Palestine Polytechnic University

College of Engineering and Technology

Mechanical Engineering Department

Graduation Project

Controlling Toxic Emission Exhaust in vehicle Using Chemically Modified Catalytic Converter

Project Team

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June- 2014

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According to the project supervisor and according to the agreement of the Testing Committee Members, this project is submitted to the Department of Mechanical Engineering at College of Engineering and Technology in partial fulfillments of the requirements of (B.SC) degree.

Supervisors Signature

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Examine Community Signature

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Department Head Signature

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June- 2014

Dedication

To our parent who

Spent nights and days doing their best

To give us the best …

To all student and who

Wish to look for

The future…

To who love the knowledge and

Looking for the new

In this world …

To our beloved country Palestine …

To all of our friends …

Acknowledgement

First of all, we would like to thank our god for the help to complete this work successfully, and we would like to acknowledge and thank Palestine polytechnic university for the effort they had done in order to facilitate our work.

We would like to thank our supervisors Dr. Maher Al-Jabari and Dr. Zuhdi Salhab for this help and continuous encouragement to the team work.

Our project is a result of hard work and participation among us "project team" and our supervisors who gave us all there energy and experience in order to pass this project.

Finally, we would like to thank our families because of their support and encouragement through our study time, then we want to thank our friends and any one help us to finish this work.

ABSTRACT

Exhaust gas pollutants emitted to the atmosphere are seriously hygienic and environmental risk. This project 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 NOx 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. We 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.

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Abbreviation

Abbreviations	Description
SIE	Spark ignition engine
CIE	Compression ignition engine
NO_X	Nitrogen oxide
CO	Carbon monoxide
UHC	Unburned hydrocarbon
PM	Particulate matter
A/F	Air fuel ratio
EGR	Exhaust gases recirculation
PVC	Positive crank case ventilation
λ	Ratio of actual A/F to stoichiometry
H_2O	Hydrogen
CO_2	Carbon dioxide
VOC_S	Volatile organic compound
NO_2	Nitrogen dioxide
EVAP	Evaporation emission control
O_3	Ozone
HC	Hydrocarbon
BaO	Barium oxides

Rh	Rhodium
Pt	Platinum
SCR	Selective catalyst converter
CPU	Central processing unit
ECU	Electronic control unit
IDE	Integration development environment
$Ag_n^{\delta+}$	Silver Clusters
MIPS	million-instructions-per-second
UV-vis	Ultraviolet-Visible
FTIR	Fourier transform infrared spectroscopy

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Chapter One

Introduction

1.1 Introduction

The development of the cars technology in the last years and competition between automotive company to give the customer more power and more comfort cars, causes increasing the number of vehicle largely over the world, resulting to increasing the emissions exhaust from the vehicle.

Spark-ignition engines (SIE) and compression ignition engines (CIE) are a major source of urban air pollution and disease to humanity; (CIE) exhaust gases contain oxides of nitrogen (NO_x), carbon monoxide (CO), organic compounds such as unburned hydrocarbon (UHC) and particulate matter (PM).

Various operational parameters affect the NO_x and CO emission concentration such as temperature, air fuel ratio (A/F), engine speed, load and ignition (injection) timing.

Recently many methods are used to solve the emission problem such as exhaust gas recirculation (EGR), fuel tank canister purge, secondary air injection pump, catalytic converter, positive crank case ventilation (PVC).

1.2 Background

The emission problem is one of the most interesting challenges in automotive technology and it is reached at alarming level. Because exhaust pollutants emitted to atmosphere by automobiles are the serious hygienic and environmental risk and the main source of air pollution, particularly in developing countries, the greatest interest and attention was devoted to use an effective technique to reduce the level of these pollutants.

Vehicle emission contribute to the increasing concentration of gases that are leading to climate change and diseases to humans, The emission from the petrol and diesel combustion engine include carbon monoxide (CO), partially burnt fuel is present in the exhaust gases forming complex of compound unburned hydrocarbons (UHC), particulate matter (PM), and nitrogen oxides (NO_x) are also product and especially prevalent in diesel exhaust.

The concentrations of emissions produced by engine, affected by the operating parameters are illustrated in these following statements:

- There is an optimum concentrated of urea compound injected in the exhaust manifold which will react with NO_x and CO emission inside catalytic converter.
- Air fuel ratio (A/F) (which effects on both the gas temperature and the oxygen concentration in the burned gases). Increasing A/F will increase the rate of NO_x to peak value when the A/F about 16, then the rate of NO_x will be decreased after the peak value when A/F still increase.
- At rich ($\lambda < 1$) mixture the concentration of CO attains high rate. Increasing A/F when ($\lambda > 1.25$), increasing the rate of CO.
- The temperature of the exhaust gasses affects the concentration of NO_x and CO emissions. When the temperature increases, concentration the NOx and CO increase. The CO_2 is dissociated at high temperature according equation (1.1):

$$CO_2 \rightarrow CO + \frac{1}{2} O_2 \qquad (1.1)$$

- Increasing engine speed reduces the total heat transfer from burned gases, resulting in increasing NO_x, and decreasing UHC.
- Exhaust gas recirculation (EGR) causes a reduction in the combustion temperature which results in decreasing NO_x and CO levels.

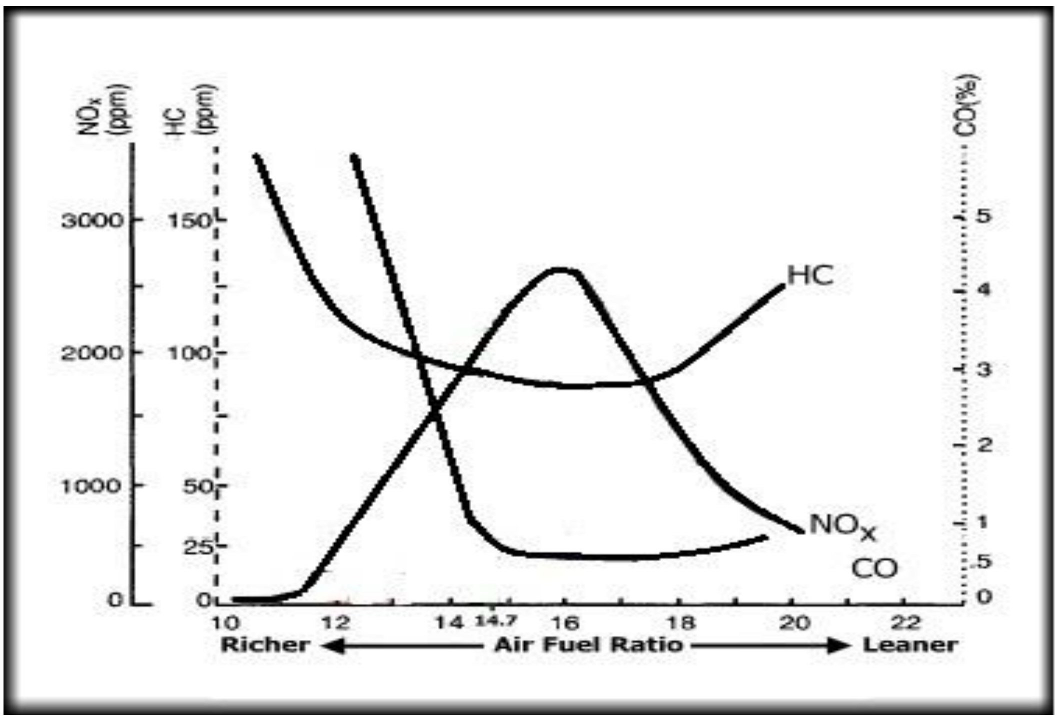

Figure (1.1): The relationship between the rates of NOx, CO, HC concentration with air fuel ratio.

1.3 Problem of Statement

- Main problem

  Experimental study for investigation the effects of operation parameter for reducing concentration of NO_x and CO emission from CIE in vehicle using chemically modified catalytic converter by urea injection .

- Sub problem

1. Confirming the technical feasibility of modifying catalytic converter by using urea injection.
2. Studying the effect of operating parameters on the efficiency of catalytic converter. These include:

    - Injection concentration amount.
    - Temperature.
    - A/F.
    - Engine speed.
    - Ignition (injection) timing.

1.4 Research Hypothesis

- Adding a urea compound in the exhaust system reduces the emissions concentration NOx and CO from internal combustion engine.
- Decreasing the temperature of the exhaust gases reduce the NO_x and CO concentration.
- Decreasing A/F reduces the rate of NO_x, while increasing A/F will decrease the rate of CO.
- Control system affects positively the system efficiency.

1.5 Goal and Objectives

The main goals is to design and build an experimental model to measure and reduce the toxic gases exhaust from internal combustion engine (CIE) by using a selected urea compound injected into exhaust manifold before entering catalytic converter, this includes monitoring and controlling the inlet and outlet streams by installing sensors at the inlet and outlet of the catalytic converter, and a control unit.

The project targets the following specific objectives:

- Designing a control system that operates the system practically with engine parameters conditions.
- Building experimental setup for evaluation of catalytic converter efficiency for diesel engine.
- Confirming the technical feasibility of the experimental system.

- Performing experiments to evaluate proportion emission exhaust from the internal combustion engine utilizing sensors.
- Studying the effect of operating parameter on emission concentration such as air fuel ratio, temperature and engine speed.
- Analyzing the results and verifying it to obtain scientific paper.

1.6 Project Scope

The scope of the project includes the following main topics:

- Evaluation of the effect of operational parameters on the chemical reaction performance in the catalytic converter.
- Reducing the effect of the emissions on the environment and public health.
- Designing and building practical setup including microcontroller to control the system, sensors at the inlet and outlet to measure the proportion of toxic gas, adding some of material such as (urea compound) in the exhaust system by using suitable injector.
- Develop a catalytic converter by adding some of material
- Reviewing the scientific background about what has been done in this branch.

1.7 Significance of Study

- This study is useful for environment and global warming.
- The current study is important for human health.
- Investigation of the effect of operation parameters for reducing the emission concentration.
- Applying the control system technology to control the NO_x and CO concentrations.
- Developing a catalytic converter to operate more efficiently.

1.8 Methodology and Implementation Plan and Time Table

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

- Planning and setting project concept and goals.
- Establishing scientific background.
- Reviewing varieties of experimental setups to identify the operational parameter effect the NO_x and CO concentration.
- Literature review.
- Proposing a suitable experimental setup design.

In the second (semester) stage, the following tasks are implemented

- Preparing the internal combustion engine.
- Buying mechanical and electrical parts.
- Building experimental setup.
- Write a project program code for control system.
- Check the project parts and perform initial experiments.
- Preform final experiments.
- Analyze the experimental results.

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Time table 1

This page for time table

Time table 2

1.9 Project Budget

The total estimated cost for implementing this project is estimated at 1720 $ as detailed in Table (1.3).

Table (1.3): The total estimated cost for implementing the project

NO.	Item	Quantity	Unit Cost ($)	Total cost ($)
1	Catalytic Converter	1	200	200
2	CO Sensor	2	100	200
3	NO_x Sensor	2	200	400
4	Pressure Sensor	1	80	80
5	Pressure Regulator	1	60	60
6	Hydrocarbon Compound		50	50
7	Pump	1	50	50
8	Microcontroller	1	100	100
9	Injector	1	300	300
10	Cost of Printing and Imaging		30	30
11	Other Costs		250	250
	Total Estimated Costs			1720

Chapter Two

Literature Review

2.1 Introduction

2.2 Internal Combustion Engine

2.3 Air Pollution from Cars

2.4 Exhaust Emission Control

2.5 Catalytic Converter

2.6 Injection Catalytic Converter

2.1 Introduction

This chapter is concerned with literature review for many topics with respect to internal combustion engine and formation of exhaust gas emission. The literature review explores many topics include air pollution and studies of impact of the gas emission on the environment, climate change and human health. Review studies related to exhaust emission control to reduce toxic emission concentration such as EGR, Injection Timing, Secondary air injection system and explore the parameter that may has impact on the gas emission concentration, review studies about catalytic converter types and performance to convert gas emission into less harmful gas, and examine the catalytic injection system and the development of this system.

2.2 Internal Combustion Engine

The internal combustion engine is an engine in which the combustion of a fuel occurs with air in a combustion chamber. In an internal combustion engine (ICE) the expansion of the high-temperature and high-pressure gases produced by combustion apply direct force to some component of the engine. The force is applied typically to pistons, this force moves the component over a distance, transforming chemical energy into useful mechanical energy.

Four-stroke internal combustion engines have four basic steps that repeat with every two revolutions of the engine (in 4-stroke engine): (1) Intake/suction stroke (2) Compression stroke (3) Power/expansion stroke and (4) Exhaust stroke [1].

2.2.1 Spark Ignition and Compression Ignition Engines

Spark ignition engines use A/F mixture that is compressed at high pressure. At this high pressure the mixture has to be near stoichiometric to be chemically inert and able to ignite. So the mixture in order to ignite needs not to be either with too much fuel or too much air but rather have an overall even amount.

Compression ignition engines differ from spark ignition engines in a variety of ways but the most obvious one being the way in which the air and fuel mixture is ignited. As stated above a spark plug is used to create a spark in the combustion chamber which ignites the mixture. In a compression ignition engine there is no spark to create the flame but rather high temperatures and pressures in the combustion chamber cause a flame to initiate at different sites of the combustion chamber. Combustion increases with increasing pressure and temperature. Diesel engines require fuel injection systems to inject fuel into the combustion chamber. Fuel injection systems are either linear or rotary. Rotary fuel injectors are used in indirect ignition engines because of low pressures.

Direct injection engines use pressures of up to 1000 bars to inject fuel into the combustion chamber. High pressure is needed because the heat addition process takes place at a compressed state, so in order to inject the fuel well the pressure has to be greater than the one that has been accumulated through compression.

Indirect ignition engines have a pre-combustion chamber where the air to fuel mixture is first stored. The purpose of the separate chamber is to speed up the combustion process in order to increase the engine output by increasing the engine speed. The two basic combustion systems are the swirl and pre-combustion chambers. Pre-combustion chambers depend on turbulence to increase the combustion speed and swirl chambers depend on the fluid motion to raise combustion speed. In divided chambers the pressure required is not as high as the pressure required for direct ignition engines. The pressure required for both type of divided chambers is only about 300 bars [1].

2.2.2 Combustion Reactions

Internal combustion engines obtain their energy from the combustion of hydrocarbon fuel with air. The chemical energy stored in the fuel is converted to energy that the engine can use in the through hot gases within the chamber. The combustion process involves the chemical reaction of hydrocarbon fuel with oxygen to produce water vapor and CO_2. The maximum amount of chemical energy from the hydrocarbon fuel is when it reacts with stoichiometric oxygen. The meaning of stoichiometric oxygen is defined as the theoretical amount of oxygen that is needed to convert all of the carbon in the fuel to CO_2 and all of the hydrogen to H_2O.

The hydrocarbon reacts with air which is composed of many substances. Nitrogen and oxygen are the two most found substances in air with a nitrogen composition of 79%, by mole, and oxygen composition of 21%. The stoichiometric combustion of isooctane with air is shown in equation (2.1):

$$C_8H_{18} + 12.5O_2 + 12.5\,(3.76)\,N_2 \rightarrow 8\,CO_2 + 9\,H_2O + 12.5\,(3.76)\,N_2 \qquad (2.1)$$

Combustion can occur with an either lean or rich mixture. If the mixture is for example 150% of stoichiometric then there will be an excess amount of air and the products will involve excess oxygen. This is called a lean mixture since there is a deficiency in fuel; the lean mixture equation is shown in equation (2.2) where λ is greater that 1:

$$C_\alpha H_\beta + \lambda\,(\alpha+\frac{\beta}{4})\,(O_2 + 3.76N_2) \rightarrow a\,CO_2 + b\,H_2O + d\,N_2 + e\,CO \qquad (2.2)$$

If on the other hand the mixture is 80% of stoichiometric then there will be excess fuel (because of air deficiency) and CO will be in the end product. This is a rich mixture since the mixture has excess of fuel, the rich mixture equation indicated in equation (2.2) which λ is less that 1 [1].

2.2.3 Formation of Undesirable Emission Products

CO is a colorless, odorless, poisonous gas which can be further burned to form CO_2. If there is a further deficiency in oxygen then more CO will go into the atmosphere as pollution. Results from the combustion in insufficient oxygen of a fuel that contains carbon. The normal combustion route is that, when a hydrocarbon fuel and oxygen interact, carbon monoxide is preferentially formed, followed by water, with the carbon monoxide then being oxidized to carbon dioxide by any remaining oxygen. If the oxygen exists in less than stoichiometric proportions, this final process is incomplete with some of the molecules remaining as CO. Carbon is a fuel that can be combusted to supply additional thermal energy as shown if equation (2.3):

$$CO + \frac{1}{2}\,O_2 \rightarrow CO_2 + \text{heat} \qquad (2.3)$$

At the high temperatures and pressures that exist during the combustion process, significant quantities of CO form even when there is sufficient oxygen for complete combustion to occur. This is due to dissociation of the CO_2 molecules into CO and O_2 because of the high temperature molecular vibration. Maximum CO is generated when an engine runs rich. Rich mixture is required during starting or when accelerating under load. Even when the intake air –fuel mixture is stoichiometric or lean, some CO will be generated in the engine. Poor mixing, local rich regions, and incomplete combustion will also be the source for CO emissions [2].

NO_x formation is a highly temperature dependent phenomenon. It occurs because the equilibrium concentrations of the various NOx compounds formed when oxygen and nitrogen coexist at high temperatures of 2000 to 3000 K are significant but are almost negligible at ambient temperatures of 300 K.

The forward reaction forming NOx compounds is reasonably fast (due to the high temperatures) and the reaction moves substantially, though usually not completely toward equilibrium in the time available under most engine operating conditions. There are a number of possible reactions that form NO shown in equations below:

$$O + N_2 \rightarrow NO + N \quad (2.4)$$

$$N + O_2 \rightarrow NO + O \quad (2.5)$$

$$N + OH \rightarrow NO + H \quad (2.6)$$

NO can further react to form NO_2 by various means, including:

$$NO + H_2O \rightarrow NO_2 + H_2 \quad (2.7)$$

$$NO + O_2 \rightarrow NO_2 + O \quad (2.8)$$

shows that values reach about 90 percent of the equilibrium condition at engine combustion temperatures in about 15 ms. The backward (or reverse) reaction during which the NOx breaks up into N_2 and O_2 is much slower (due to the gas cooling) and the NOx is at least partially frozen (retained as NO_x for a long period after it is exhausted from the engine). This gives it time to react with other substances such as the UHC compounds and ozone 03, aided by the presence of sunlight, to form photochemical smog, which is very persistent [3].

HC general mechanisms for producing HC are included in these following brief statements, when the fresh mixture is stored in combustion chamber crevices which are released during the expansion and exhaust processing. Part of fuel is absorbed in oil layer during intake and compression processes and then is desorbed after normal combustion. In certain condition a liquid part of fuel has no time to be evaporated and mixed with air in intake and compression stroke, and when the flame quenches at a finite distance from cold wall surface of combustion chamber. Sometime fresh mixture escapes from combustion chamber through exhaust valve during compression and combustion processes [2]

PM formation from CIE contains solid carbon soot particles that are generated in the fuel-rich zones within the cylinder during combustion. Maximum density of particulate emissions occurs when the engine is under load at wide open throttle. At this condition maximum fuel is injected to supply maximum power, resulting in rich mixture and poor fuel economy.

Soot particles are clusters of solid carbon spheres. These spheres have diameters from 9 nm to 90 nm. The spheres are solid carbon with HC and traces of other components absorbed on the surface. Carbon spheres are generated in the combustion chamber in the fuel rich zones where there is enough oxygen to convert all carbon to CO_2:

$$C_x H_y + z O_2 \rightarrow a CO_2 + b H_2O + c CO + d C \qquad (2.9)$$

Up to about 25% of the carbon in soot comes from lubricating oil components which vaporize and then react during combustion [2].

2.3 Air Pollution Impact

Emissions from land transport and from road transport in particular, have significant impacts on the atmosphere and on climate change. Emissions from land transport, impacts on the atmospheric composition, air quality, human health and climate change.

2.3.1 Impacts on Greenhouse Gases and Climate Change

The greenhouse effect that is caused by CO_2 emission from internal combustion engine, when pollution goes into the upper layers of the earth's atmosphere it gets trapped and becomes what is called a greenhouse gas. Too much greenhouse gases in the earth's atmosphere make it so that the sun's rays can't bounce off the earth and back into space. This in turn makes it so the earth is slowly becoming warmer and warmer. Eventually if not stopped the earth will get to hot and destroy all the ecosystem across the globe, along with causing extreme weather events to happen across the globe to. If this problem is not stopped soon it will make the world inhabitable for humans [4].

By predicting how the global climate will respond to various perturbations, projections can be made to determine how global climate will change under different conditions, CO_2 levels are predicted to increase over the 21th century from 369 ppm, to between 540 and 970 ppm. This translates to an increase in globally averaged temperatures of between 1.4 and 5.8 °C in turn leading to an increase in extreme weather events and a rise in sea levels. The growth in CO_2 emissions is unsustainable and will soon exceed the level required for stabilization (currently estimated to be in the region of 400–450 ppm). It is this inertia that means that some impacts of anthropogenic climate change may yet remain undetected and will ensure that global warming will continue for decades after stabilization [5].

2.3.2 Tropospheric Air Pollution

Tropospheric air pollution has impacts on scales ranging from local to global. Reactive intermediates in the oxidation of mixtures of volatile organic compounds (VOCs) and NO_x play central roles: the hydroxyl radical (OH), during the day; the nitrate radical (NO_3), at night; and ozone (O_3), which contributes during the day and night. Halogen atoms can also play a role during the day. Here the implications of the complex VOC-NO_x chemistry for O_3 control are discussed. In addition, OH, NO_3, andO_3 are shown to play a central role in the formation and fate of airborne toxic chemicals, mutagenic polycyclic aromatic hydrocarbons, and fine particles [6].

2.3.3 Impact on Ozone

For atmospheric chemistry, the main concern related to land transport derives from emissions of nitrogen oxides mainly NO_x = NO+ NO_2, which are precursors of ozone and thus affect the oxidizing capacity of the atmosphere. The ozone production efficiency per emitted NO_x molecule decreases at higher NO_x levels as shown in equation (2.10). At very high NO_x concentrations ozone titration becomes important:

$$NO + O_3 \rightarrow NO_2 + O_2 \qquad (2.10)$$

This can lead to a local reduction of ozone in high NO emission areas. However, further downwind from road traffic or in case of direct NO_2 emission from vehicles with particle filters ozone is increased [7].

The potential effects of a global increase in O_3 and other photochemical oxidants are Far-ranging. Ozone is a source of the hydroxyl radical (OH), which reacts rapidly with most air pollutants and trace species found in the atmosphere. Hence, increased concentrations of O_3 might be expected to lead to increased OH concentrations and decreased lifetimes of globally distributed compounds such as methane. Because both O_3 and methane are greenhouse gases, this chemistry has implications for global climate change. In addition, changes in O_3 levels can affect the levels of ultraviolet radiation to which we are exposed [6].

2.3.4 Impact on Acid Rain

Nitrogen deposition and acid rain are enhanced through road traffic emissions of NO_x, CO and sulphur components. NO_x from road traffic is converted into nitric acid as shown in equation (2.11), which is highly water soluble and washed out, leading to nitrogen deposition.
This reaction can counteract the OH enhancement due to NO_x emissions from road traffic, especially under low-sunlight conditions [7].

$$NO_2 + OH \rightarrow HNO_3 \qquad (2.11)$$

Acid rain is slowly destroying habitats and planet life across the nation. It causes bodies of water to acidify, and make it unstable for fish and other wildlife to survive in. It also damages trees and the soil so that no more planets can grow in the soil, along with killing the ones that are already there [6].

2.3.5 Impact on Health.

Emissions are a major contributor to degradation of air quality and pose a risk to human health risk. Table (2.1) summarizes the impact of toxic emission on human health

Table (2.1): Impact on health [8]

NAME	**PHYSIOLOGICAL EFFECTS ON HUMANS**	
	ACUTE EFFECTS	**CHRONIC EFFECTS**
1. Carbon Dioxide (CO_2)	. Carbon monoxide reduces the volume of oxygen that enters the bloodstream and can slow reflexes.	Cause drowsiness, impair judgment and vision and even cause death.
2. Carbon Monoxide (CO)	Asphyxiation, heart and brain damage, impaired perception.	Increased red blood cells (polycythemias) in blood, leading to increased resistance to blood to flow, weakness fatigue, and headaches.
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; this leads to tissue fluid accumulation and swelling (edema),	Contributes to and aggravates lung diseases like chronic bronchitis, pulmonary fibrosis via irritation leading to decreased 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 (SPM)	Effect varies depending on nature and size of particles. Can cause irritation, altered immune defense, or systematic toxicity.	Depending on the nature and size of the particles can cause decreased pulmonary function and stress on the heart.

2.4 Exhaust Emission Control

The technologies or methods that are used to control the exhaust emissions are either direct engine-related methods, called primary methods, since they affect the emissions at the source of formation, or secondary methods after treatment methods that convert the pollutants created during combustion after they have left the combustion chamber completely or partially into harmless substance.

2.4.1 Exhaust Gas Recirculation.

The EGR system recirculates a fraction of exhaust gases into the intake manifold where it mixes with the fresh incoming charge. By diluting the air fuel charge, peak combustion temperatures and pressures are reduced resulting in a reduction of NOx concentration.

The EGR systems shown in figure (2.1) work with EGR valve which recycle exhaust gases into intake systems. Exhaust gases have already combusted, so they do not burn again when they are recycled. These gases displace some of the normal intake charge. This chemically slows and cools the combustion process by several hundred degrees, thus reducing NOx formation. The decrease in NOx emissions with increasing EGR rate [9]

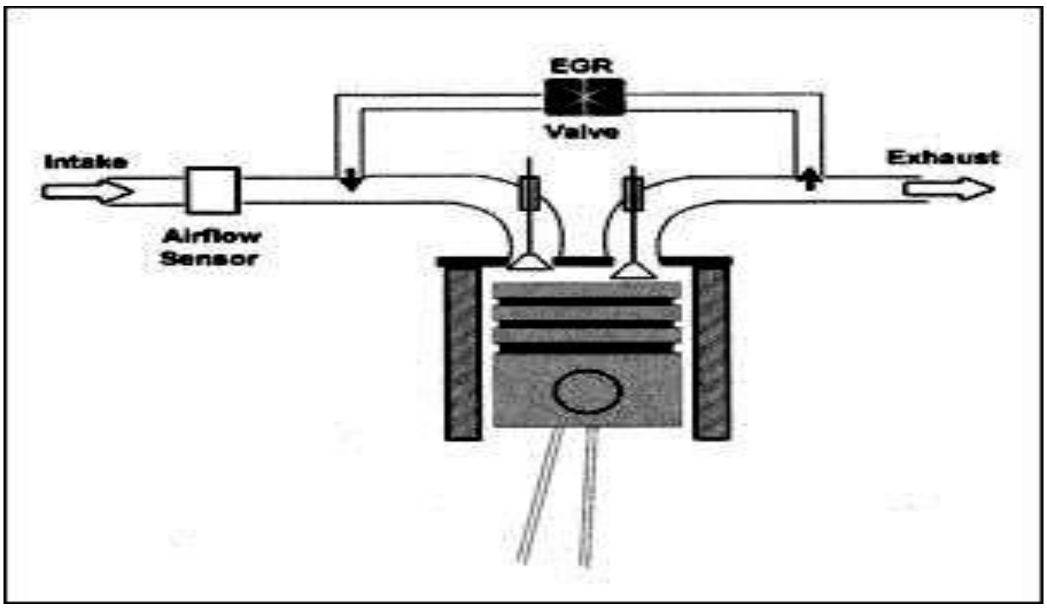

Figure (2.1): Principle operation of EGR.

2.4.2 Injection Timing

The NOx 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 NOx is related more closely to the early combustion phase around TDC, where the temperatures are high [10].

2.4.3 Catalytic Converter

Catalytic converter was introduced and this is now the most common method of exhaust emission control .The catalyst materials which will reduce the NOx and which will oxidize the CO and UHC. The noble metals of platinum, palladium, and rhodium provide a suitable combination, although a base metal combination is also possible but with less efficiency. The use of such an oxidizing-reduction system in the one bed is known as a three-way system as shown in figure (2.2). That is, it handles all three of the major emissions in the one bed. This is now the most commonly used approach to exhaust cleanup [11].

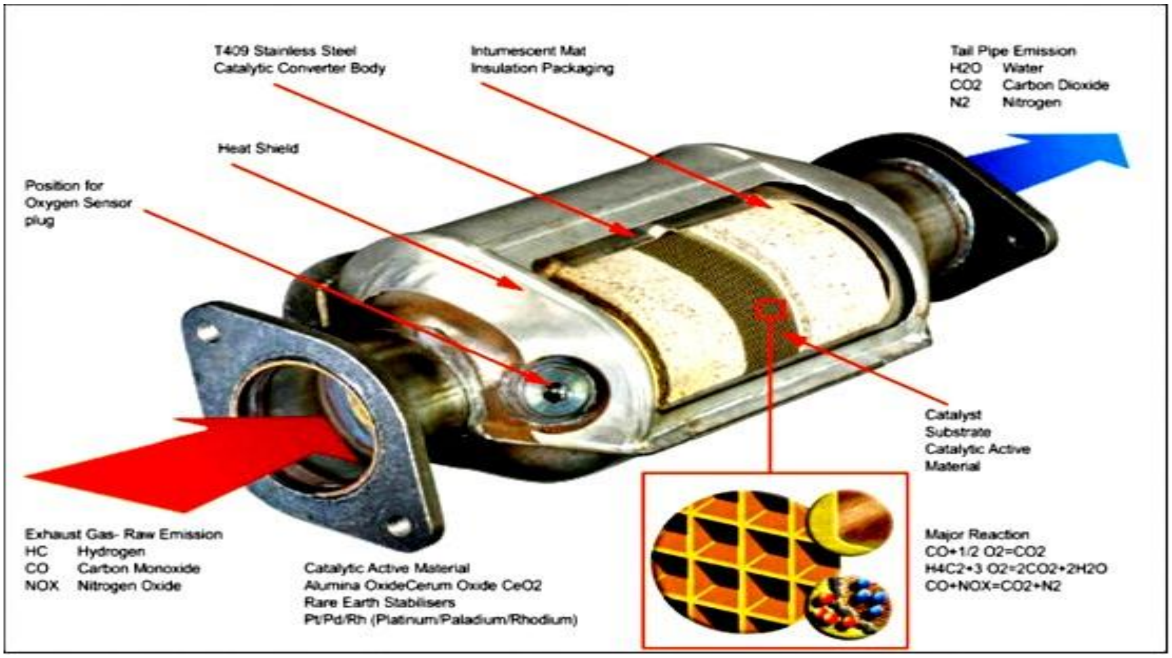

Figure (2.2): Catalytic converter.

2.4.4 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 (2.3) is used to introduced air into the exhaust flow, thereby allowing combustion to continue well into the exhaust system .This prolonged combustion period help to lower the level of UHC and CO emission that are 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 [12].

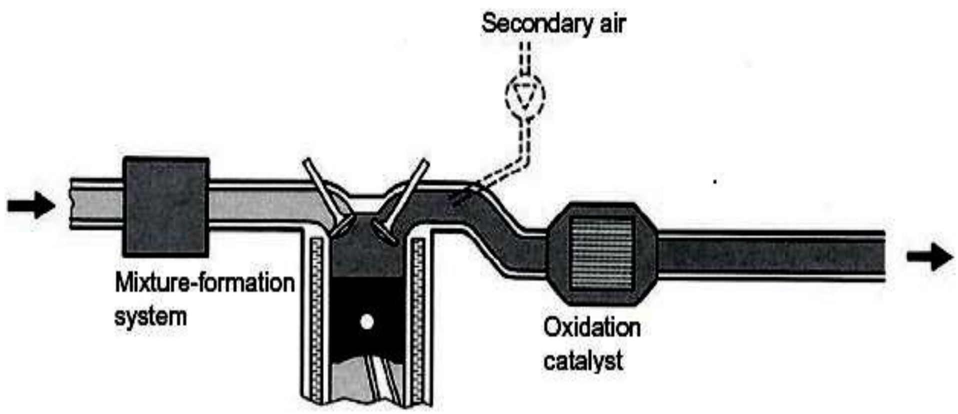

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Figure (2.3): Secondary air injection system.

2.4.5 Evaporation Emission Control System

Approximately 20% of all hydrocarbon (HC) emission from automobile originates from evaporative source. The Evaporative emission control (EVAP) is design to store and dispose of fuel vapor normally is created in the fuel system; thereby, preventing its escape to the atmosphere. 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 a fully closed system designed to maintain stable fuel tank pressures without allowing fuel vapors to escape to the atmosphere. Fuel vapor is normally created in the fuel tank as a result of evaporation. It is then transferred to the EVAP system charcoal canister when tank vapor pressure becomes excessive [13].

2.4.6 Overview for Emission Control Method

The Methods that are used to control toxic emission uses variable principal to achieve it.

- Reduce the toxic emission left the combustion engine into less harmful substance such as catalytic converter.
- Recycle the portion of gas into intake manifold where it mixes with fresh incoming charge and burn with the fuel inside the combustion chamber.
- Replace the type of fuel by using suitable fuel (unleaded, low sulpher)
- Reuse the exhaust gas energy to drive the turbo charger to improve performance and reduce emission

2.5 Catalytic Converter

A catalytic converter is a vehicle emissions control device which converts toxic products of combustion in the exhaust of an internal combustion engine to less toxic substances by catalytically chemical reactions. In a catalytic converter, the catalyst (in the form of platinum and palladium) is coated onto ceramic beads that are housed like package attached to the exhaust pipe. The catalyst helps to convert carbon monoxide into carbon dioxide. It converts the hydrocarbons into carbon dioxide and water. It also converts the nitrogen oxides back into nitrogen and oxygen. Two main types of catalytic converter: (1) Two-way catalytic converter (2) Three-way catalytic converter [14].

A two-way ("oxidation") catalytic converter has two simultaneous tasks:

1. Oxidation of carbon monoxide to carbon dioxide:

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

2. Oxidation of hydrocarbons (unburnt and partially burnt fuel) to carbon dioxide and water (a combustion reaction):

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

A three-way catalytic converter has the additional advantage of controlling the emission of nitrogen oxides NO_x, and has three simultaneous tasks:

1. Reduction of nitrogen oxides to nitrogen and oxygen:

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

2. Oxidation of carbon monoxide to carbon dioxide:

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

3. Oxidation of unburnt hydrocarbons (HC) to carbon dioxide and water:

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

2.5.1 NOx Storage Catalytic Converter

The three-way catalyst is inactive when excess oxygen is present in the exhaust gas. The new concept for the removal of NOx from a lean-burn engine calls the NOx storage catalyst. This technology involves NOx adsorption during lean conditions and, then, NOx reduction when the engine is turned to rich modes for a short period [15].

The NOx storage catalyst consists of three key components:

- oxidation catalyst Platinium (Pt)
- NOx storage medium Barium Oxides (BaO)
- a reduction catalyst Rhodium (Rh).

The overall fundamentals of NOx adsorption and reduction processes are illustrated in Figure (2.4) [22]

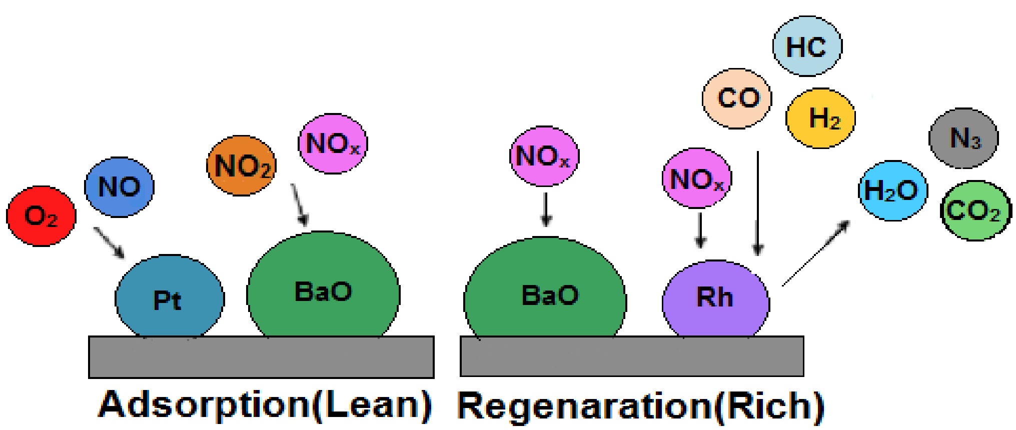

Figure (2.4): The overall fundamentals of NO_x adsorption and reduction processes.

The NOx storage catalyst can make traditional TWC active properly for lean-burn. Operation engines; however, there are a number of other possible problems reported in the literature. Sulphur compounds that are present in the exhaust react with a NOx storage medium to form sulphates which accumulate gradually on the active catalyst surface during lean conditions. This makes the NOx storage medium saturated with sulphates and lost active sites for NOx adsorption. Although sulphates can be thermally decomposed, high temperatures (T>600 °C) are required to disulphate under rich conditions because they are more stable than corresponding nitrates on the storage medium [16]

2.5.2 Selective Catalytic Converter (SCR) Reduction

By using the method of SCR, NOx contained in the exhaust gas can be converted to N_2 when it reacts catalytically with a reductant such as ammonia, urea, oxygenated hydrocarbon and hydrocarbon in the presence of a catalyst as illustrated in equation (2.17). Unlike the NOx storage catalyst, SCR removes NOx continuously through the active reductant on the catalyst surface.

$$NO_2 + NO + 2NH3 \rightarrow 2N_2 + 3H_2O \qquad (2.17)$$

As reported by many researchers, the advantage of SCR over the NOx storage catalyst is that it is effective in the different kinds of reductants such as urea, oxygenated hydrocarbons and hydrocarbons, catalyst materials as ion-exchanged zeolites, Pt and Ag. Moreover, the SCR has been reported to have moderate tolerance to poisoning from sulphur [17]

2.5.3 Promotion Effect of Hydrogen on Hydrocarbon-SCR

Hydrogen is widely considered as an ideal co-feeder gas in active mode such as injected HCs (HC-SCR) operation in order to decrease the minimum temperature needed to drive the NOx-reducing reactions. Hydrogen promotes indirectly the SCR-NOx reduction through the changes in some states of the active catalyst but hydrogen itself is not active as it is neither a reducing agent nor an intermediate species.

Research studies show the effect of H_2 and CO during the SCR of NOx over a silver/alumina catalyst by using in-situ ultraviolet-visible (UV-vis) and Fourier transform infrared spectroscopy (FTIR) spectroscopy techniques. They found that the formation of silver cluster ($Ag_n^{\delta+}$) clusters was observed in both H_2 and CO as the co-reductant but the promotion of NOx reduction was found only in the case of H_2.

They concluded that the promotional effect of H_2 on the NOx reduction activity at low temperature did not relate to the formation of $Ag_n^{\delta+}$clusters. However, they also suggested that hydrogen itself participates in the NOx reduction processes with a chemical function resulting in the acceleration of critical SCR-NOx reaction steps [18].

2.5.4 Performance of Catalytic Converter

The performance of the catalytic converter is substantially affected by the flow distribution within the substrate. A uniform flow distribution increases the efficiency, causes less pressure drop and increases engine performance. Flow distribution in converter assembly is controlled by the geometry configurations of inlet and outlet cones, the substrate and exhaust gas compositions. Hence better design of the catalytic converter is necessary. The analysis shows that the flow field in the catalytic converter is influenced by the flow resistance of the substrate for a given geometric configuration.

As the mass flow rate increases the pressure drop also increases. The conversion efficiency depends upon the substrate temperature and composition of the inlet. By increasing the temperature the conversion efficiency also increases. At lower temperature the catalytic converter will be inactive. The heat release due to chemical reaction does not play a significant role [19].

2.6 Injection Catalytic Converter

One of the exhaust emission control systems is catalytic injection. Originally, this system was used to inject chemical compound into the exhaust ports to provide oxidation reaction in the catalytic converter to reduce emissions.

2.6.1 Urea Injection

Urea $CO(NH_2)_2$ is an organic chemical compound which essentially is waste produces when the body metabolizes protein. It is a compound not only produces by human but also by many other mammals, as well as amphibians and some fish.

Synthetic urea is created from synthetic ammonia (NH_3) and carbon dioxide (CO_2) and can be produced as a liquid or a solid.it turns out that urea, which is being sold under the more marketable name “ diesel exhaust fluid” is also a chemically efficient way to reduce nitrogen oxide emission

Urea is injected into the hot exhaust-gas flow ammonia and carbon dioxide is formed from it through a decomposition reaction as shown in equation (2.18). The ammonia generated in this way is then available in the SCR arranged downstream. During the conversion of ammonia with the nitrogen oxides in the exhaust gas, reaction takes place, with $H_2O$and N_2being formed.

$$CO(NH_2)_2 + H_2O \rightarrow 2NH_3 + CO_2 \tag{2.18}$$

The urea is injected into the exhaust stream from the urea dosing system. The injection point should preferably be some distance before the catalyst to ensure proper mixing. The urea is decomposed (thermalized) to ammonia and isocyanic acid. The isocyanic acid is further hydrolyzed to ammonia and carbon monoxide.

The ammonia reacts on the catalyst surface with NO according to equation (2.19):

$$4NH_3 + 4NO + O_2 \rightarrow 4N_2 + 6H_2O \tag{2.19}$$

The result after the reduction is nitrogen and water only. Unfortunately, it is not possible to reach 100 % NOx reduction, especially not during transient conditions. One of the key factors for achieving high conversion is temperature. The SCR catalyst has a temperature window with a lower limit of approximately 200ºC and a higher limit of around 450-500ºC. Outside this window, the reduction capability of the catalyst is severely decreased. The catalyst also has much slower dynamics compared to the engine; the catalyst typically requires several minutes before reaching chemical equilibrium compared to a few milliseconds for the diesel engine. It is also important to have proper control of the urea dosing to avoid ammonia slip, i.e. ammonia in the exhaust gas after the catalyst. Ammonia has a distinct unpleasant smell and is also regulated by legislation [20].

2.6.2 Two Stage Urea Injection

The process is a two-step process with heat recuperation. The inlet feed enters at approximately 150 ºC and passes through a heat exchanger. This heat exchanger increases the temperature to 455 ºC, using the heat in the stream exiting the two-stage SCR system, The system shown in figure (2.5), In the first stage, primary ammonia is dosed in an ammonia-to-NOx ratio of 0.98. Before entering the first reactor, the dosed ammonia (25% solution in water) is vaporized and the temperature of the stream drops to 350 ºC. The NOx is then 96% converted in the first reactor, leaving a NOx slip of approximately 800 ppm and some ammonia, depending on the selectivity. However, the most marked feature is that the exit temperature is 530 ºC.

A second reactor has been added to the system as a polishing step, reducing NOx by 90% using a secondary ammonia injection. This yields an exit temperature of 535 ºC, which is used to heat the incoming stream before the gas is released to the ambient atmosphere. This secondary reactor operates under more normal conditions, although the temperature is much higher than normal. The fact that the system operates auto thermally, at least according to the process simulations, makes the reactor system suitable as a tail-end application. The system will, however, require catalysts especially suited to the relatively high operating temperature, since normal vanadia-based catalysts lose their selectivity via ammonia oxidation at approximately 425 ºC [21].

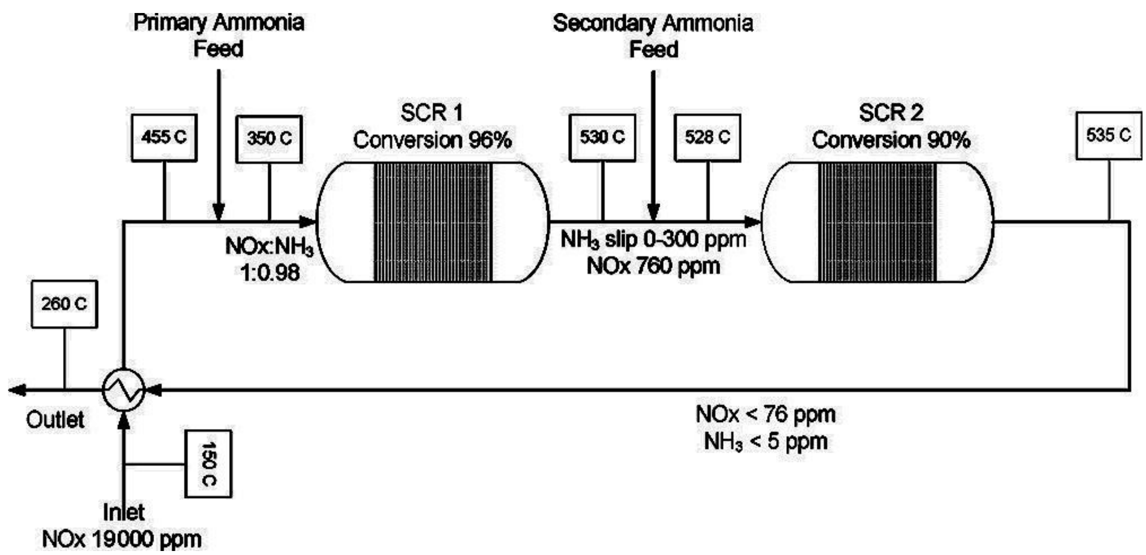

Figure (2.5): Two stage urea injection.

2.6.3 Urea Control Strategy

Open loop or closed loop control strategy, when applying an open loop control strategy, it is recommended to use ambient or inlet manifold temperature as a parameter to determine actual engine-out NO_X. The open loop NO_x or urea map can be automatically corrected for influencing parameters such as for ambient condition, fuel composition, wear and maintenance.

The closed loop control strategy can deal with catalyst aging a NO_x sensor is placed downstream of the catalyst. The maximum NO_x conservation can be as high as 98% under ideal condition [22].

Figure (2.6) shown the conversion characteristic and typical catalyst temperature for open loop and closed loop

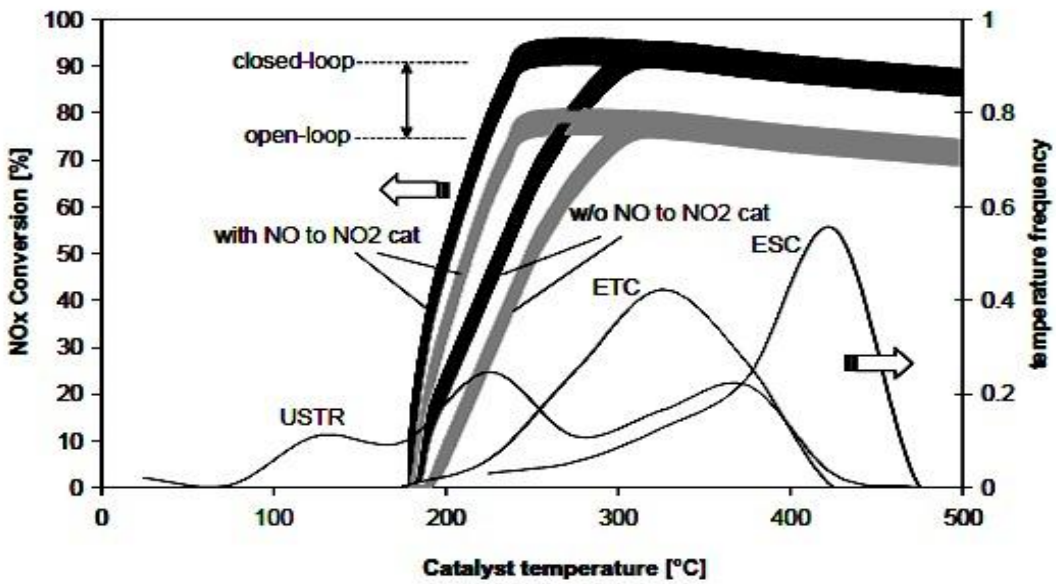

Figure (2.6): Comparison between open and closed loop control strategy.

2.6.4 De-No$_X$ System

Addition of an NO to NO_2 oxidation catalyst has proven to increase NO_x conversion at a temperature up to 300ºC. An NO/NO_2 ratio about 1 gives the best results. The application of the NO to NO_2 catalyst has considerable packaging implication since urea injection between the NO to NO_2 catalyst and the SCR catalyst; well configured ducts and sufficient volume are necessary for mixing and evaporation of the aqueous urea [22]

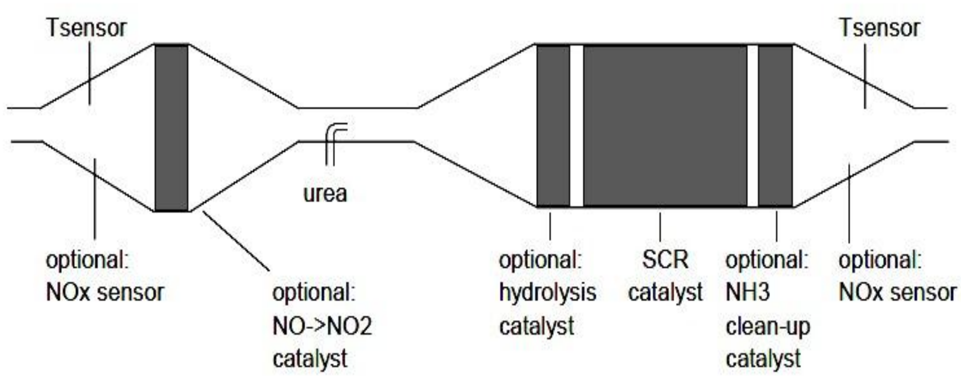

Figure (2.7): layout of urea SCR De-No$_x$ system.

Chapter Three

Design of Experimental Setup

3.1 Design Concept

3.2 Mechanical System Layout

3.3 Electrical Control Design

3.4 Project Implementation

3.5 Fluid Path Structure

3.1 Design Concept

The goal of the system design is to achieve the desired results of minimum rate of emission produced.

The system involves mechanical and electrical components which are practically connected to each other. The electrical components are used to control the mechanical component action such as electrical control unit (ECU), receives an electrical signal from source such as sensor, It then calculate the required output signals values for the actuators.

The mechanical components are used to do the tasks that are sets by the electrical components. It is used to transfer the fluid used in the system from point to another desired point such as pipes. Also, it is used to inject the fluid inside the exhaust pipe which employs the other mechanical component like pump, which is used to raise the pressure of the fluid to the target pressure of the system. And other component used to maintain the pressure at that value and to protect the mechanical system as in pressure regulator.

The exhaust gases emitted from internal combustion engine are fed to the catalytic converter. Before entering the catalytic converter, the chemical compound (urea) that is used to improve the reaction is injected into the fed gases. Two types of sensors (NO_x and CO) are installed at the inlet and outlet of the catalytic converter.

The main design and flow of the system is illustrated in Figure (3.1).

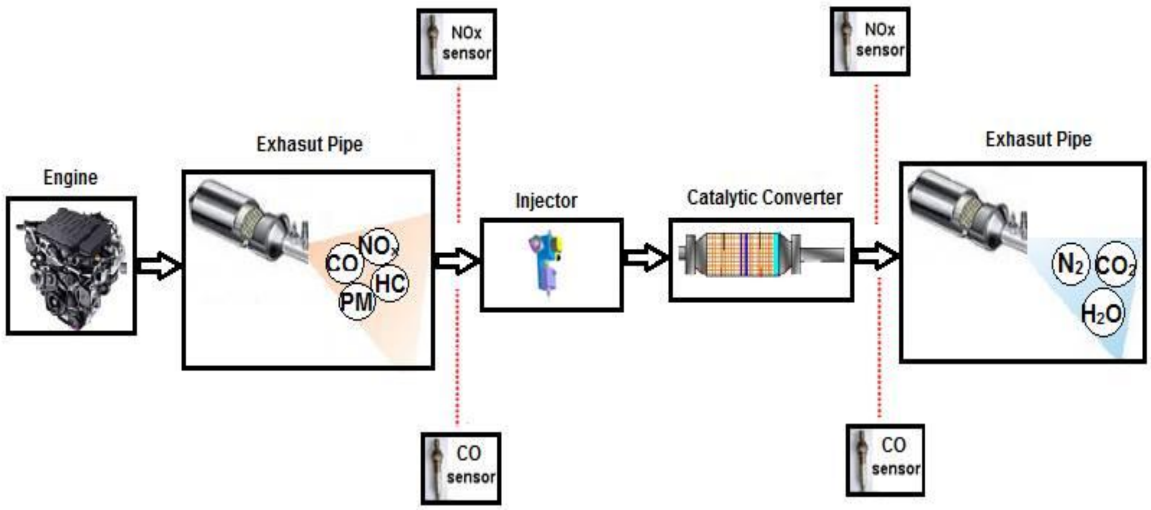

Figure (3.1): Block diagram for the main components of the system.

3.2 Mechanical System Layout

In this project the system is design to inject the optimal amount of urea into the exhaust system. The amount of urea injected is dependent on the NO_X and CO concentrations in exhaust gases. The urea injected into exhaust system before catalytic converter to reacts with NO_X and CO inside the catalytic converter. Special injector is required to withstand the temperature above 700 ºC.

The mechanical process diagram is shown in Figure (3.2):

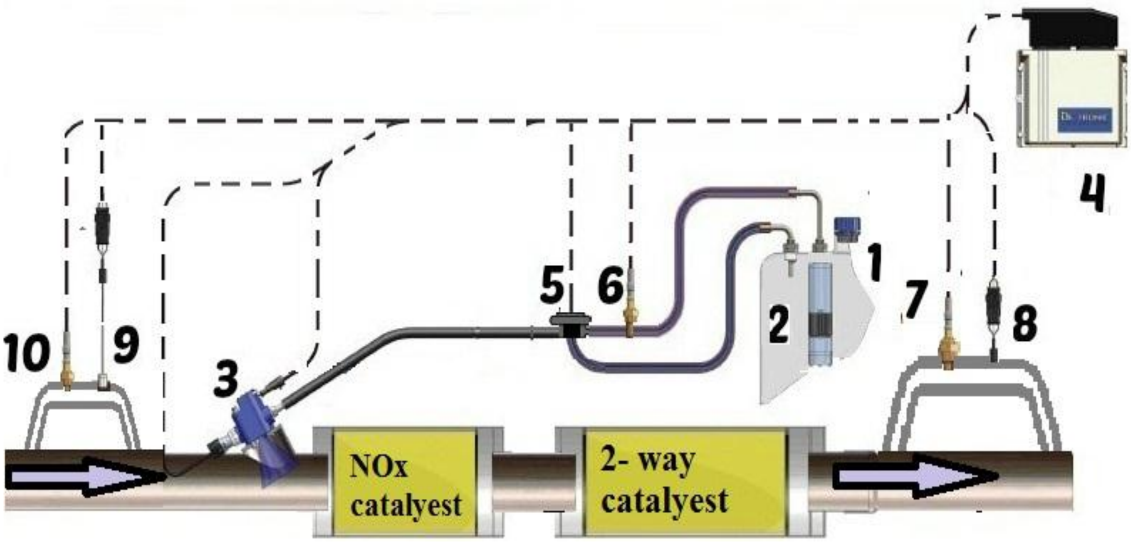

Figure (3.2): Mechanical process diagram.

The Components of the system include the followings

1. Urea tank
2. Electrical pump
3. Electrical injector
4. Electric control unit
5. Pressure regulator
6. Pressure sensor
7. NO_x sensor after catalytic converter
8. CO sensor after catalytic converter
9. NO_x sensor before catalytic converter
10. CO sensor before catalytic converter

Special sensor are required to measure the concentrations of gas emission NO_X and CO, this project require CO and NO_X sensors are installed on the inlet and outlet of the catalytic converter. Sensor before catalytic converter require to give output signal to operate the electrical injector according to this value and sensor after catalytic converter is required to evaluate the system performance.

3.3 Electrical Control Design

The function of the electronic components is to operate the system to give the maximum system performance.

3.3.1 Electrical Control Unit (ECU)

The ECU is an electronic microcomputer with a central processing unit (CPU) or microprocessor. The CPU includes software programs that compare all sensor input data with a fixed map of operating conditions. It then calculates the required output signal values for the injection valves and other actuators.

A "brain" of the system, receives an electrical signal from the source such as sensors, the signal is proportional to a calibrated physical quantity measured represented in engine operating parameter such as temperature, air fuel ratio, system pressure, and engine speed. The other function of the ECU is to calculate and send the output signals to the system actuators such as injector, pump.

The ECU also operates the emission control components at appropriate times depending on the engine operating conditions. Typical emission control actuators are the canister purge solenoid valve, the EGR valve and the secondary air solenoid valve, urea injector. The selection of microcontroller is based on realizing a sufficient capacity of input and output required by the system.

3.3.1.1 Microcontroller Programming

Microcontrollers typically programmed in many languages. These languages are either designed especially for the purpose, or versions of general purpose languages such as the C programming language. In this projects using the arduino hardware to program a microcontroller which builds it inside an electrical panel or we can use aurdoino in the final form. A programmed microcontroller and the electrical panel form the main part of ECU

Arduino is a single-board microcontroller. The hardware consists of an open-source hardware board designed around an 8-bit Atmel AVR microcontroller, or a 32-bit Atmel ARM. The software consists of a standard programming language compiler and a boot loader that executes on the microcontroller

The Arduino integrated development environment (IDE) is a cross-platform application, and is derived from the IDE for the Processing programming language and the Wiring projects. It includes a code editor with features such as syntax highlighting, brace matching, and automatic indentation, and is also capable of compiling and uploading programs to the board with a single click.

The Arduino environment is based on Atmel Atmega microcontrollers. The AVR language is a "C" environment for programming Atmel chips. Much of the Arduino language is written with AVR constants and functions and there are many things that are still not easy to accomplish with the Arduino language without using some AVR code.

Arduino programs are written in C or C++. The Arduino IDE comes with a software library called "Wiring" from the original Wiring project, which makes many common input/output operations much easier. Users only need define two functions to make a runnable cyclic executive program [23].

3.3.1.1.1 ATMega Development Board

The new ATMega Development Board is a great way to start working with Atmel's latest range of microcontrollers the ATMega series.

The board is ideal for experimenters or as a main CPU board for a more advanced system. Program download and run is easily executed in-system by an RS232 connection to the computer parallel port. The board utilizes the new advanced Atmel AVR ATMega168 microcontroller with 16kof In-System Flash Memory, running at 16 MHz, allowing up to 8 MIPS (million-instructions-per-second). All power supply components and main crystal is in place for the microcontroller. Connectors are provided for RS232, SPI, power and all I/O pins, via standard polarized connections and IDCC connectors [24].

The figure (3.3) is the Pin Diagram of Atmega 168 microcontroller

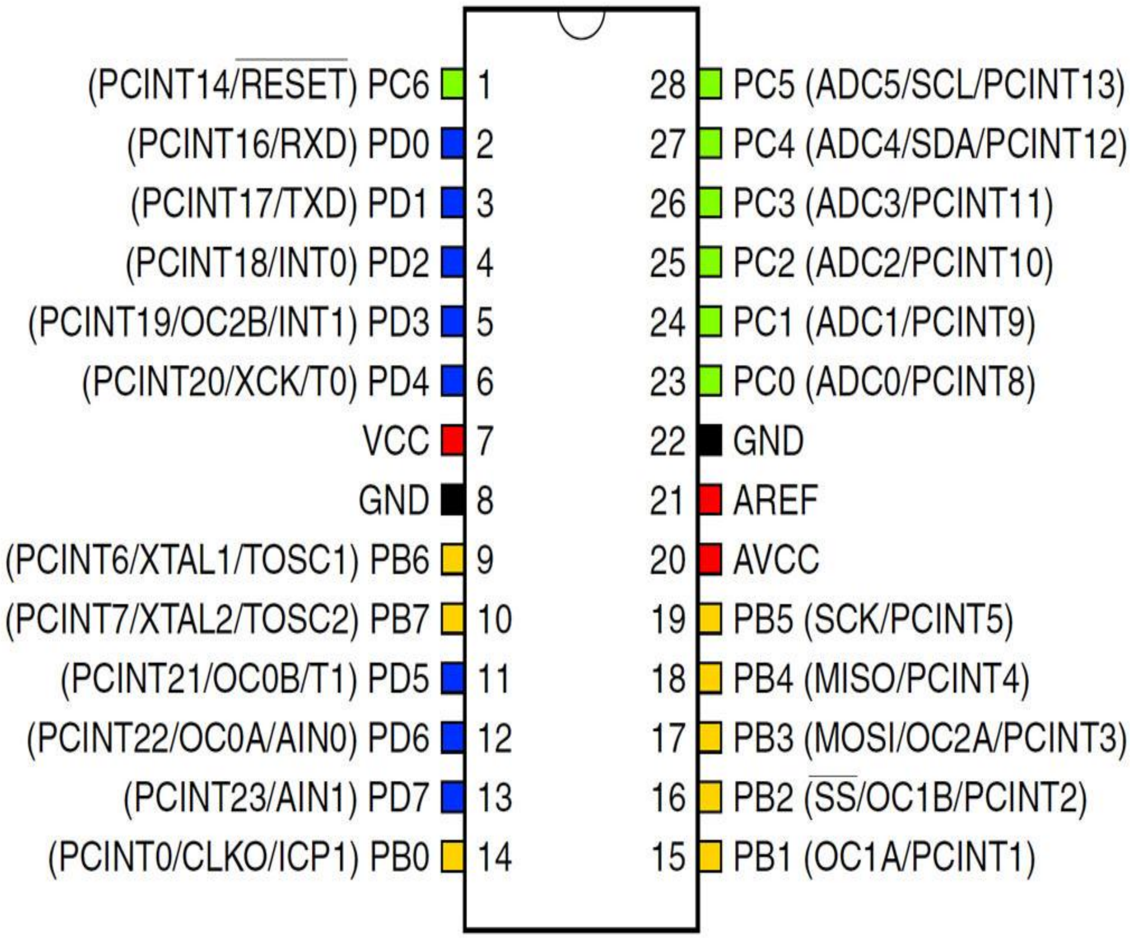

Figure (3.3): Microcontroller Atmeg 168 pin diagram.

Pin description of Atmega 168 are shown in Table (3.1)

Table (3.1): Pin description.

Pin No.	Pin name	Arduino Function	Pin No.	Pin name	Arduino Function
1	PC6	Reset	15	PB1	Digital pin 9 (PMW)
2	PD0	Digital pin0 (RX)	16	PB2	Digital pin 10 (PMW)
3	PD1	Digital pin1(TX)	17	PB3	Digital pin 11 (PMW)
4	PD2	Digital pin2	18	PB4	Digital pin 12
5	PD3	Digital pin 3(PWM)	19	PB5	Digital pin 13
6	PD4	Digital pin 4	20	AVCC	VCC
7	VCC	VCC	21	AREF	Analog reference
8	GND	GND	22	GND	GND
9	PB6	Crystal	23	PC0	Analog input 0
10	PB7	Crystal	24	PC1	Analog input 1
11	PD5	Digital pin 5(PWM)	25	PC2	Analog input 2
12	PD6	Digital pin 6(PWM)	26	PC3	Analog input 3
13	PD7	Digital pin 7	27	PC4	Analog input 4
14	PB0	Digital pin 8	28	PC5	Analog input 5

Arduino hardware is available in the final form as shown in Figure(3.4), without building in the electrical lab, this requires connect it to a computer using a USB cable to programming it using Arduino software.

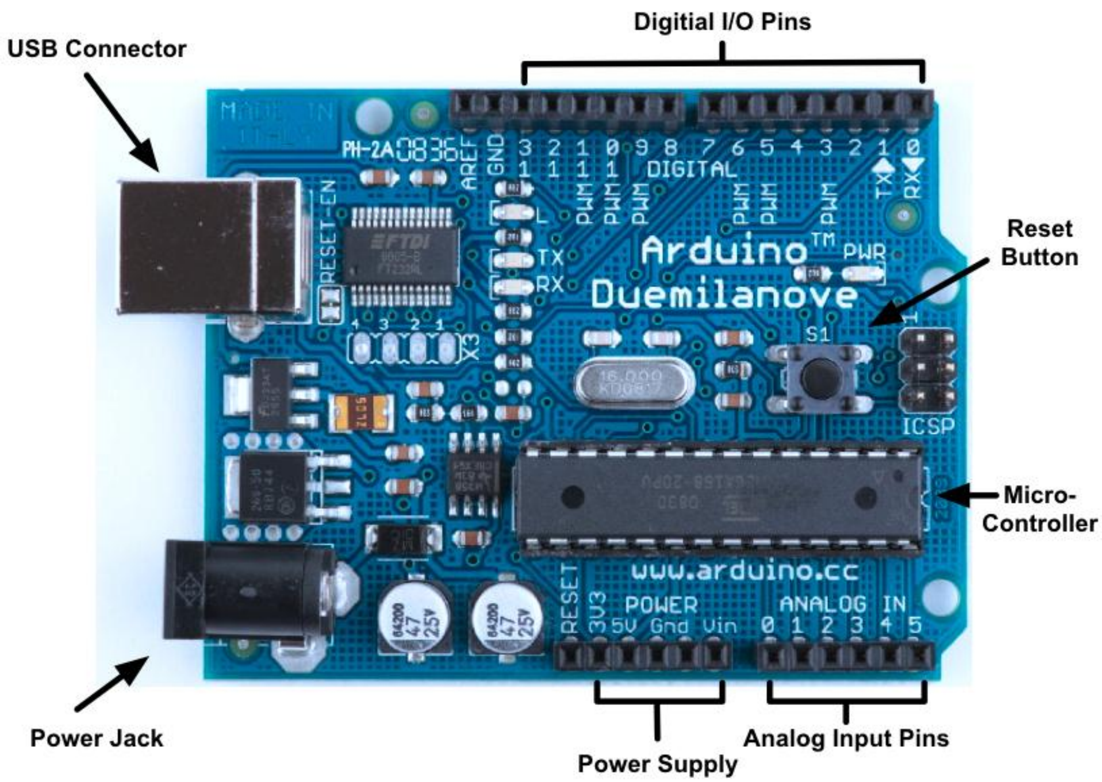

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Figure (3.4): Arduino microcontroller.

The features of the Arduino include the followings:

- Includes ATMega168 with 16kb internal Flash Program Memory
- All necessary power supply components and crystal (8.000MHz) already installed.
- All input/output pins connected to headers for easy external connections.
- In-circuit programming via computer download cable (provided)
- Easy to understand
- Test LED for program run testing
- Power and Programming LED
- Code Examples Provided
- Dramatically reduces program development time

3.3.2 Sensors

Sensor is an electronic device used to measure a physical quantity such as pressure, temperature, speed and convert it into an electronic signal of some kind such as voltage. Sensor is normally component of some larger electronic system such as a computer control and/or measurement system [25].

3.3.2.1 Carbon Monoxide (MQ-7) Sensor

A carbon monoxide detector or CO detector illustrated in figure (3.5) is a device that detects and measures the concentration of the CO gas. This Carbon Monoxide gas sensor detects the concentrations of CO and outputs its reading as an analog voltage.

The sensor can measure CO concentrations in the range of 10 to 10,000 ppm. The sensor can operate at temperatures from -10 to 50°C and consumes less than 150 mA at 5 V.

Sensitive material of MQ-7 gas sensor is SnO_2, which has lower conductivity in clean air. It makes detection by method of cycle high and low temperature. The sensor's conductivity is higher along with the gas concentration rising. A simple electrical circuit can convert the change in conductivity to an output signal which corresponds to the gas concentration

Figure (3.5): CO sensor MQ-7.

The features of CO sensor (MQ-7) include the following:

- High sensitivity to carbon monoxide
- Stable and long life
- High sensitivity to organic solvent vapors such as ethanol

- Uses simple electrical circuit

Structure and configuration of MQ-7 gas sensor is shown in Figure (3.6). The sensor is composed by micro AL_2O_3 ceramic tube with Tin Dioxide (SnO_2) sensitive layer, measuring electrode and heater are fixed into a crust made by plastic and stainless steel net. The heater provides necessary work conditions for work of sensitive components. The enveloped MQ-7 has 6 pin,4 of them are used to fetch signals, and the other 2 are used for providing heating current.

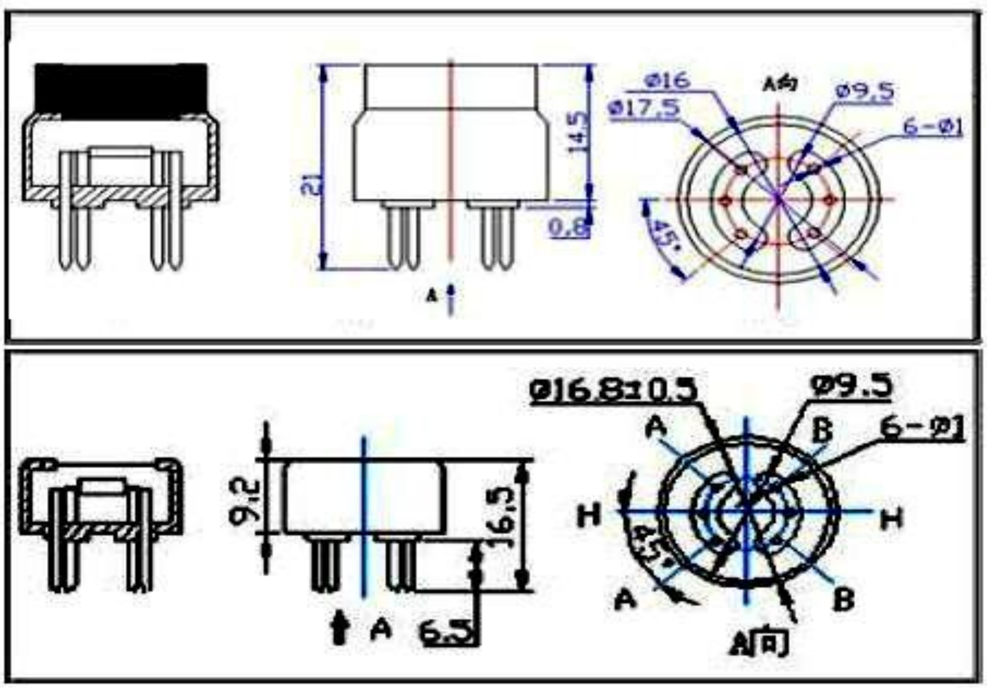

Figure (3.6): Configuration of MQ-7 CO sensor.

3.3.2.2 Nitrogen Oxide Sensor (MQ-135) Sensor

A nitrogen oxide detector or NO_X detector is a device that detects and measures the concentration of NO_X gas. This NO_X gas sensor detects the concentrations of NO_X and outputs its reading as an analog voltage.

Sensitive material of (MQ-135) gas sensor as shown in figure (3.7) is SnO2, which with lower conductivity in clean air. When the target combustible gas exist, the sensor's conductivity is higher along with the gas concentration rising. A simple electrical circuit can convert the change in conductivity to an output signal which corresponds to the gas concentration.

The features of NOx (MQ-135) sensor include the following:

- High sensitivity to exhaust gases diesel-fueled engines
- Long life, low cost ,stable and fast response
- Uses simple electrical circuit.
- Measure concentration 10-10000 ppm

Figure (3.7): NO_X sensor MQ 135.

Structure and configuration of MQ-135 gas sensor is shown in Figure (3.8)**,** the sensor is composed of micro AL_2O_3 ceramic tube with Tin Dioxide (SnO_2) sensitive layer, measuring electrode and heater are fixed into a crust made by plastic and stainless steel. The heater provides necessary work conditions for work of sensitive components. The enveloped MQ-135 has 6 pin, 4 of them are used to fetch signals, and the other 2 are used for providing heating current.

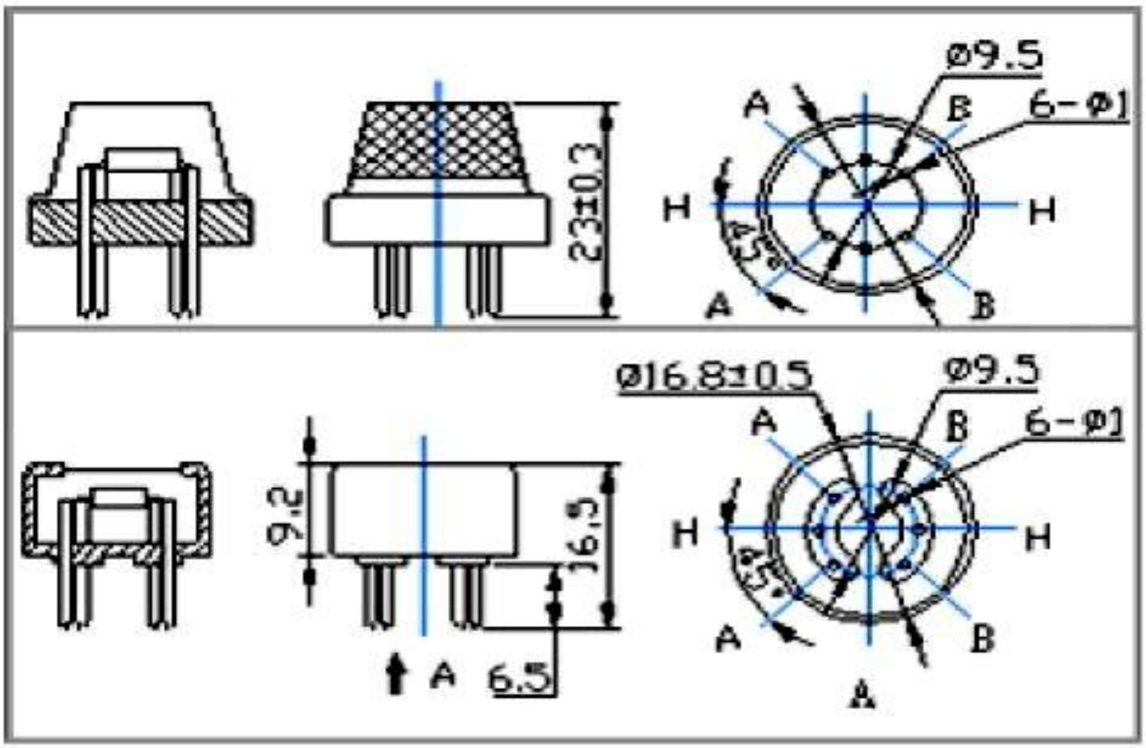

Figure (3.8): Configuration of MQ-135 gas sensor.

Sensor Sensitivity Adjustment

Resistance value of MQ-135 is different to various kinds and various gas concentrations. Thus, when using this sensor, sensitivity adjustment is very necessary.

3.3.2.3 Pressure Sensor

A pressure sensor measures pressure, typically of gases or liquids. Pressure is an expression of the force required to stop a fluid from expanding, and is usually stated in terms of force per unit area. A pressure sensor as shown in figure (3.9) usually acts as a transducer; it generates a signal as a function of the pressure imposed such electrical signal [26].

Figure (3.9): Pressure sensor.

3.3.3 Actuator

There are many ways to providing control over variables in vehicle. 'Actuators' is a general term used to describe a control mechanism. When controlled electrically actuators will work by the magnetic effect. The term actuator will be used to mean a device that converts electrical signals into mechanical movement.

3.3.3.1 Electrical Injector

Urea solution is injected into the exhaust system by electronic injector (solenoid actuator), and the pressure is built up by the electronic pump.

The basic operation of solenoid actuator injector is very simple. The term 'solenoid' means: 'many coils of wire wound onto a hollow tube' When the windings are energized the armature is attracted due to magnetism and compresses the spring. The time it takes an injector to open and close is also critical for accurate urea solution metering.

The operational range temperature for urea injector -40°C to 125° C, so in this project use special injector with cooling circuit to inject the optimum amount of urea into the exhaust system[27].

Figure (3.10) illustrated special injector to inject urea solution.

Figure (3.10): Electrical injector.

3.3.3.2 Pressure Regulator Valve

A pressure regulator is a valve that automatically cuts off the flow of a liquid or gas at a certain pressure. This keeps the system pressure in the return constant at 5 bar. Regulators are used to allow high-pressure fluid supply lines or tanks to be reduced to safe and usable pressures for various applications. A pressure regulator's primary function reduce the pressure of the fluid from a high value to a lower value and, thereafter, maintains a constant output. The out pressure of the regulator can be adjusted. This is achieved bypassing a portion of the fluid back to the inlet side of the tank [28].

The figure (3.11) illustrated pressure regulator valve.

Figure (3.11): Pressure regulator.

3.3.3.3 Electrical Pump

A pump is a frequently essential component in the urea injection system; urea solution has to be pumped from the urea tank under high pressure to the injector. Electric pumps generate positive electrical pressure in liquid lines, which drives urea solution to the injector. An ignition switch activates a relay that manages the higher current necessary to increase fuel pressure.

The system uses magnetic coupling technology so all electrical connections are isolated from the fluid flow; the compact brushless motor and gerotor pump allow controlled flow of 5 to 50 liters per hour.

Electrical pump as shown in figure (3.12) is available in low cost and achieve the appropriate pressure 5 bar for this reason we choose electrical pump in this project [29].

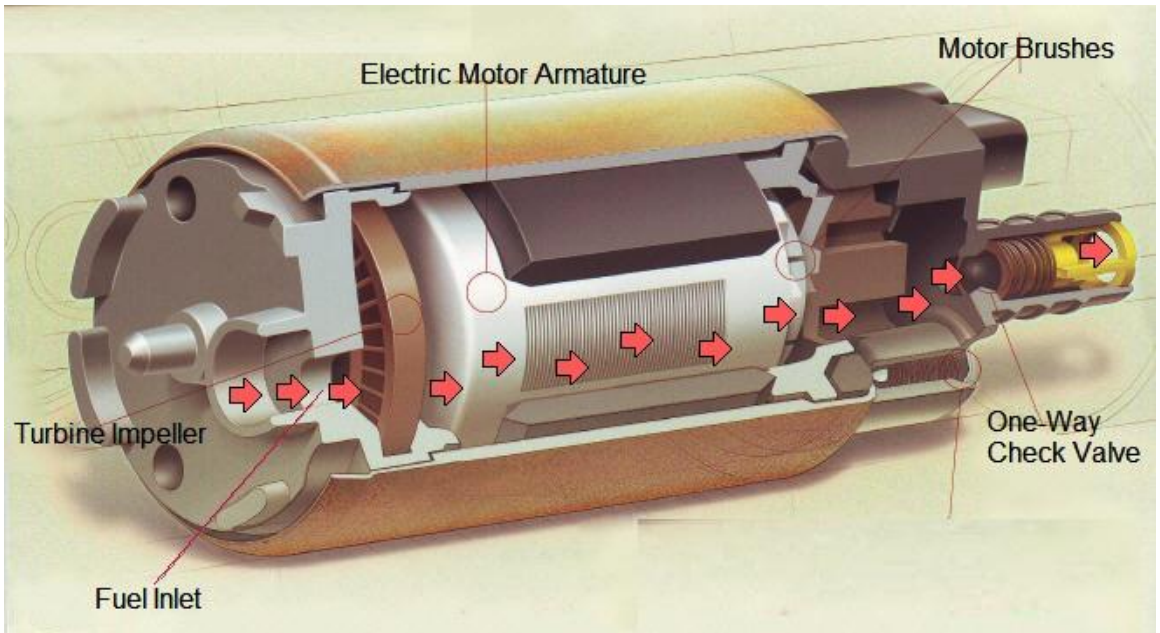

Figure (3.12): Electrical pump.

3.3.4 LCD Screen

In this project using LCD screen as shown in figure (3.13) to display the experimental data , This screen must be connect with arduino microcontroller to display data.

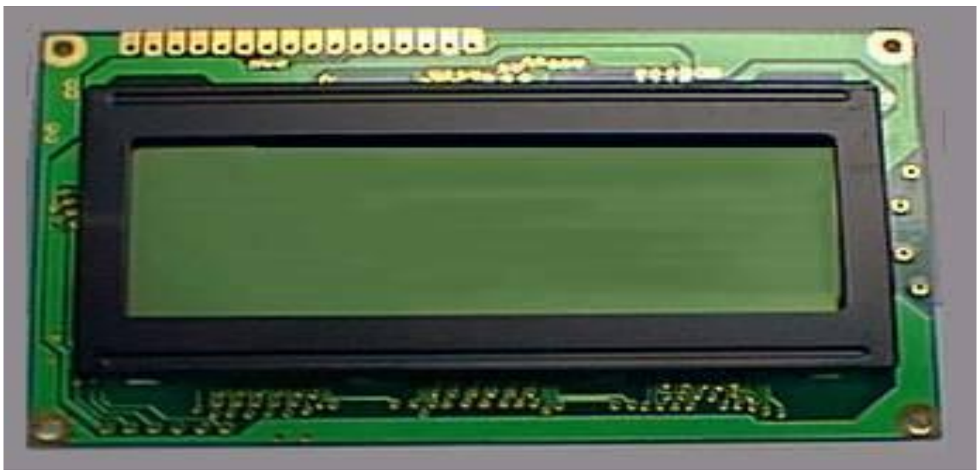

Figure (3.13): LCD screen Size 4x20**.**

3.3.5 Electrical Circuit

Control unit receives a multi input from sensors, to determine the optimum amount of urea must be inject into the exhaust system, according to the map build inside it, supply voltage for it is 9 volt from voltage regulator. A pump is supplied by 12 volt from battery, a positive pulse from control unit represented in a digital signal output to active pump.

Injector is supplied by 12 volt from battery, a positive pulse from control unit represented in a digital signal output to active injector, this signal is depends on the NO_x and CO concentration in the exhaust system.

The output of CO sensor which measure the CO concentration in the exhaust pipe is sends the signal to the control unit as analogue signal. The same thing of the output of the NO_x sensor, which measures the NO_x concentration, these sensors is supplied by 5 volt from the voltage regulator to the heater circuit. And supplied 5 volt from voltage regulator to the circuit voltage.

The output voltage for the NO_x and CO sensor before and after catalytic converter is display using 20*4 LCD screen as shown in figure (3.15)

Wiring diagram for the electrical circuit illustrated in figure (3.16) is drawing by proteus software and the actual electrical circuit building for the project illustrated in figure (3.14).

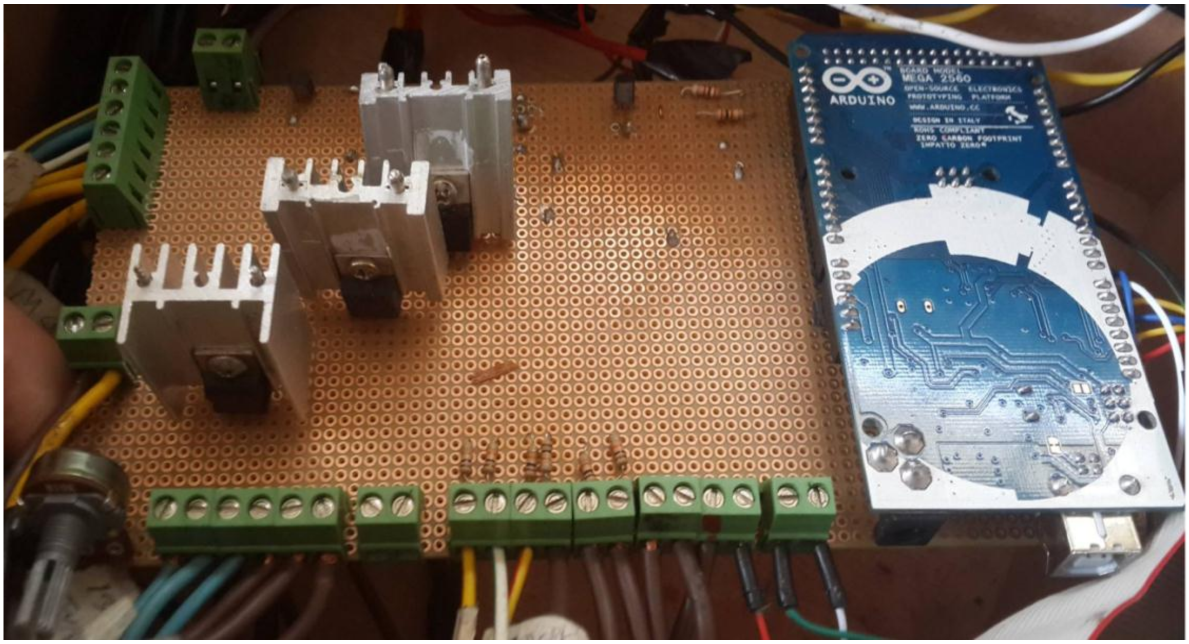

Figure (3.14): Electrical circuit for project.

Figure (3.15): LCD screen on the project.

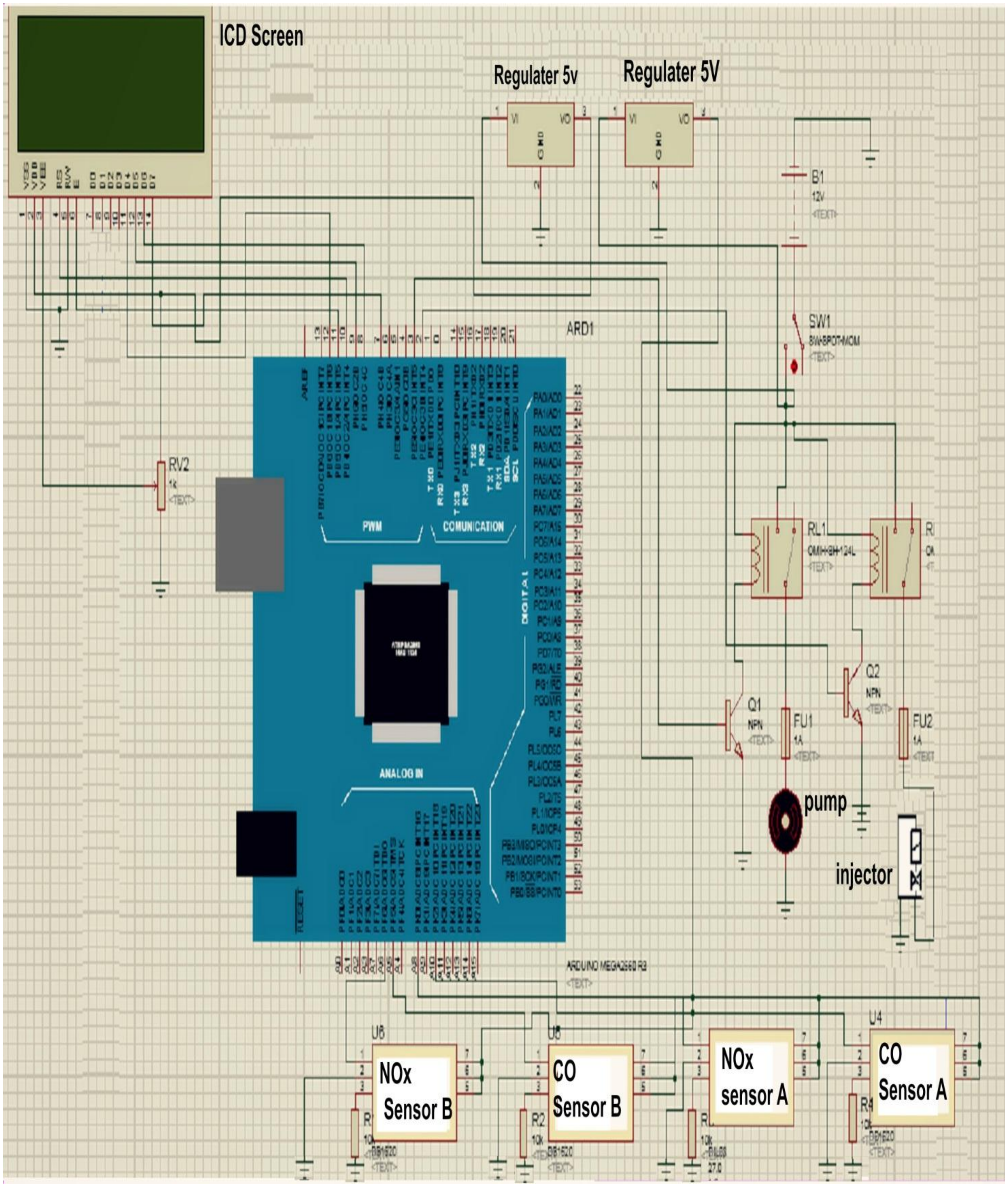

Figure (3.16): Electrical circuit using proteus software.

3.4 Project Implementation

A suitable design must take into consideration to ensure that the systems do well, and to protect the electrical and mechanical parts from damage.

A favorable shape layout as shown in figure (3.17), taken into account, the main problem is to compensate between system working correctly, shape and high temperature.

The main factor affect the operation and building the experiment is temperature of exhaust gases, it must not be too high or low. The operational temperature of catalytic converter to be effective is about 300C.

Figure (3.17): Project shape layout.

3.4.1 NO_x and 2-way Catalytic Converter

The selection of catalytic converter is to treat the NO_x and CO gases into less harmful gases and to produce chemical reaction with urea inside it, so that a NO_x catalyst and 2 way catalytic converter chosen as shown in figure (3.18).

Figure (3.18): NO_x and 2-way catalytic converter.

NO_x catalytic converter is installed before 2-way catalytic converter because of the outlet gases from the first one is O_2 plus N_2 according to equation (3.1), and the second one need for O_2 to interact with CO to produce CO_2 as shown in equation (3.2)

$$2NO_x \rightarrow O_2 + N_2 \tag{3.1}$$

$$2CO + O_2 \rightarrow 2CO_2 \tag{3.2}$$

3.4.2 Injector and Sensors Isolation

In order to reduce the temperature to avoid damaging the sensors and injector from high temperature a bypass is built over the exhaust pipe as shown in the figure (3.19) with suitable inclined angle and shape for smoothing flow of gases and accurate result as much as possible.

Figure (3.19): Gases flow bypass.

A wood fiber is used as isolated material from temperature and to fix the sensors in their positions on the drilled halls on bypass as shown in the figure (3.20).

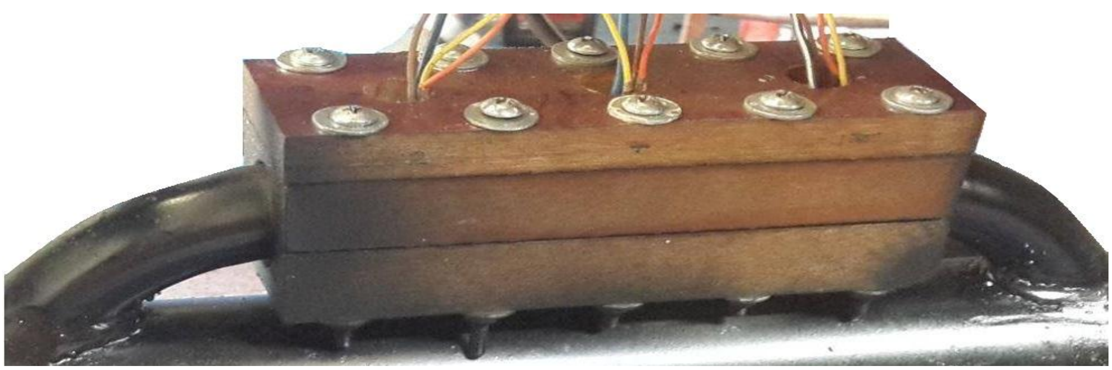

Figure (3.20): Sensors isolation using wood fiber.

To reduce high temperature from evaporate the fluid when its flow inside the injector a wood fiber is installed too as a shell of the injector external side, and to maintain it on the inclined pipe which is combined with exhaust pipe as shown in the figure (3.21).

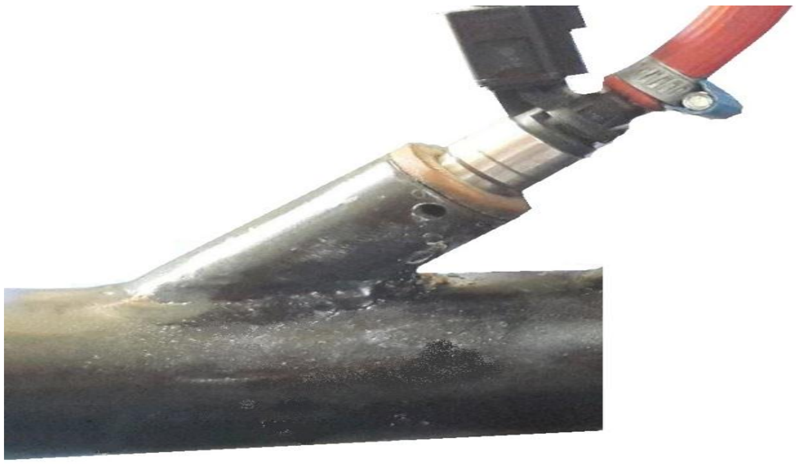

Figure (3.21): Injector isolation using wood fiber.

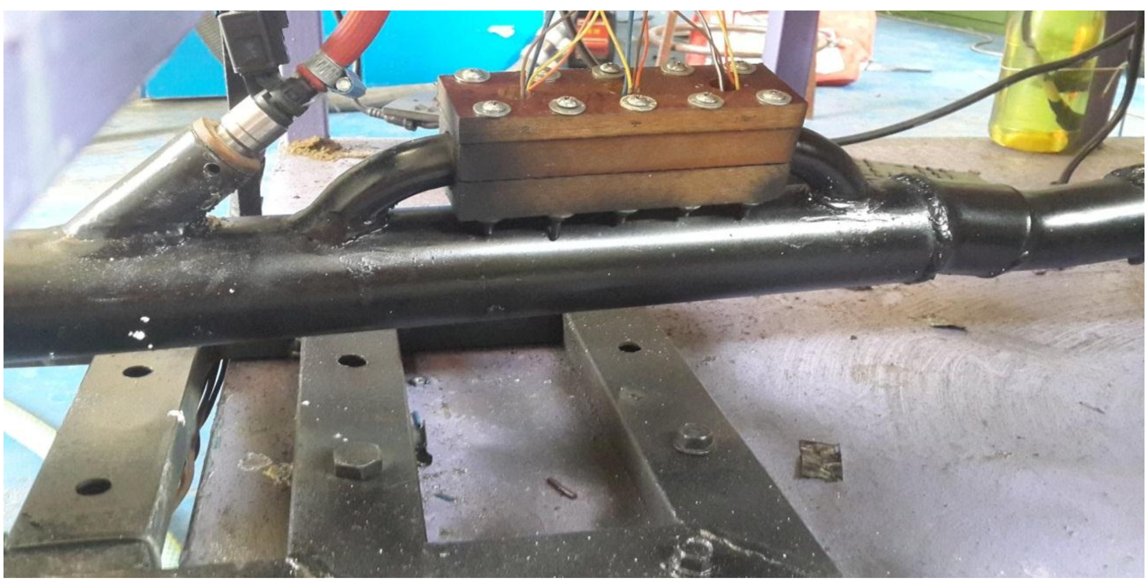

Figure (3.22): Electrical injector and gases sensors before catalytic converter.

The geometrical dimension for injector and sensors is illustrated in figure (3.23).

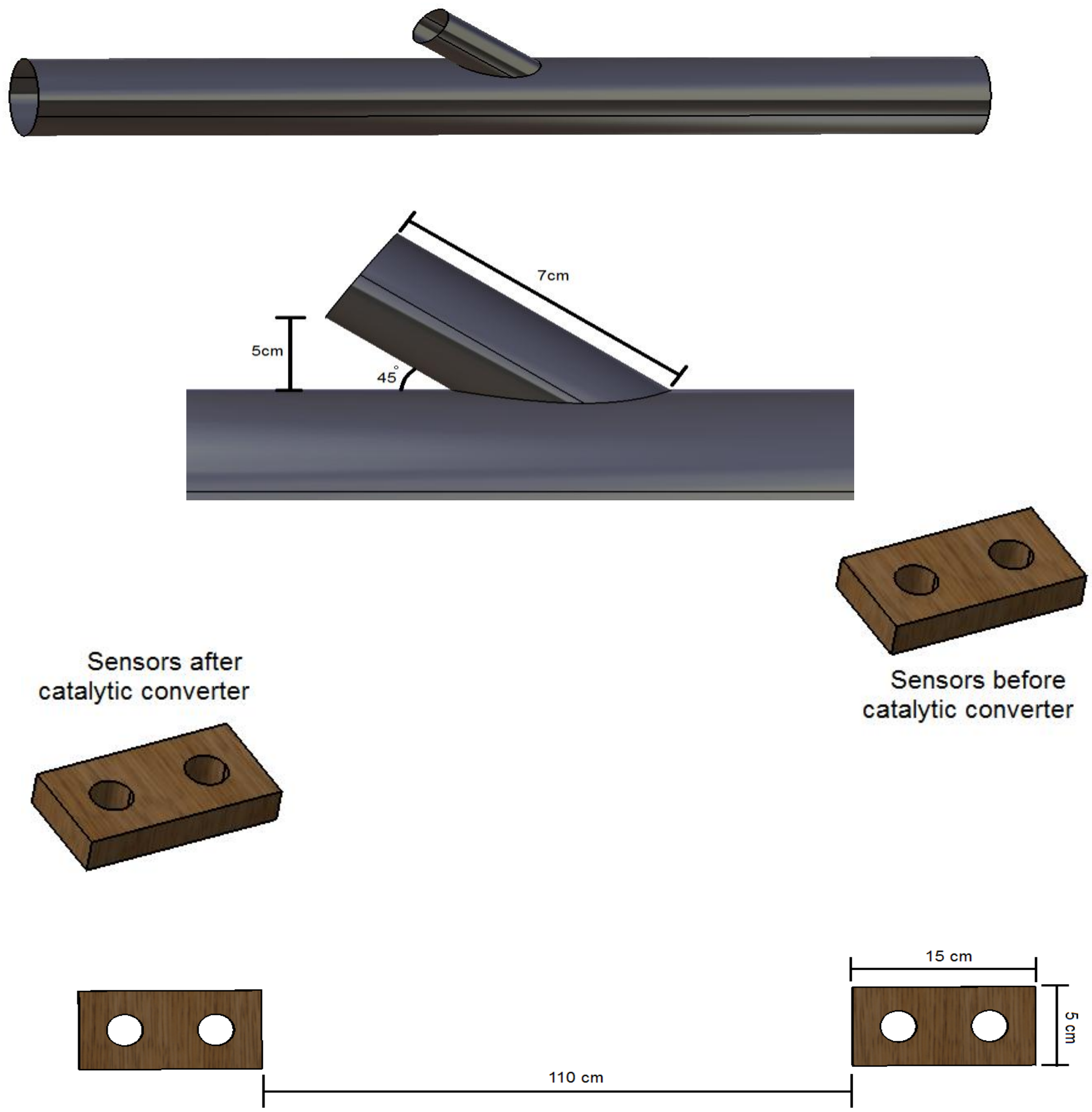

Figure (3.23): Geometrical dimensions for injector and sensors.

3.5 Fluid Path Structure

In this project fluid path is building to transfer fluid from point to another point using elastic pipe. Also, Electrical pump inside urea tank is used to raise the pressure of the fluid to the target pressure to deliver it to the electrical injector as shown in figure (3.24). Urea filter is used to remove impurities from the fluid, and pressure gauge is used to measure the system pressure.

The output pressure of the electrical pump can be adjusted by manual valve. This is achieved bypassing a portion of the fluid back to the inlet side of the tank as shown in figure (3.25).

Figure (3.24): Fluid Flow Path.

Figure (3.25): Fluid regulation path.

Chapter Four

Experimental Results

4.1 Introduction

4.2 Engine Specification

4.3 Diagnostic Device

4.4 NOx Analysis

4.5 CO Analysis

4.1 Introduction

Developing the exhaust system treatment to reduce the concentration of NOx and CO in diesel engine by injecting the optimum amount of urea before catalytic converter and measuring the output signal before and after catalytic converter

In this project the system have been designed and applied on a diesel engine (CITROEN Berlingo vehicle), to limit and reduce the concentration of NOx and CO.

After applying the system on the diesel engine, many experiments had been performed to study the effect of operational parameters on the efficiency of the catalytic converter before and after urea injection such as engine speed, diesel injection timing and A/F ratio. All experiments applied after the catalytic converter reaches to operational temperature range after 270ºC, which required of about 30 minutes to reach operational temperature.

All experiments performed without applying load on the engine and without using dynamometer.

4.2 Engine Specification

In this project we choose CITRON Berlingo (diesel) engine as shown in figure (4.1) to perform the experiment. The technical specification for **CITROEN Berlingo II 2.0 HDI 2007** illustrated in table (4.1)

Figure (4.1): CITRON Berlingo 2007.

Table (4.1): Technical specification **CITROEN Berlingo II 2.0 HDI 2007**

Model	Berlingo 2,0 HDI
Engine code	RHY
Year	2007
Car engine capacity	1997 ccm (121,25 cube inches)
Number of cylinder	4 cylinders
Car valve per cylinder	2 valves
Compression ratio	18.0:1
Car fuel type	Diesel
Car transmission	Manual, 6 speed
VIN code:	VF7GJRHYB6J0026

4.3 Diagnostic Device

In this project we choose important diagnostic device (autocome CDP +) as shown in figure (4.2) to record and store the engine operational parameters such as engine speed, injection timing, and A/F ratio.

This device is connect with diagnostic interface (OBD II) in vehicle to perform many tasks such as storage , reading operational parameters, reading fault code, and activation many electrical and mechanical device .

Figure (4.2): Diagnostic device autocome CDP+.

4.4 NOx Analysis.

The concentration of NOx emission in diesel engine is depends on the engine operational parameters such as engine speed and diesel injection timing. The output signal from NOx sensors was measured with operational temperature for catalytic converter after 300ºC.

4.4.1 Effect of Engine Speed

In this experiment we study the effect of various engine speeds on the output signal (concentration) for NOx sensors and the efficiency of the catalytic converter before and after urea injection.

Increasing engine speed reduces the total heat transfer from burned gases, resulting in increasing the concentration of NO_x emission, the output signal from NO_x sensor after catalytic converter is reduced with urea injection and efficiency of the catalytic converter is increased with urea injection.

The output signal from NOx sensor before and after catalytic convert at various engine speed are illustrated in table (4.2)

Table (4.2): Output signal from NOx sensors and at various engine speed.

Engine speed (RPM)	NOx Before Catalyzer (Volt)	With urea injection		Without urea injection	
		NOx After catalyzer With urea(volt)	Efficiency After catalyzer with urea	NOx After Catalyzer Without urea(Volt)	Efficiency Catalyzer Without urea
890	1.98	0.59	0.70	1.02	0.48
1500	2.18	0.56	0.74	1.04	0.52
2000	2.29	0.48	0.79	.21	0.47
2500	2.40	0.65	0.73	1.10	0.54
3000	2.90	0.67	0.77	1.42	0.51
3500	3.09	0.74	0.76	1.66	0.46

The effect of engine speed on the output signal for NOx sensor before catalyzer, after catalyzer with injection urea and after catalyzer without injection urea are shown in figure (4.3)

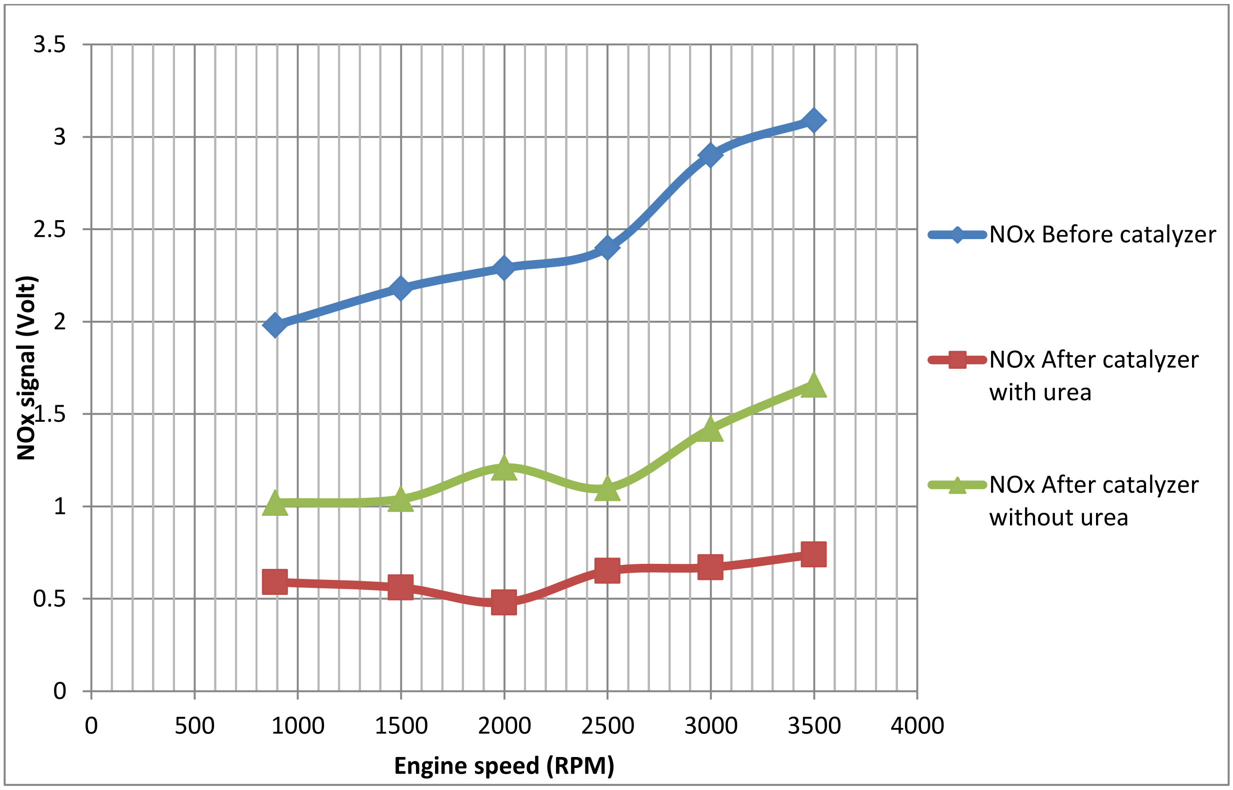

Figure (4.3): Effect of engine speed on the output NOx signal before and after catalytic converter.

4.4.2 Effect of Air Fuel Ratio

In this experiment we study the effect of A/F on the output signals for NOx sensor, the A/F will change when the engine speed is changed. From air mass and diesel injection quantity A/F is calculated at these condition

Air fuel ratio (A/F) (which effect on both gas temperature and oxygen concentration in the burned gases), diesel engine operation at high A/F ratio (lean mixture) the rate of NOx will be decreased when A/F ratio still increase.

The output signal from NOx sensor before and after catalytic convert with various values of engine A\F ratio are illustrated in table (4.3)

Table (4.3): Output signals from NOx sensors and catalytic converter efficiency at various A/F ratio.

Engine Speed (RPM)	Air mass (mg/stoke)	Injection quantity (mg/stroke)	A/F	NOx Before Catalyze (Volt)	Without urea injection		With urea injection	
					NOx after Catalyzer Without urea (volt)	Efficiency catalyzer without urea	NOx after Catalyzer With urea (volt)	Efficienc y catalyzer with urea
890	430	5.50	78	1.96	0.99	0.49	0.54	0.72
1500	463	6	77	2.21	1.08	0.51	0.55	0.75
2000	501	6.75	74	2.29	1.21	0.47	0.52	0.77
2500	539	7.50	71	2.44	1.17	0.52	0.70	0.71
3000	577	8.75	65	2.93	1.46	0.50	0.68	0.76
3500	620	10	62	3.06	1.71	0.44	0.67	0.78

The output signals from NOx sensor after catalytic converter will be decreased with injection urea and the efficiency of the catalytic converter is increased.

The effect of A/F ratio on the output signal for NOx sensor before catalyzer, after catalyzer with injection urea and after catalyzer without injection urea are shown in figure (4.4)

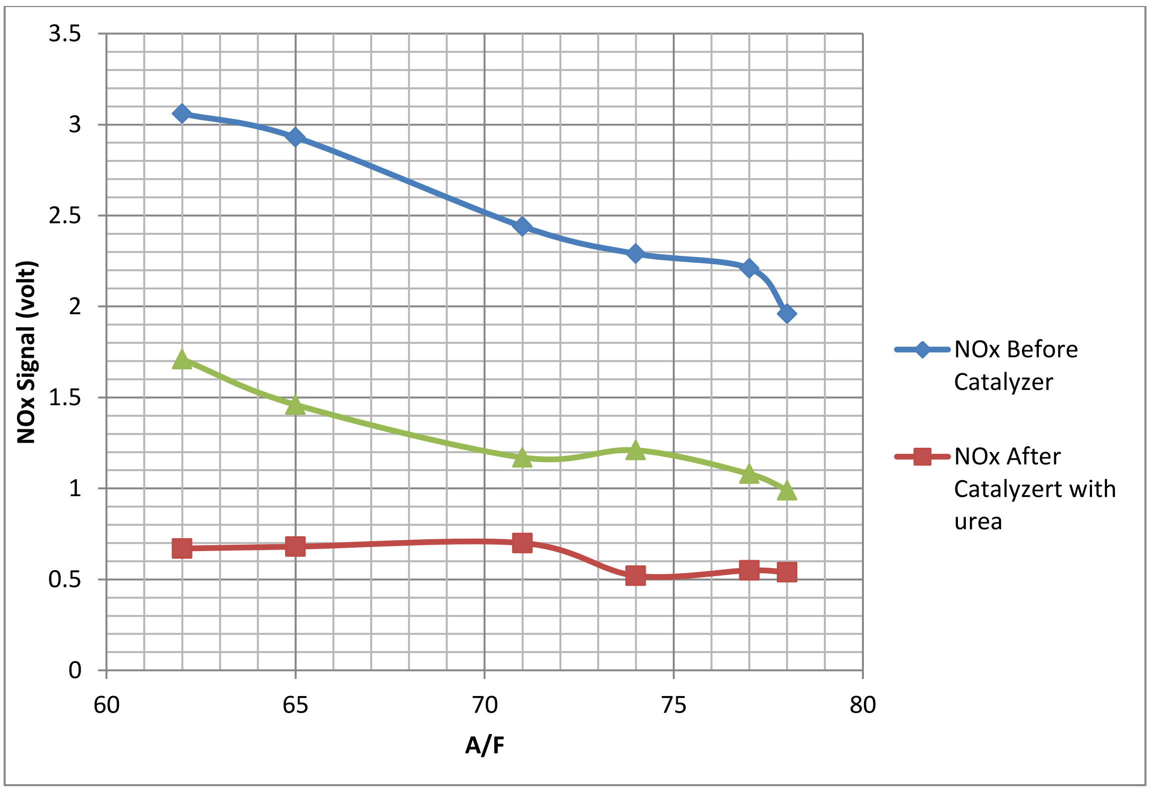

Figure (4.4): Effect of A/F on the output signal from NOx sensors before and after catalytic converter.

4.4.3 Effect of diesel injection timing

In this experiment we study the effect of various injection timing on the output signal (concentration) for NOx sensor and the efficiency of the catalytic converter before and after urea injection.

The advancement of injection time leading to higher flame temperature causing increase the NOx emission where's retarding the injection helps to reduce the flame temperature and reduce concentration of the NOx emission.

The output signal from NOx sensor before and after catalytic convert at various diesel injection timing are illustrated in table (4.4)

Table (4.4): Output signals from NOx sensors and catalytic converter efficiency at various diesel injection timing

Diesel Injection timing (degree)	Engine speed (RPM)	NOx Before catalyst (volt)	With urea injection		Without urea injection	
			NOx After Catalyzer with injection urea (volt)	Efficiency	NOx After Catalyzer without injection urea (volt)	Efficiency
-12	950	2.14	0.53	0.75	1.01	0.52
-16	1200	2.19	0.61	0.72	1.07	0.51
-20	1600	2.26	0.58	0.74	1.06	0.53

-28	2590	2.68	0.77	0.71	1.36	0.49
-31	2700	2.75	0.60	`0.78	1.33	0.51

The output signals for the NOx sensors before and after catalytic converter are illustrated in figure (4.5).When starting urea injection the output signals after catalytic converter is decreased and the efficiency for the catalytic converter is increased.

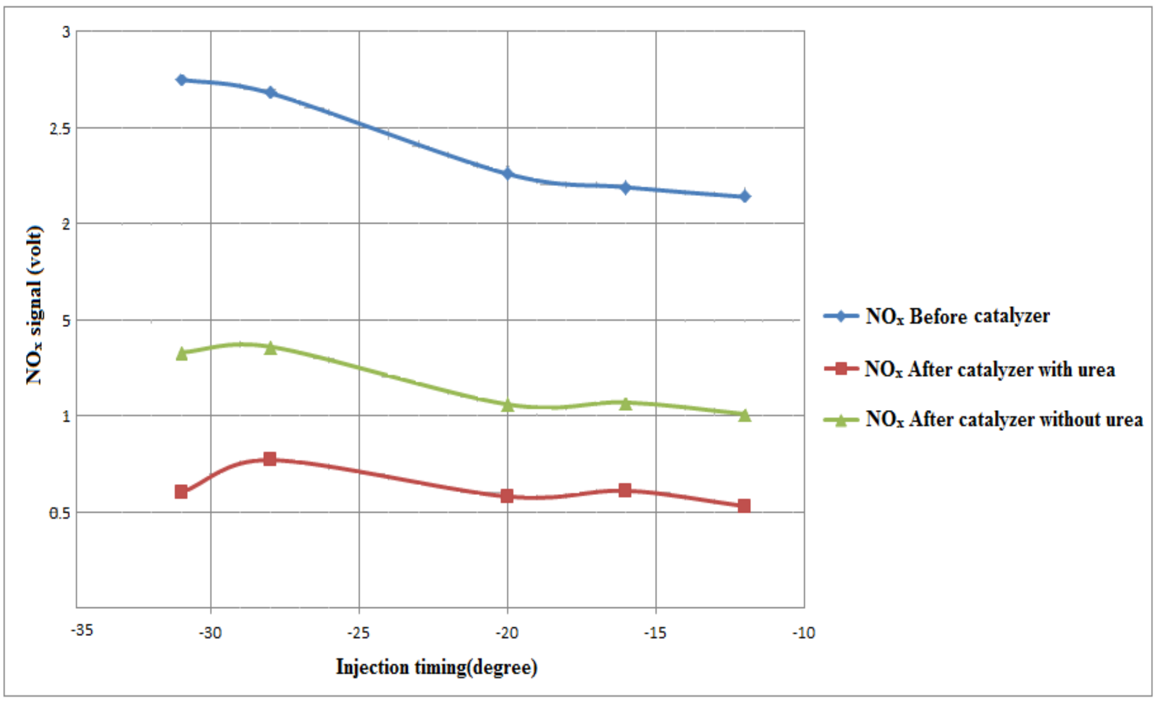

Figure (4.5): Effect of the injection timing on the NOx signal before and after catalytic converter with and without urea injection.

4.4.4 Effect of Urea Injection Quantity

In this project direct gasoline injector used for injection urea before catalytic converter and the flow rate of this injector is (2 mg/s) at constant urea pressure 5 bar [30].

In this experiment we study the effect of the various urea injection quantities at constant engine speed on the output NOx sensor and the efficiency of the catalytic converter before and after urea injection

4.4.4.1 Effect of Urea Injection Quantity at 2000 RPM

Output NO_X signal before catalytic converter at 2000 RPM is constant and NOx signal after catalytic converter is decreased with increase of the urea injection quantity. When urea injection quantity is more than 2 mg the output signal after catalytic convert remains constant as shown in figure (4.6)

The output signal for NOx sensor before and after catalytic converter at constant engine speed 2000 RPM and various urea injection quantities are illustrated in table (4.5).

Table (4.5): Output signals for NOx sensors before and after catalytic converter at constant engine speed 2000 RPM

Urea Injection quantity (mg)	Time (second)	NOx Before Catalyzer (volt)	NOx After Catalyzer with urea injection (volt)	Efficiency with urea injection
0	0	2.28	1.21	0.47
0.5	0.25	2.29	0.79	0.65
1	0.5	2.29	0.70	0.69
1.5	0.75	2.29	0.59	0.74
2	1	2.30	0.53	0.77
2.5	1.25	2.31	0.53	0.77
3	1.5	2.31	0.55	0.76
4	2	2.30	0.53	0.77

The efficiency of the catalytic converter with various urea injection quantities illustrated in figure (4.7). The efficiency remains constant when urea injection quantity reaches 2 mg. Despite of the injection quantity is still increasing over this value (2mg), the efficiency almost remains constant.

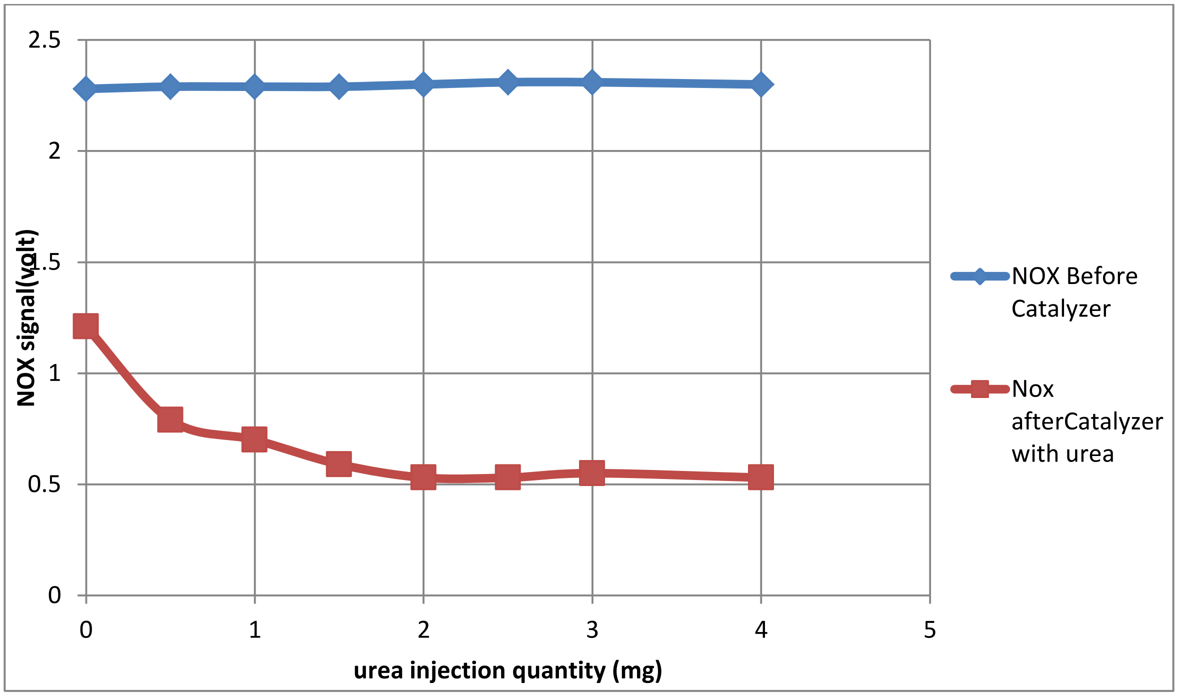

Figure (4.6): Effect of urea injection quantity on the NOx signal after catalytic converter at constant engine speed 2000 RPM

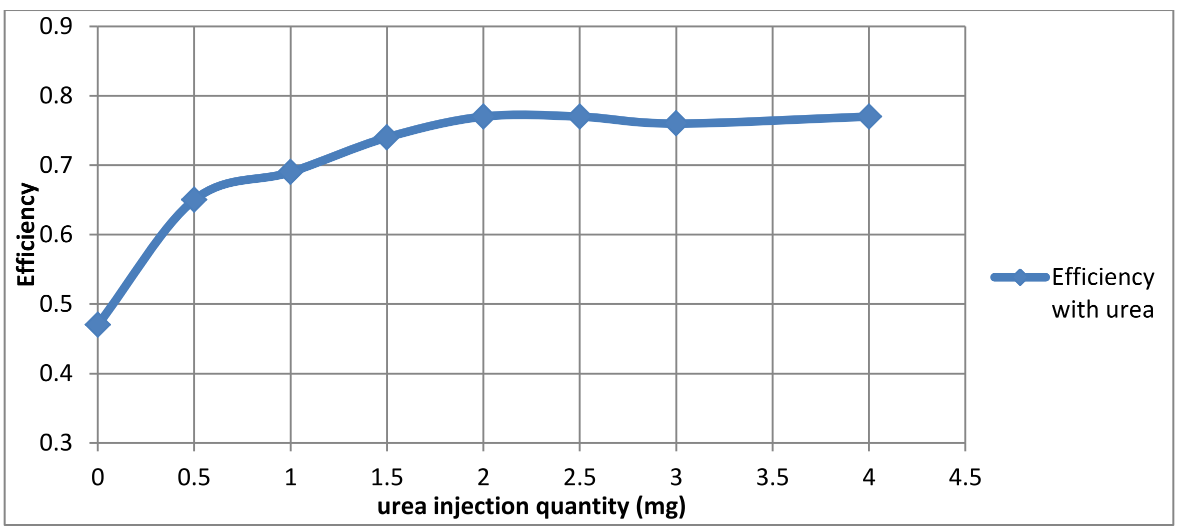

Figure (4.7): Effect of urea injection quantity on the catalytic converter efficiency at constant engine speed 2000 RPM.

4.4.4.2 Effect of Urea Injection Quantity at 3000 RPM

Output NO_X signal before catalytic converter at 3000 RPM is constant and NOx signal after catalytic converter is decreased when increased the urea injection quantity, when urea injection quantity is more than 2.5 mg the output signal after catalytic convert remain constant as shown in figure (4.8)

The output signal for NOx sensor before and after catalytic converter at constant engine speed 3000 RPM and various urea injection quantities are illustrated in table (4.6).

Table (4.6): Output signals for NOx sensors before and after catalytic converter at constant engine speed 3000 RPM

Urea Injection quantity(urea) (mg)	Time (second)	NOx Before Catalyzer (volt)	NOx After Catalyzer with urea injection (volt)	Efficiency with urea injection
0	0	2.28	1.42	0.51
1	0.5	2.29	0.84	0.63
1.5	0.75	2.29	0.73	0.68
2	1	2.30	0.66	0.71
2.5	1.25	2.31	0.57	0.75
3	1.5	2.31	0.57	0.75
4	2	2.30	0.59	0.74

The efficiency of the catalytic converter at various urea injection quantities illustrated in figure (4.9), the efficiency remains constant when urea injection quantity reached 2.5 mg. Despite of the injection quantity is still increase increasing over this value (2.5mg), the efficiency almost remains constant

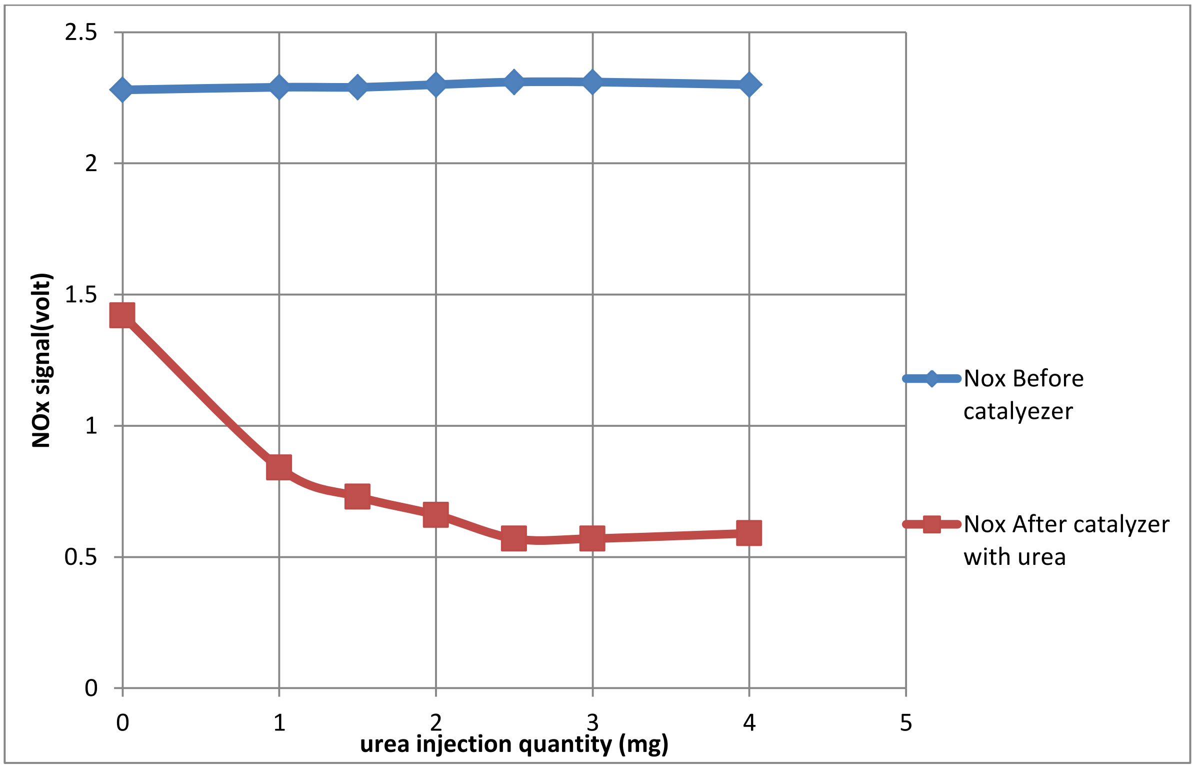

Figure (4.8): Effect of urea injection quantity on the NOx signal after catalytic converter at constant engine speed 3000 RPM.

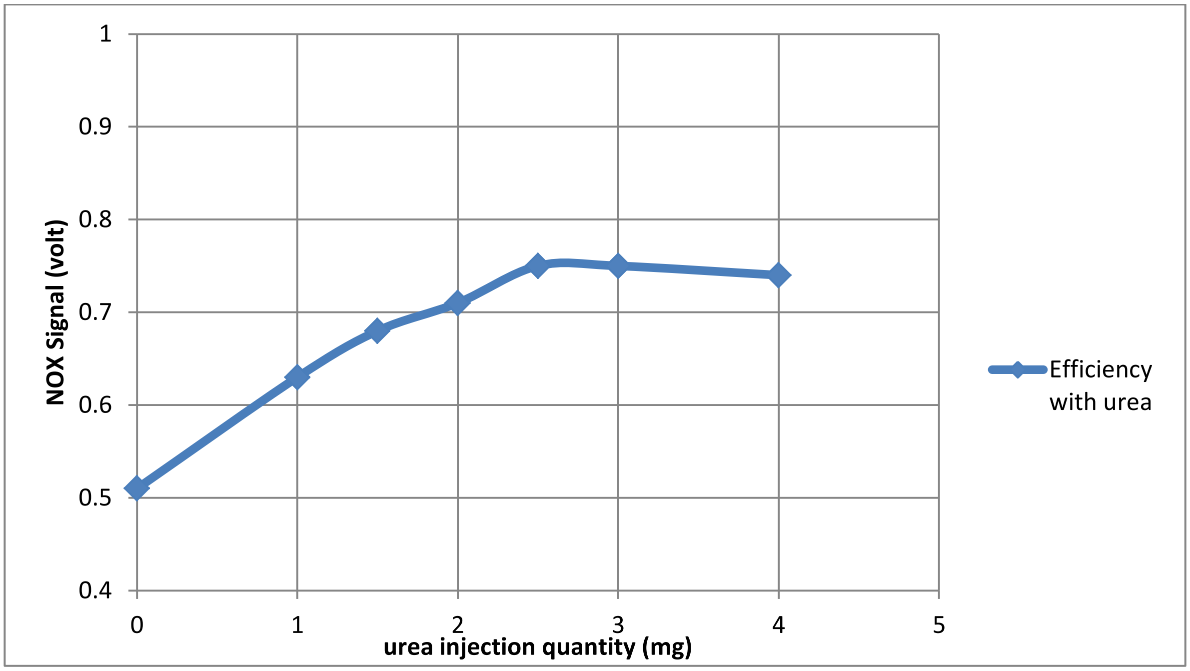

Figure (4.9): Effect of urea injection quantity on the catalytic converter efficiency at constant engine speed 3000 RPM.

4.5 CO Analysis

The concentration of CO emission depends on engine operational parameters such as engine speed, injection timing, A/F. CO results from incomplete combustion, and when the temperature of gases is high.

4.5.1 Effect of Engine Speed

Increasing engine speed reducing the total heat transfer from burned gases, lead to increasing gases temperature, resulting in increasing the concentration of CO emission.

The output signal from CO sensor after catalytic converter is reduced with urea injection at the same engine speed and efficiency of the catalytic converter is increased too. The output signals from CO sensor before and after catalytic convert at various engine speeds are illustrated in table (4.7).

Table (4.7): Output signal from CO sensors and at various engine speed.

Engine speed	CO Before catalytic converter	With urea		Without urea	
		CO After catalytic converter	Efficiency	CO After catalytic converter	Efficiency
890	1.32	0.33	0.75	0.63	0.52
1500	1.64	0.42	0.74	0.83	0.49
2000	2.36	0.63	0.73	1.22	0.48
2500	2.32	0.70	0.73	1.1	0.52
3000	2.24	0.56	0.75	1.05	0.53
3500	2.19	0.63	0.71	1.18	0.46

The effect of engine speed on the output signals of CO sensor before and after catalytic converter with injection and without injection urea are shown in figure (4.10)

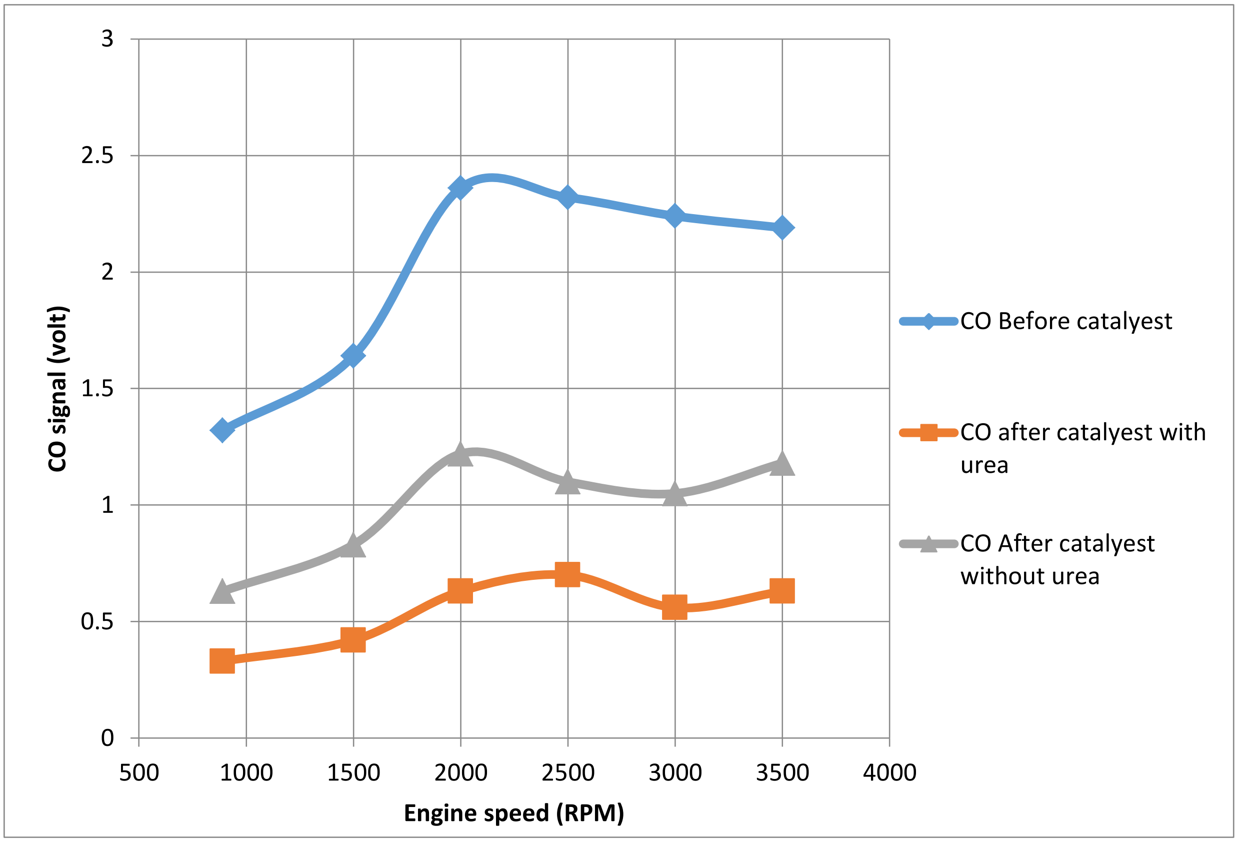

Figure (4.10): Effect of engine speed on the output CO signal before and after catalytic converter.

4.5.2 Effect of Air Fuel Ratio

For fuel lean mixture higher than 18:1, CO concentration in the exhaust decreases with increasing A/F, because the mixture become more lean and the oxygen rate is increases which will react with CO in the catalytic converter to produce CO_2 according to equation (4.1) resulting in decreasing the concentration of CO.

$$2CO + O_2 \rightarrow 2CO_2 \qquad (4.1)$$

The output signals from CO sensor after catalytic converter will decreases with injection urea, and the efficiency of the catalytic converter is increased.

The output signals from CO sensor before and after catalytic convert at various A/F ratio are illustrated in table (4.8).

The effect of A/F ratio on the output signal of CO sensor before and after catalytic converter with injection and without injection urea is shown in figure (4.11).

Table (4.8): Output signals from CO sensors and catalytic converter efficiency at various A/F ratio.

Engine Speed (RPM)	Air mass mg/stroke	Injection quantity mg/stroke	A/F	CO Before catalytic converter (Volt)	Without urea injection		With urea injection	
					CO after catalytic converter (Volt)	efficiency of catalytic converter	CO after catalytic converter (Volt)	Efficiency of catalytic converter
890	430	5.50	78	1.36	0.63	0.53	0.32	0.76
1500	463	6	77	1.63	0.71	0.56	0.40	0.75
2000	501	6.75	74	2.38	1.02	0.57	0.66	0.72
2500	539	7.50	71	2.33	1.16	0.50	0.72	0.69
3000	577	8.75	65	2.26	1.01	0.56	0.61	0.73
3500	620	10	62	2.19	0.91	0.58	0.65	0.70

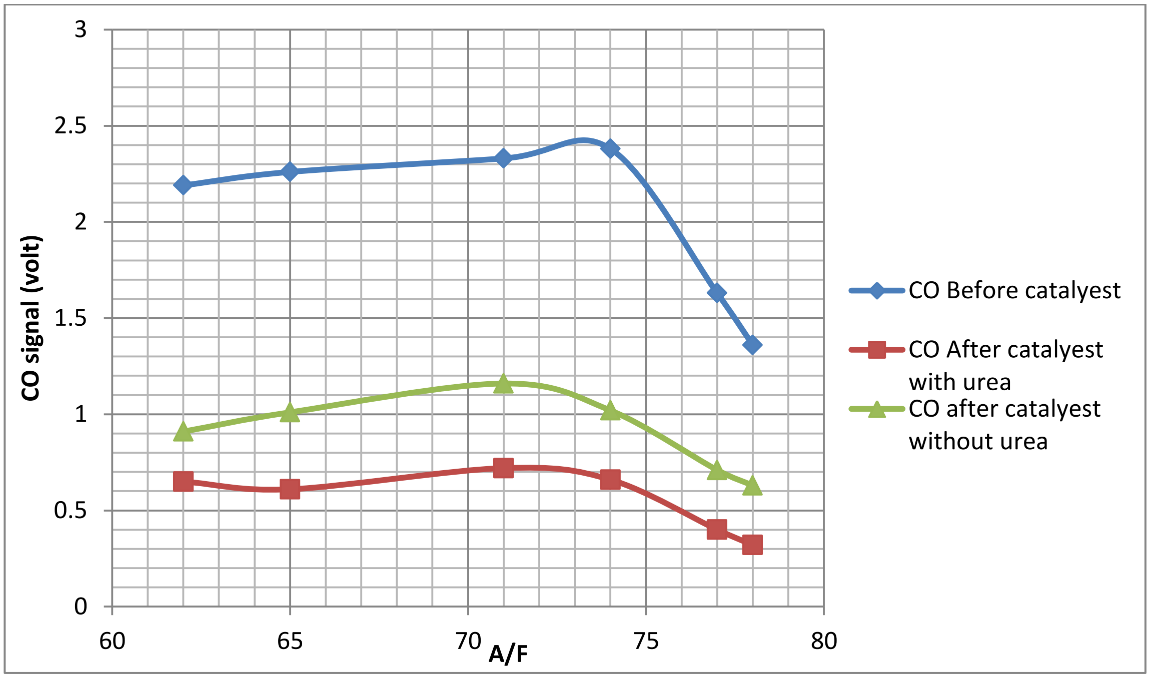

Figure (4.11): Effect of A/F on the output signal of CO sensors before and after catalytic converter.

4.5.3 Effect of Diesel Injection Timing

Advancing injection timing increases the temperature of burnt gases, and the rate of CO emission, because of the dissociation of CO_2 to CO at high temperature, where retarding the timing reduces the temperature and the concentration of the CO too.

The output signals from CO sensor after catalytic converter will decreases with injection urea, and the efficiency of the catalytic converter is increased. The output signals from

CO sensor before and after catalytic convert at various diesel injection timing are illustrated in table (4.9).

Table (4.9): Output signals from CO sensors and catalytic converter efficiency at various diesel injection timing.

Diesel Injection timing (degree)	Engine speed	CO Before catalyst	CO After catalyst with injection urea	Efficiency
-12	950	1.39	0.38	0.72
-16	1200	1.60	0.40	0.75
-20	1600	1.97	0.51	0.74
-28	2590	2.52	0.68	0.73
-31	2700	2.35	0.57	`0.76

The output signals of CO sensors before and after catalytic converter are illustrated in figure (4.12).

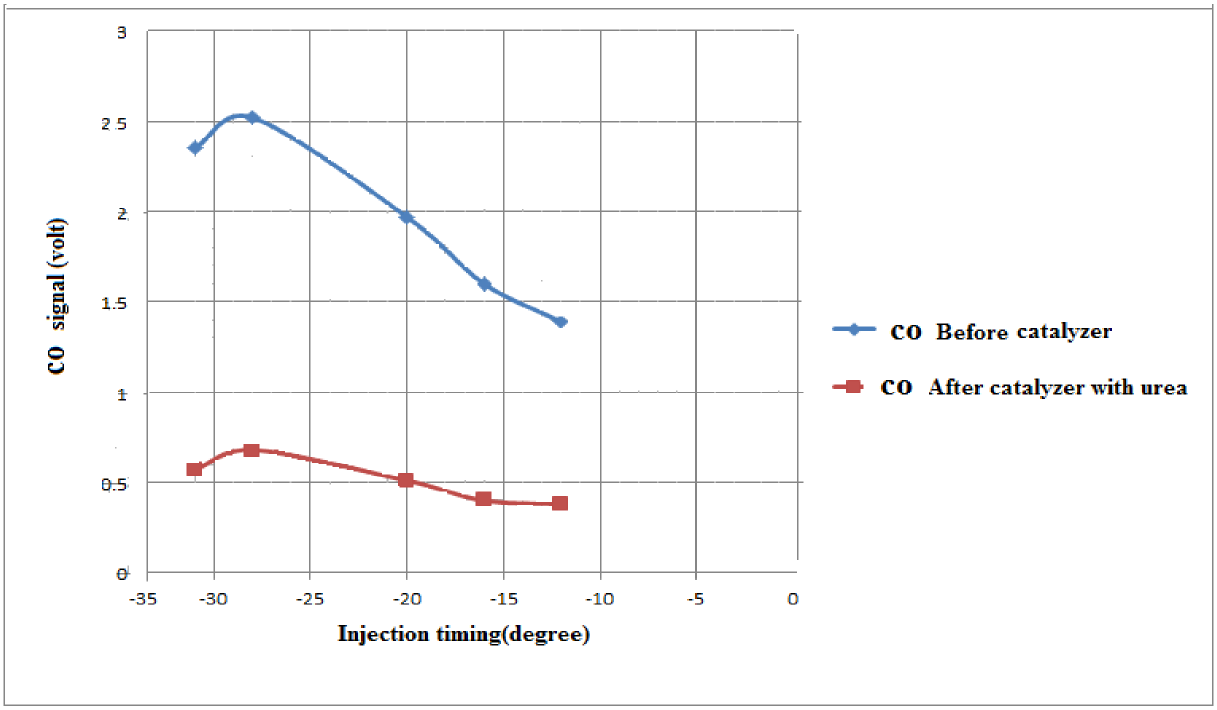

Figure (4.12): Effect of the injection timing on the CO signal before and after catalytic converter with and without urea injection.

4.5.4 Effect of Urea Injection Quantity

In this experiment we study the effect of changing urea injection quantities at constant engine speed 2000 RPM. The output CO signal before catalytic converter at 2000 RPM is constant, and CO signal after catalytic converter is decreased when increasing the urea injection quantity.

The output signal of CO sensor before and after catalytic converter at constant engine speed 2000 RPM and various urea injection quantities are illustrated in table (4.10)

Table (4.10): Output signals from CO sensors before and after catalytic converter at constant engine speed 2000 RPM.

Urea Injection quantity (mg)	Time (second)	CO Before catalyst (volt)	CO After catalysts with urea injection (volt)	EFFICENCY
0.5	0.25	2.38	0.78	0.67
1	0.5	2.38	0.73	0.69
1.5	0.75	2.36	0.63	0.73
2	1	2.36	0.66	0.72
2.5	1.25	2.37	0.64	0.73
3	1.5	2.38	0.64	0.73

When urea injection quantity is more than 1.7 mg the output signals after catalytic convert remain constant as shown in figure (4.13).

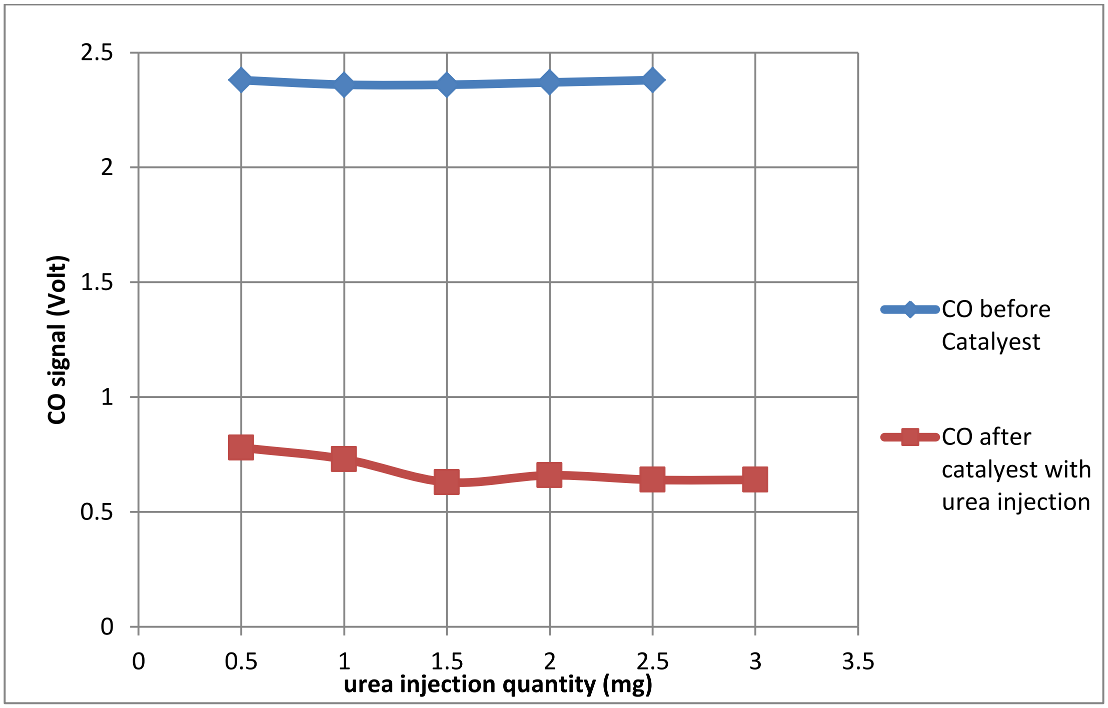

Figure (4.13): Effect of urea injection quantity on the CO signal after catalytic converter at constant engine speed 2000 RPM.

The efficiency of the catalytic converter at various urea injection quantity illustrated in figure (4.14), the efficiency remain constant when urea injection quantity reached 1.7 mg, after this value when the injection quantity still increased the efficiency remain constant.

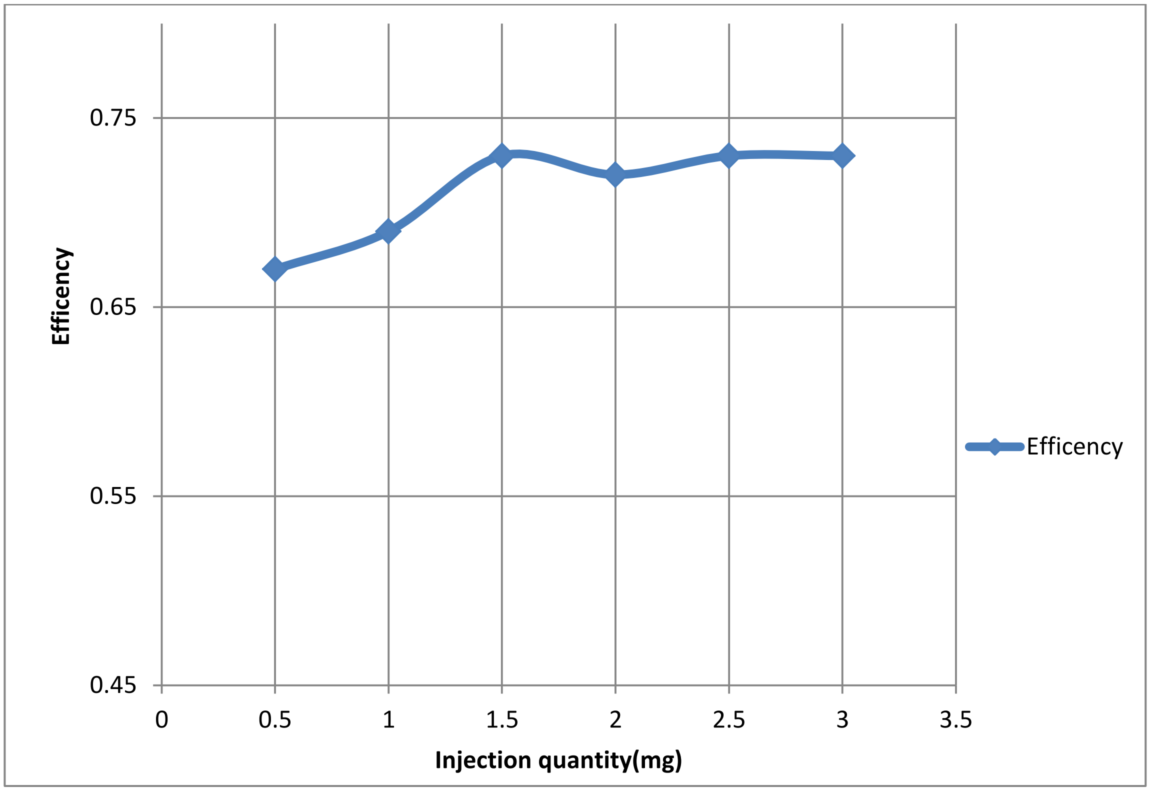

Figure (4.14): Effect of urea injection quantity on the catalytic converter efficiency.

Chapter Five

Conclusion and Recommendations

5.1 Conclusions

5.2 Recommendations

5.1 Conclusion

According to our study and experiments, we confirm the risks of the CO and NO_x emissions, and our treating system reduces their concentration and effect, and enhanced the efficiency of catalytic converter.

We see that it affected by engine operating parameters, we 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 of both CO and NO_x still decreasing. There is a point of chemical equilibrium and the excess amount leave the exhaust pipe without reacting in the form of ammonia.

There is slight deviation in our experiments results about the logic values. Because of the bad condition of the engine, high fuel consumption, many electrical parts must replace and some mechanical components must repair.

5.2 Recommendation

After performing the experiments and studying the results we reach these recommendations including the following:

1- We recommend to use another engine with for working, because it has many problems with accuracy in performing experiments and take the results, high fuel consumption and many electrical and mechanical components must replace.

2- We recommend to use gas analyzer for investigating the system, and to make calibration of the output signal of the sensors to know the exact concentration of these gases.

3- The gas analyzer determine the optimum amount of urea injection, an excess injection will increase the rate of ammonia and that is not efficient to treat some gases and other will increases.

4-To completion the system by studying the smoke and the effect of urea injection on its concentration, we recommend to use diesel particle filter (DPF) when working on smoke treatment.

5-we recommend to apply load on the engine using dynamometer to obtain more accurate result at different operational parameters.

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The time 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																
Literature Review																
Documentation of Literature Review																
Suggestion a Setup Project Design																
Writing First draft Report																
Presentation of First Semester																