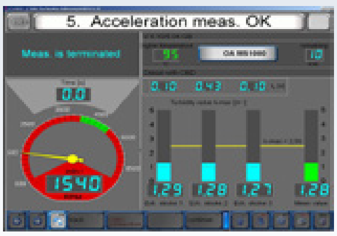
Display of a measurement result



Display: Measurement



Display of the particle mass concentration



Inspection workflow, diesel

MET measurement, car (connected to LPS)

Diesel Engine Emission Tester (Opacimeter)
Model: MDO 2 Export

The MDO 2 Export diesel emission tester essentially consists of 2 components: opacimeter (testing unit) and the hand terminal with data printer for graphic and digital display of the measurement values.
The opacimeter is placed near the exhaust pipe and the remote control is conveniently taken along into the vehicle.

- ► Emission test based on statutory guidelines
- ► High-quality stainless steel emission-carrying parts (chamber / probe)
- ► Single and/or continuous testing
- ► Full throttle suitability for adjustment work on a dynamometer
- ► High-powered test chamber heating
- ► Menu-driven user-guidance
- ► Graphic correlation of RPM to turbidity line. Graphic and digital documentation of measurement values.
- ► Serial interface RS 232 for connection to bar code reader, PC and various external reading devices.

Hand terminal with integrated LCD display for test value display and user-guidance through the official diesel emission test cycles and other various programs. Graphical and digital test result print out with the integrated data printer. Keyboard is used for test vehicle data input and calling up target data from the chipcard.

Truck probe 2 (27 mm) with 3.5 m hose (standard length)

230 V / 12 V / 24 V Power supply via cigarette lighter

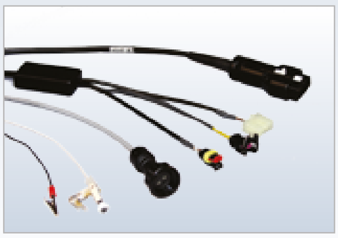
Hand Terminal
- Printer and control unit with LCD display
- 5 m connection cable between opacimeter and hand terminal

Accesssories

Various emission probes for cars and trucks

Trolley and test chamber transport case for mobility

Sturdy accessory case



Large selection of RPM sensor adapters for various kinds of vehicle types

Application

The MDO 2 Export's compact design makes it ideal for mobile use. The testing program design allows for single acceleration testing as well as continuous testing under load. Even under extreme temperature conditions the high-powered test chamber heat-up is fast and efficient and the opacimeter is ready for use in no time flat.

Emission Tester for Diesel Engines (Opacimeter) Model: MDO 2 LON

- Future-oriented basis unit, designed for adaption to user's diversified requirements with special accessories (e.g. measurement under load). Modified emission testing standards can easily be adapted to (e.g. E-OBD).
- Presents the concept of an individual, compact unit for stationary as well as mobile application. The same conceptual design of the Otto engine emission tester MGT 5 creates a multi-functional combi-unit for emission testing of gasoline and diesel engines.
- The networking and connection of the MGT 5 to the PC is possible at any time via RS 232 interface. This can be done without damaging calibration or warranty seals.
- Easy, comfortable operation with clearly structured software
- Extremely short warm-up phase at unit switch-on
- The proven sturdy and rugged design means very low maintenance
- Network capabilities (EUROSYSTEM, ASA, Citrix, Giegnet, NCTC...)
- Integration of vehicle target databases (country-specific limit values) (Optional)
- Connection any time to MAHA function and performance dynamometers

OBD Scan Tool for operating the measurement chamber with PC

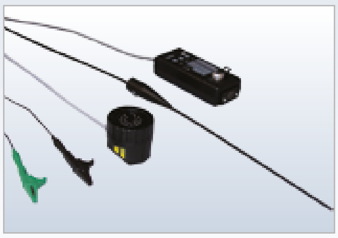
OBD scan tool for operation with hand version

Chipcard reader for vehicle target data (with hand terminal version)

The measurement chamber, positioned near the exhaust pipe, can be operated via a hand terminal and a PC/laptop

Accesssories

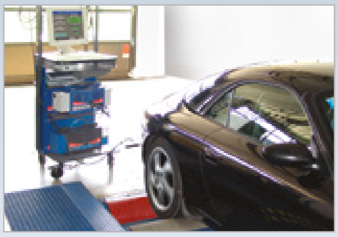
Hand terminal



Large selection of RPM sensor adapters for various kinds of vehicle types

Push cart for individual & combi-unit (with gasoline tester MGT 5)

Application



Connection to LPS function and performance dynamometer

MDO LON in data network with EUROSYSTEM test lane

MDO LON measurement on TRUCK

Emission Tester for Gasoline and Gas Powered Otto Engines Model: MGT 5

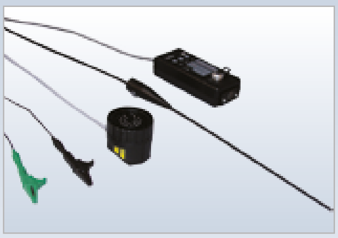
- The concept of an individual, compact unit for stationary as well as portable usage; the same conceptual design of the diesel emission tester MDO2 LON creates a multifunctional combi-unit for emission testing of gasoline and diesel engines.
- Wide application range from easy, portable stand alone unit with internal LED display to a sophisticated, networked PC station with simple, self-explanatory software screen.
- Device for measurement of vehicle with liquid gas (LPG) and natural gas (CNG) engines
- Easy, comfortable operation with clearly structured screen display. Intelligent software provides adequate operation and all necessary information.
- Future-oriented concept with variable plug-in function module, e.g. multi-RPM recording, E-OBD communication unit
- Interface module for various connection possibilities to PC and test lane (LON, USB...)
- Network capabilities (EUROSYSTEM, ASA, Citrix...)
- NOx measurement optionally available
- Combi-unit for diesel and gasoline emission testing in connection with the MAHA MDO 2 LON (Diesel Emission Tester)
- Integration of vehicle target databases (country-specific limit values) (Optional)

Activated carbon filter, electrochemical sensors.
Front: RPM plug-in module. All components are easily accessible and, if necessary, can be simply replaced.

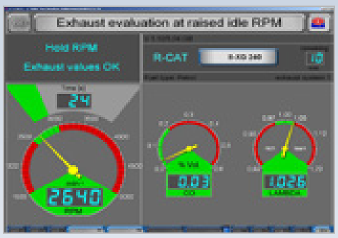
New kind of main filter unit with activated water separator, condensate is automatically pumped out.

E OBD Communication module

Accessories

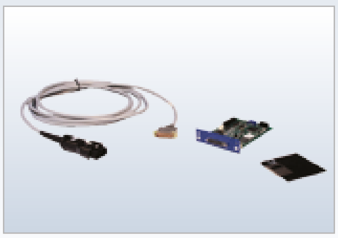


Various possibilities for vehiclespecific RPM and oil temperature measurement



Display of a test procedure (country specific) All important information at one glance.

Hand terminal



Kit for OBD retro-fitting

Application

MGT 5 measurement on CAR

RPM Counter for Emission Testers

Model: DITEST SPEED 2000

- No setting of number of cylinders needed
- Covers most types of gasoline and diesel engines
- For static and dynamic RPM curves
- Automatic self-calibration and function monitoring
- Easy mounting with integrated permanent magnets
- Universal, connection to any kind of emission tester
- Unique, direct signal measurement
- Future-proof, operates independently from electrical engine signals

Application range:
Universal RPM measurement for gasoline and diesel engines.

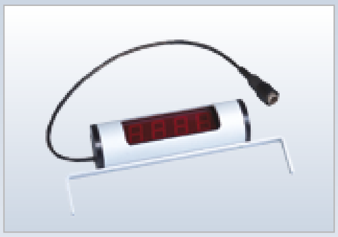
Model: MGT 300 EVO

- RPM determination via vibration sensor for cars
- RPM determination via vibration of the on-board voltage
- Distinct RPM display via LCD- screen
- RPM transmission using cable to MAHA emission testers
- RPM transmission using loop for trigger clamp to emission testers from other manufacturers
- Battery operated, hence no power supply cable (to the vehicle´s battery) required

Application range:
Universal RPM measurement for gasoline and diesel engines.

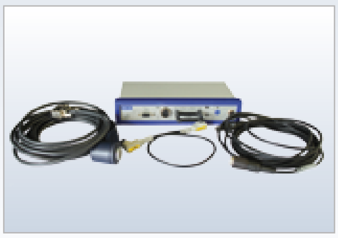
Accessories SPEED 2000

Connection cable to MAHA Emission Tester



Digital display (optional) for application without emission tester

Combi-sensor for RPM determination



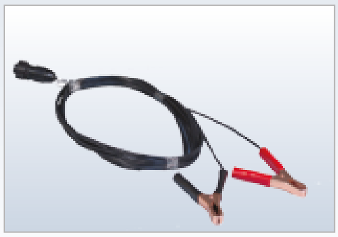
Standard delivery

Accessories MGT 300 EVO

Standard delivery

Vibration sensor for RPM determination

Connection cable for MAHA emission tester



Voltage supply cable for RPM via on-board voltage

Technical Data

MET (complete series)		
Weight roughly		5 kg
Dimensions (H x W x B)		406 × 220 × 160 mm
Supply voltage	Direct connection Power pack	10–30 V (DC) / 60 W 90–265 V (AC) / 50–60 Hz / 60 W
Operating temperature		+5 °C – +45 °C
Storage temperature		-10 °C – +60 °C
Interfaces		LAN, OBD Bluetooth, optional W-LAN / RS 232
Speed input		400–8000 rpm / resolution 1 rpm
Oil thermometer input		0 °C to +150 °C / resolution 1 °C
Flow rate		5.5 l/min

MET 6.1/6.3						
Measureable gases	CO	CO_2	HC	O_2	NO optional	NO_2 optional
Measuring ranges	0–15.0 vol. %	0–20.0 vol. %	0–2000 ppm vol. (hexane) 0–30000 ppm vol. (propane)	0–25.0 vol. %	0–1000 ppm vol.	0–500 ppm vol.
Measurement value resolution (max.)	0.01 vol. %	0.01 vol. %	1 ppm vol.	0.01 vol. %	1 ppm vol.	
Measurement principle	Infrared	Infrared	Infrared	Electrochem.	Electrochem.	
lambda value	Display range: 0–9.999 / resolution: 0.001 / Brettschneider calculation					
Warm-up phase	Roughly 2 min.					
Leaktightness test	Menu-driven / 1x daily					
HC residue test/zero-balance adjustment	Automatic					
Calibration	Once a year/menu-driven via PC/special calibration gas required (country-specific)					
Approval	PTB in accordance with MID, Directive 2004/22/EC					
Precision class	PTB: Class 1 / OIML: Class 0					

MET 6.2/6.3		
Measuring range, turbidity		0–99 %
Measuring range	K value Particle mass concentration	0–9.99 m^{-1} 0–1100 mg/m
Measurement method		Opacimeter
Measuring chamber length		287 mm

MDO 2 Export	
Measurement principle	Light obscuration measurement method (absorption photometry)
Length of measuring cell	430 mm
Wavelength of emitter light	567 mm
Outer/inner diameter of measuring cell	28/25 mm
Heat-up time for measuring cell	Roughly 3 min
Dimensions (L x W x H)	550 × 245 × 240 mm
Weight	approx. 13 kg
Supply voltage	230 V / 50 Hz
On-board power supply (cigarette lighter)	12/24 V
Power consumption, average/max.	110 / 130 W
Port	RS 232 and MF2 keyboard

Hand terminal	
Single-chip processor	Hitachi H8/532
LCD display	2 × 16 characters
Measuring range, turbidity	0 – 100 %
Absorption coefficient	0 m^{-1} to 9.99 m^{-1}
Dimensions (L x H x W)	245 × 65 × 120 mm
Weight	0.85 kg
Supply voltage via opacimeter	12 V
Power consumption, average/max.	250 / 500 mA
Connection options for speed measurement	Piezo terminal sensor, light signal sensor, alternator terminal W, speed microphone, diagnostic connector, TDC sender unit depending on make vibration speed counter MGT 300 EVO

MDO 2 LON	
Measurement principle	Light obscuration measurement method (absorption photometry)
Length of measuring cell	430 mm
Wavelength of emitter light	567 mm
Outer/inner diameter of measuring cell	28/25 mm
Dimensions (L x W x H)	550 × 245 × 240 mm
Weight	approx. 13 kg
Supply voltage	230 V / 50 Hz
On-board power supply (cigarette lighter)	12/24 V
Power consumption, average/max.	110 / 130 W
Port	RS 232

Hand terminal	
Single-chip processor	Hitachi H8/532 with separate Flash EEPROM
LCD display	2 × 16 characters
Measuring range, turbidity	0 – 100 %
Absorption coefficient	0 m^{-1} – 9.99 m^{-1}
Dimensions (L x H x W)	245 × 55 × 125 mm
Weight	0.76 kg
Supply voltage via opacimeter	12 V
Power consumption, average/max.	250 / 900 mA
Connection options for speed measurement	Piezo terminal sensor, light signal sensor, alternator terminal W, speed microphone, diagnostic connector, TDC sender unit depending on make

MGT 5					
Areas of application	Mobile or stationary emission measurement using partial current method, with partial load, for petrol-driven or gas-driven Otto engines				
Measureable gases	CO	CO_2	HC	O_2	NO (optional)
Measuring ranges	0–15.0 vol. %	0–20.0 vol. %	0–2000 ppm vol. (hexane) 0–4000 ppm vol. (propane)	0–25.0 vol. %	0–5000 ppm vol.
Measurement value resolution (max.)	0.01 vol. %	0.01 vol. %	1 ppm vol.	0.01 vol. %	1 ppm vol.
Measurement principle	Infrared	Infrared	Infrared	Electrochem.	Electrochem.
lambda value	Display range: 0.500–9.999 • Resolution: 0.001 • Brettschneider calculation				
Warm-up phase	min. 30 s, max. 10 min., average 2.5 min. • Temperature-controlled				
Flow rate, total	Max. 3.5 l/min. • Min. 1.5 l/min.				
Measurement gas flow rate	Max. 2.5 l/min. • Diaphragm pump				
Nominal voltage	85–280 V • 50 Hz • 65 W /12–24 V DC				
Operating temperature	+5 to +45 °C • Deviation ±2 °C				
Storage temperature	−10 to +60 °C • Deviation ±2 °C				
Leaktightness test	Menu-driven • Min. 1x daily				
HC residue test/zero-balance adjustment	Automatic				
Calibration	Menu-driven via PC • Special calibration gas required (country-specific)				
Ports (optional)	LON • OBD • USB				
Dimensions	560 × 240 × 300 mm				
Weight	approx. 10 kg				
Tachometer (option)	100–10 000 rpm • Resolution 1, 5, 10 or 50 rpm • Various recording sensors				
Oil thermometer (optional)	0 to +150 °C • Resolution 1 °C				
Precision class	PTB: Class 1 • OIML: Class 0				

Technical Data

DITEST SPEED 2000	
Motor	Two-stroke and four-stroke diesel and petrol engines
Signal inputs	Combined AVL sensor for structure-borne noise and air-borne noise
Signal outputs	Charge signal – simulation of a terminal sensor signal Digital pulse – 5 V TTL compatible Inductive pulse – simulation of an ignition signal
Operating voltage	12 V DC, 350 mA; integrated power supply when MAHA emission tester is connected
Operating temperature	4–40 °C
Dimensions (W x H x T)	234 × 128 × 48 mm
Weight (without cable):	0.8 kg

Measurement values	
Resolution	10 rpm
Speed, petrol engine	400 – 8000 rpm
Speed, diesel engine	400–6000 rpm

Accessories	Display

MGT 300 EVO	
Display	LCD 3,5″, 320 x 240
Keypad	Softtouch Keypad
Nominal voltage	battery, LiIon, rechargeable
Dimensions	200 x 100 x 30 mm
Weight	385 g
Speed measurement range	300 – 9990 rpm
Resolution	10 rpm
Manual input	Rpm recording mode, number of cylinders, engine stroke
Interface	USB 2.0

GLOBAL PLAYER

... in more than 150 countries worldwide

Subsidiaries

Australia
Brazil
Canada
Chile
China
France
India
Ireland
Japan
New Zealand
Philippines
Poland
Russia
Serbia
Singapore
Spain
South Africa
Thailand
UK
USA
Vietnam
West Africa

MAHA Maschinenbau Haldenwang GmbH & Co. KG
Hoyen 20 · 87490 Haldenwang · Germany

Tel.: +49 8374 585 -0 · Fax: +49 8374 585 -497
Internet: www.maha.de · E-Mail: sales@maha.de

Experimental Measurements

- The readings before the catalytic converters
- Engine speed: 850 RPM
- Engine speed: 1500 RPM
- Engine speed: 2500 RPM
- Engine speed: 3500 RPM

- The readings after the first catalytic converter
- Engine speed: 850 RPM
- Engine speed: 1500 RPM
- Engine speed: 2500 RPM
- Engine speed: 3500 RPM

- The readings after the second catalytic converter
- Engine speed: 850 RPM
- Engine speed: 1500 RPM
- Engine speed: 2500 RPM
- Engine speed: 3500 RPM

Readings before the catalytic converters

Engine speed: 850 RPM

Car		Car	
Name/Co.:		License pl. no.:	
Street:		Mileage:	
Zip code, city:		Init.reg.:	/ /
Telephone:		Vehicle manuf.:	
Test date:	11/14/2015	Vehicle type:	
Time time:	10:51	Veh. chassis no.:	
		number of axles:	-

4-Gas tester

CO	0.73	% Vol.
CO_2	10.30	% Vol.
$CO_{corrected}$	0.81	% Vol.
HC	475	ppm
O_2	0.86	% Vol.
NO_X	22	ppm
Lambda	0.982	
Temperature	---	°C
rpm	0	rpm
AFR	--.--	%
Oil temp.	19	°C

Inspector: ...

Signature: ....

Readings before the catalytic converters

Engine speed: 1500 RPM

Maha Emission Software
V 7.51.007

Car		Car	
Name/Co.:		License pl. no.:	
Street:		Mileage:	
Zip code, city:		Init.reg.:	/ /
Telephone:		Vehicle manuf.:	
Test date:	11/14/2015	Vehicle type:	
Time time:	10:51	Veh. chassis no.:	
		number of axles:	-

4-Gas tester

CO	0.56	% Vol.
CO_2	12.10	% Vol.
$CO_{corrected}$	0.63	% Vol.
HC	144	ppm
O_2	1.28	% Vol.
NO_X	95	ppm
Lambda	1.040	
Temperature	---	°C
rpm	0	rpm
AFR	--.--	%
Oil temp.	19	°C

Inspector: ...

Signature: ....

Readings before the catalytic converters

Engine speed: 2500 RPM

Maha Emission Software
V 7.51.007

	Car		Car
Name/Co.:		License pl. no.:	
Street:		Mileage:	
Zip code, city:		Init.reg.:	/ /
Telephone:		Vehicle manuf.:	
Test date:	11/14/2015	Vehicle type:	
Time time:	10:51	Veh. chassis no.:	
		number of axles:	-

4-Gas tester

CO	0.28	% Vol.
CO_2	12.60	% Vol.
$CO_{corrected}$	0.36	% Vol.
HC	140	ppm
O_2	2.04	% Vol.
NO_X	276	ppm
Lambda	1.079	
Temperature	---	°C
rpm	0	rpm
AFR	--.--	%
Oil temp.	19	°C

Inspector: ...

Signature: ....

Readings before the catalytic converters

Engine speed: 3500 RPM

Car		Car	
Name/Co.:		License pl. no.:	
Street:		Mileage:	
Zip code, city:		Init.reg.:	/ /
Telephone:		Vehicle manuf.:	
Test date:	11/14/2015	Vehicle type:	
Time time:	10:51	Veh. chassis no.:	
		number of axles:	-

4-Gas tester

CO	0.20	% Vol.
CO_2	12.90	% Vol.
$CO_{corrected}$	0.34	% Vol.
HC	125	ppm
O_2	2.76	% Vol.
NO_X	805	ppm
Lambda	1.109	
Temperature	---	°C
rpm	0	rpm
AFR	--.--	%
Oil temp.	19	°C

Inspector: ...

Signature: ....

Readings after the first catalytic converter

Engine speed: 850 RPM

Maha Emission Software
V 7.51.007

Car		Car	
Name/Co.:		License pl. no.:	
Street:		Mileage:	
Zip code, city:		Init.reg.:	/ /
Telephone:		Vehicle manuf.:	
Test date:	11/14/2015	Vehicle type:	
Time time:	10:51	Veh. chassis no.:	
		number of axles:	-

4-Gas tester

CO	0.62	% Vol.
CO_2	11.50	% Vol.
$CO_{corrected}$	0.77	% Vol.
HC	113	ppm
O_2	0.56	% Vol.
NO_X	10	ppm
Lambda	1.039	
Temperature	---	°C
rpm	0	rpm
AFR	--.--	%
Oil temp.	19	°C

Inspector: ...

Signature: ....

Readings after the first catalytic converter

Engine speed: 1500 RPM

	Car		Car
Name/Co.:		License pl. no.:	
Street:		Mileage:	
Zip code, city:		Init.reg.:	/ /
Telephone:		Vehicle manuf.:	
Test date:	11/14/2015	Vehicle type:	
Time time:	10:51	Veh. chassis no.:	
		number of axles:	-

4-Gas tester

CO	0.49	% Vol.
CO_2	13.60	% Vol.
$CO_{corrected}$	0.59	% Vol.
HC	98	ppm
O_2	1.05	% Vol.
NO_X	72	ppm
Lambda	1.059	
Temperature	---	°C
rpm	0	rpm
AFR	--.--	%
Oil temp.	19	°C

Inspector: ...

Signature: ....

Readings after the first catalytic converter

Engine speed: 2500 RPM

	Car		Car
Name/Co.:		License pl. no.:	
Street:		Mileage:	
Zip code, city:		Init.reg.:	/ /
Telephone:		Vehicle manuf.:	
Test date:	11/14/2015	Vehicle type:	
Time time:	10:51	Veh. chassis no.:	
		number of axles:	-

4-Gas tester

CO	0.21	% Vol.
CO_2	14.20	% Vol.
$CO_{corrected}$	0.32	% Vol.
HC	69	ppm
O_2	1.70	% Vol.
NO_X	201	ppm
Lambda	1.085	
Temperature	---	°C
rpm	0	rpm
AFR	--.--	%
Oil temp.	19	°C

Inspector: ...

Signature: ....

Readings after the first catalytic converter

Engine speed: 3500 RPM

Maha Emission Software
V 7.51.007

	Car		Car
Name/Co.:		License pl. no.:	
Street:		Mileage:	
Zip code, city:		Init.reg.:	/ /
Telephone:		Vehicle manuf.:	
Test date:	11/14/2015	Vehicle type:	
Time time:	10:51	Veh. chassis no.:	
		number of axles:	-

4-Gas tester

CO	0.10	% Vol.
CO_2	14.90	% Vol.
$CO_{corrected}$	0.30	% Vol.
HC	57	ppm
O_2	2.30	% Vol.
NO_X	585	ppm
Lambda	1.112	
Temperature	---	°C
rpm	0	rpm
AFR	--.--	%
Oil temp.	19	°C

Inspector: ...

Signature: ....

Readings after the second catalytic converter

Engine speed: 850 RPM

Maha Emission Software
V 7.51.007

Car		Car	
Name/Co.:		License pl. no.:	
Street:		Mileage:	
Zip code, city:		Init.reg.:	/ /
Telephone:		Vehicle manuf.:	
Test date:	11/14/2015	Vehicle type:	
Time time:	10:51	Veh. chassis no.:	
		number of axles:	-

4-Gas tester

CO	0.47	% Vol.
CO_2	11.70	% Vol.
$CO_{corrected}$	0.65	% Vol.
HC	60	ppm
O_2	0.31	% Vol.
NO_X	6	ppm
Lambda	1.081	
Temperature	---	°C
rpm	0	rpm
AFR	--.--	%
Oil temp.	19	°C

Inspector: ...

Signature: ....

Readings after the second catalytic converter

Engine speed: 1500 RPM

	Car		Car
Name/Co.:		License pl. no.:	
Street:		Mileage:	
Zip code, city:		Init.reg.:	/ /
Telephone:		Vehicle manuf.:	
Test date:	11/14/2015	Vehicle type:	
Time time:	10:51	Veh. chassis no.:	
		number of axles:	-

4-Gas tester

CO	0.46	% Vol.
CO_2	14.30	% Vol.
$CO_{corrected}$	0.55	% Vol.
HC	59	ppm
O_2	0.98	% Vol.
NO_X	49	ppm
Lambda	1.091	
Temperature	---	°C
rpm	0	rpm
AFR	--.--	%
Oil temp.	19	°C

Inspector: ...

Signature: ....

Readings after the second catalytic converter

Engine speed: 2500 RPM

Maha Emission Software
V 7.51.007

Car		Car	
Name/Co.:		License pl. no.:	
Street:		Mileage:	
Zip code, city:		Init.reg.:	/ /
Telephone:		Vehicle manuf.:	
Test date:	11/14/2015	Vehicle type:	
Time time:	10:51	Veh. chassis no.:	
		number of axles:	-

4-Gas tester

CO	0.19	% Vol.
CO_2	15.70	% Vol.
$CO_{corrected}$	0.31	% Vol.
HC	43	ppm
O_2	1.52	% Vol.
NO_X	146	ppm
Lambda	1.106	
Temperature	---	°C
rpm	0	rpm
AFR	--.--	%
Oil temp.	19	°C

Inspector: ...

Signature: ....

Readings after the second catalytic converter

Engine speed: 3500 RPM

Car			Car
Name/Co.:		License pl. no.:	
Street:		Mileage:	
Zip code, city:		Init.reg.:	/ /
Telephone:		Vehicle manuf.:	
Test date:	11/14/2015	Vehicle type:	
Time time:	10:51	Veh. chassis no.:	
		number of axles:	-

4-Gas tester

CO	0.09	% Vol.
CO_2	16.10	% Vol.
$CO_{corrected}$	0.28	% Vol.
HC	25	ppm
O_2	1.76	% Vol.
NO_X	342	ppm
Lambda	1.153	
Temperature	---	°C
rpm	0	rpm
AFR	--.--	%
Oil temp.	19	°C

Inspector: ...

Signature: ....