PPU College Of Engineering and Technology

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**Mechanical Engineering Department**

**Automotive Engineering Program**

**Bachelor Thesis**

## Graduation Project

# The Effect of EGR on The Performance and Emissions of Engine Powered by Gasoline and LPG


Project Team

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# الإهداء

إلى الذين خضبت دماءهم تراب فلسطين الطهور، إلى شهداء فلسطين الميامين

إلى الذين صنعوا من صمودهم قصة كفاح وتحدي للسجّان، إلى الأسرى الصامدين خلف القضبان

إلى شعب فلسطين  المرابط على أرض الإسراء والمعراج وفي الشتات

إلى أمتنا العربية والإسلامية

إلى من سهروا على راحتنا، وكان همّهم الأول تقدمنا، آباءنا وأمهاتنا

إلى إخوتنا وأخواتنا وأهلنا وأقاربنا

إلى الدكتور زهدي سلهب، مشرف هذا المشروع

إلى أصدقاءنا وأحباءنا و كل من لهُ فضل علينا

إليكم جميعا نهدي هذا العمل المتواضع الذي نسأل فيه رضى الله عز وجل وأن يوفقنا لما يحب ويرضى

والله وليّ التوفيق ،،

**فريق المشروع**

## شكر و تقدير

- الشكر و الإمتنان إلى الله الذي أعطانا القدرة و الاستعداد لبدء واستكمال هذا المشروع
- الشكر إلى آبائنا و أمهاتنا و الأخوة والأخوات ، والأصدقاء على دعمهم و تشجيعهم
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**فريق المشروع**

# Abstract

Internal combustion engines are one of the sources of harmful pollution to the environment and human health, through which gases are emitted from the exhaust nozzle, as carbon monoxide (CO), unburned hydrocarbons (HC) and nitrogen oxides ($NO_x$). Because in recent years from the significant increase in the number of vehicles on the world roads and the consequent increase in the amount of exhaust emitted as a result of this increase.

The scientists and automotive engineers are produced several effective ways to reduce the largest possible quantity of emissions without affecting the power of the engine, one of these methods, which proved to be effective is to use exhaust gas recirculation (EGR).

In this project the research team will study experimentally the effect of EGR on the engine performance, emissions, and powered by gasoline and liquefied petroleum gas (LPG), and design a mechanical EGR to investigate its impact on engine performance and emissions with and without EGR for both fuels. This design is used to avoid the complexity of the programming Electronic Control Unit (ECU).

The importance of this project is study the EGR effect on the engine power, percentage of emission and fuel consumption, then comparison this effect with gasoline and LPG engine. and to protect the environment and human health from $NO_x$ emission.

The results obtained without used EGR in gasoline and LPG indicate to brake power of LPG is less about 21% than gasoline and brake fuel consumption of LPG is less 23.6% than gasoline and the $NO_X$, CO, CO2 emissions are reduced in LPG, while the higher hydrocarbons (HC) emissions were obtained in LPG compared with gasoline. On the other hand the results obtained without used EGR in gasoline and LPG indicate to brake power of LPG is less about 24% than gasoline and brake fuel consumption of LPG is less 27% than gasoline and the $NO_X$ decrease in both fuel. CO, HC are increased in both fuel.

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
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# Chapter One

## Introduction

- Importance of the study.
- Study objectives.
- Methodology of the study.
- Gasoline.
- Liquefied petroleum gas (LPG).
- How safe are LPG vehicles?
- Advantages and Disadvantages of LPG.

## 1.1 Importance of the study:

Motor vehicles are considered as a significant source of pollution that can damage the environment and human health. Air pollution from motor vehicles is the result of fuel burning in the engine. Harmful chemicals are produced during combustion process and released as exhaust gases. These chemicals cause a variety for human health and environmental problems.

The importance of this project is to protect the environment and human health from exhaust gases, by reducing these gases using mechanical exhaust gas recirculation (EGR). An experimental engine is modified to run on gasoline and LPG to attain this goal, particularly nitrogen oxides by more than 80 %.

## 1.2 Study objectives:

1) Comparison the performance and emissions parameters of the engine powered by both fuels without using EGR.

2) Design a mechanical EGR, and investigate its impact on engine performance and emissions using both fuels (with EGR).

## 1.3 Methodology of the study:

The study is relied on the experimental method, data collection and analyzing the results.

The research team will designed experiments applying the following procedure:

1) Checking engine and improve it's ability to work.
2) Switch on the engine.
3) Using dynamometer to measure the brake power and fuel consumption.
4) Using Exhaust Gas Analyzer to evaluate the emissions.
5) Designing Mechanical EGR.
6) Installing EGR on the engine.
7) Using dynamometer to measure the brake power and fuel consumption.
8) Using Exhaust Gas Analyzer to evaluate the emissions.
9) Compare the results with and without EGR.
10) Record the final conclusion of using EGR.

## 1.4 Gasoline

Gasoline, also called gas (United States and Canada), or petrol (Great Britain) or benzene (Europe) is a mixture of hydrocarbons that usually boil below 180°C or, at most, below 200°C. [1]

Gasoline ($C_8H_{16}$) is a mixture of about 150 chemicals refined from crude oil. It's usually a colorless, light brown or pink liquid. Gasoline is used in cars, boats, motorcycles, lawn mowers and other engines. Gasoline usually contains additives affecting the way it burns (A separate chemical fact sheet is available for MTBE, an additive used to reduce air pollution).

Gasoline evaporates quickly when exposed to air. Most gasoline spilled in lakes, streams or soil evaporates. Some spilled gasoline can seep into groundwater and remain unchanged for years. Private Wells located near a spill or a buried leaking tank may become contaminated. Scientists refer to gasoline components that mix with water as gasoline range organics (GRO).

- **Some of properties of gasoline**

Table 1.1: Some of properties of gasoline. [3]

| Formula (phase) | Molecular Weight | Specific gravity (Kg/$m^3$) | Specific heat (KJ/Kg) L | Higher heating Value(MJ/kg) | Air/Fuel ratio |
|---|---|---|---|---|---|
| $C_nH_{1.87n}$ | 110 | 0.72-0.78 | 2.4 | 47.3 | 14.6 |

## 1.5 Liquefied Petroleum Gas (LPG)

Liquefied petroleum gas (LPG) is the term applied to certain specific hydrocarbons and their mixtures, which exist in the gaseous state under atmospheric ambient conditions but can be converted to the liquid state under conditions of moderate pressure at ambient temperature. [2]

LPG is mostly propane ($C_3H_8$), butane ($C_4H_{10}$) or a mix of the two. It also includes ethane, ethylene, propylene, butylene, isobutene and isobutylene; these are used primarily as chemical feed stocks rather than fuel.

### 1.5.1 The Combustion of LPG

When LPG is burnt in enclosed spaces, adequate ventilation must be provided. Otherwise asphyxiation, directly due to the depletion of oxygen and the formation of carbon dioxide, will rapidly occur.

Incomplete combustion products, such as carbon monoxide, will also be produced when there is insufficient air for correct combustion. Carbon dioxide is an asphyxiate gas, and carbon monoxide is toxic.

### 1.5.2 Physical and Chemical Properties of LPG

The physical properties of LPG owe their characteristics to their chemical composition. The following properties of these gases are normally most significant.

Table 1.2: Typical Physical and Chemical Properties of LPG. [5]

| | Relative Density | Higher Heating Value kJ/mol | Air/Fuel ratio- $m^3$of air to $m^3$of Fuel | Flame Temp. ℃ | Flame Speed m/s |
|---|---|---|---|---|---|
| Propane | 1.52 | 2220 | 25 | 1967 | 0.460 |
| Butane | 1.96 | 2877 | 32 | 1973 | 0.870 |

## 1.6 How safe are LPG Vehicles?

Any motor fuel can be dangerous if handled improperly. Fuels contain energy, which must be released by burning. Gasoline is a potentially dangerous fuel, but over time, we have learned to use it safely. The same is true for LPG. LPG safely generates our electricity, heats our homes and cooks our meals. But like gasoline, LPG must be understood and respected to be used safety. [6]

## 1.7 Advantages and Disadvantages of LPG:

Liquefied petroleum gas has higher potential as an alternate fuel for internal combustion engines. Compared to nature gas which has more positive points. [3]

### 1.7.1 Advantages of LPG:

1) LPG contains less carbon than petrol. LPG powered vehicle produces 50 per cent less carbon monoxide per kilometer, though only slightly less nitrogen compounds. Therefore emission is much reduced by the use of LPG.

2) LPG mixes with air at all temperatures.

3) In multi-cylinder engines a uniform mixture can be supplied to all cylinders.

4) There is no crankcase dilution, because the fuel is in the form of vapor.

5) Automobile engines can use propane, if they have high compression ratios (10:1).

6) Its heat energy is about 80 per cent of gasoline, but its high octane value compensates the thermal efficiency of the engine.

7) Running on LPG translates into a cost saving of about 50%.

8) The engine may have a 50 per cent longer life.

### 1.7.2 Disadvantages of LPG:

1) Engines are normally designed to take in a fixed volume of the mixture of fuel and air. Therefore LPG will produce 10 per cent less horse power for a given engine, at full throttle.

2) The ignition temperature of LPG is somewhat higher than petrol. Therefore running on LPG could lead to a five per cent reduction in valve life.

3) A good cooling system is quite necessary, because LPG vaporizer uses engine coolant to provide the heat to convert the liquid LPG to gas.

4) The vehicle weight is increased due to the use of heavy pressure cylinders for storing LPG.

5) A special fuel feed system is required for liquid petroleum gas.

Table 1.3: Comparison of Petrol and LPG. [3]

| Petrol | Liquefied Petroleum Gas ( LPG ) |
|---|---|
| Fuel consumption in petrol engine is less when compared to LPG | Compared to petrol, running the engine on LPG results in around a 10% increase in consumption. |
| Petrol has odour | LPG is adourless |
| Octane rating of petrol is 81 | Octane rating of LPG is 110 |
| Petrol engine isn't as smooth as LPG engine | Due to higher octane rating, the combustion of LPG is smoother and knocking is eliminated and the engine runs smoothly. |
| In order to increase octane number petrol required lead additives. | LPG is lad-free with high octane number |
| The mixture of petrol and air always leaks past the piston rings and washes away the lubricating oil from the upper cylinder wall surface in the process. This results in lack of lubricant which causes more wear. It also carries with it unburnt fuel components (black carbon) and falls into the engine oil. Thus the life of petrol engine is shorter. | When LPG leaks past the rings into the crankcase, it doesn't wash oil from cylinder walls and doesn't generate black carbon. Hence, the lubricating layer is not washed away. Thereby, the engine life is increased by 50% |
| Due to formation of carbon deposits on the spark plugs, the life of the spark plugs is shortened. | Due to absence of carbon deposits on the electrodes of the spark plugs, the life of the spark plugs is increased. |
| Carburetor supplies the mixture of petrol and air in the proper ratio to the engine cylinders for combustion. | The vaporizer functions as the carburetor when the engine runs on LPG. It is a control device that reduces LPG pressure, vaporizes it and supplies to the engine with a regular flow of gas as per the engine requirement. |

# Chapter Two

# Engines Emissions

- Introduction.
- Sources of vehicles emissions.
- Exhaust Emissions.
- Health and environmental aspects of air pollution from motor vehicles.
- Control and reducing emission method.

## 2.1 Introduction:

The enormous increase in the use of fossil energy sources in world, in particular, has caused increased pollution of the air, the vehicle exhaust emissions is one of the most important sources of pollution.

Internal combustion engines generate undesirable emissions during the combustion process, the emissions exhausted into the surrounding pollute the atmosphere and cause problems such as global warming, acid rain, smog, odours, and health hazard.

Examples of the harmful gases emitted from vehicle engines are hydrocarbons, nitrogen oxides ($NO_x$), and carbon monoxide (CO).

In this chapter, the research team explained how to configure the gases emitted from vehicle engines and explain the damage resulting from gases.

## 2.2 Sources of Vehicles Emissions:

There are many sources lead to vehicles emission such as:

1) Exhaust Pipe:

The main source for gases emission vehicles produced from combustion processes and which contribute in large pollution ($HC, NO_x, CO, CO_2$).

2) Fuel Tank:

The fuel tank emits fuel vapors into the atmosphere. As the temperature inside the engine rises, the fuel tank heats up. The air inside the fuel tank expands, part of which goes out through the tank vent tube or leaves through the vent of the cap in the tank. This air is mixed with gasoline vapours.

As the temperature decreases, the tank cools. The air inside the tank contracts and there is more space inside the tank. Air enters the tank from the atmosphere and ventilates it. This process of ventilation is called breathing. [3]

3) Crankcase:

It emits blow-by gases and fuel vapors into the atmosphere.

## 2.3 Exhaust Emissions:

The major exhaust emission in SI engine are:[3]&[6]

1) Hydrocarbons (HC).
2) Nitrogen oxides ($NO_x$).
3) Carbon Monoxide ($CO$).
4) Carbon Dioxide ($CO_2$).
5) Particular matters (PM)

### 2.3.1 Hydrocarbons:

Hydrocarbons emissions result from the presence of unburned fuel in the engine exhaust. However, some of the exhaust hydrocarbons are not found in the fuel, but are hydrocarbons derived from the fuel whose structure was altered due to chemical reaction that did not go to completion.

The causes for hydrocarbon emissions from engine are:

1) Incomplete combustion.
2) Crevice volumes and flow in crevices.
3) Leakage past the exhaust valve.
4) Valve overlap.
5) Deposits on walls and valves.
6) Oil on combustion chamber walls.

### 2.3.2 Nitrogen Oxides ($NO_x$):

Exhaust gases of an engine can have up to 2000 ppm of oxides of nitrogen. Most of this will be nitrogen oxide (NO). NO is formed during the post flame combustion process in a high temperature region.

The principal source of NO formation is the oxidation of the nitrogen present in atmospheric air. The nitric oxide formation chain reactions are initiated by atomic oxygen, which forms from the dissociation of oxygen molecules at the high temperatures reached during the combustion process. The principal reactions governing the formation of NO from molecular nitrogen are:

$$O + N_2 \rightarrow NO + N \qquad (2.1)$$

$$N + O_2 \rightarrow NO + O \qquad (2.2)$$

$$N + OH \rightarrow NO + H \qquad (2.3)$$

### 2.3.3 Carbon Monoxide (CO):

Carbon monoxides is a colorless and odorless but a poisonous gas. It is generated in an engine when it operates with a rich mixture and also there are: [3]

- Incomplete combustion

When there is not enough oxygen to convert all carbon to $CO_2$.

- Dissociation

CO concentration increases rapidly in the flame zone.

$$CO_2 \rightarrow CO + \frac{1}{2}O_2 \qquad (2.4)$$

- Freezing

In the expansion stroke, the velocity of flame is reduced and the temperature is also reduced (K<1500) so the flame will be quenched and the reaction will also be stopped (breezed).

The figure shown below illustrate the concentrations of emissions versus air-fuel ratio[7].

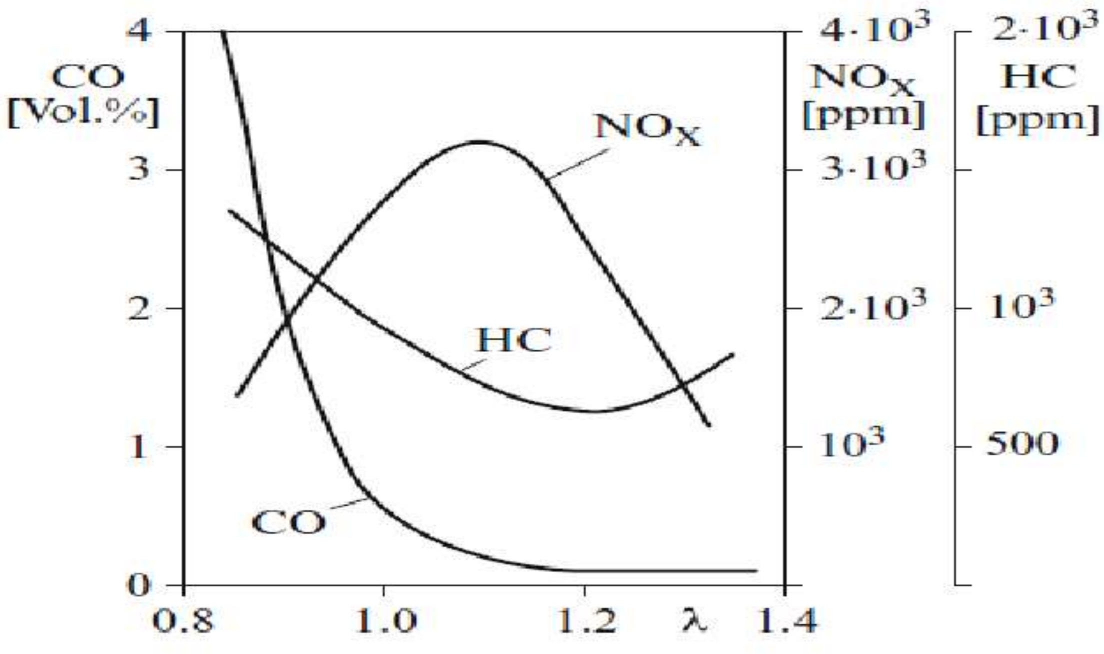


Figure 2.1: Emission as a function of excess air ratio (λ) for an SI engine.

## 2.4 Health and Environmental Aspects of Air Pollution from Vehicles Motor:

An air pollution is measured by the changes occur on composition reflected on the living creatures on earth which affects them in different ways. The effect of exhaust pollution are.[9]

- **Hydrocarbons (HC):**

A major component of smog. Ozone irritates the eyes, damages the lungs, and aggravates respiratory problems. It is our most widespread, with the potential to cause cancer.

- **Nitrogen Oxides ($NO_x$):**

Like hydrocarbons, are precursors to the formation of ozone. They also contribute to the formation of acid rain. They are toxic and colorless gasses, cause damage the lungs, irritation the eye and throat.

- **Carbon Monoxide (CO):**

Carbon monoxide reduces the flow of oxygen in the blood stream and is particularly dangerous to persons with heart disease.

- **Carbon Dioxide ($CO_2$):**

Carbon dioxide does not directly impair human health, but it is a “greenhouse gas” that traps the earth’s heat and contributes to the potential for global warming.

## 2.5 Control and Reducing Emission Method: [8]

By identifying the health and environmental damage caused by emissions of the engines, governments set the rates of certain gases, the auto engineers making several ways to reduce these gases.

Some of these methods to control and minimize the ratio of gases: EGR valve, catalytic converter, Secondary Air Injection, charcoal canister, and manifold with low thermal capacity

EGR is the most effective way of reducing $NO_x$ emissions to hold combustion chamber temperatures down. The next chapter shows and explains the EGR.

# Chapter Three

# Exhaust Gas Recirculation

- Introduction.
- Definition of the Exhaust Gas Recirculation (EGR).
- EGR Technique for $NO_x$ Reduction.
- Operating Condition of the EGR.
- Classification of EGR Systems.
- Types of EGR Valve.
- Advantages of EGR.
- Disadvantages and Difficulties of EGR.
- EGR Operating Concept.

## 3.1 Introduction:

Over recent past years, stringent emission legislations have been imposed on $NO_x$from automotive engines worldwide. EGR is the most effective way to reduce emission, practically $NO_x$.

This chapter discussed the definition EGR and advantages and disadvantages of the EGR.

## 3.2 Definition of the Exhaust Gas Recirculation (EGR):

The EGR system reduces $NO_x$ production by recirculating small amounts of exhaust gases into the intake manifold where it mixes with the incoming air/fuel charge. By diluting air/fuel mixture under these conditions, peak combustion temperatures and pressures are reduced, resulting in an overall reduction of $NO_x$ output**.** $NO_x$is formed in high concentration whenever combustion temperatures exceed 2500 K [9].

## 3.3 EGR Technique for $NO_x$ Reduction:

EGR is a useful technique for reducing $NO_x$ formation in the combustion chamber. The exhaust consists of $CO_2$, $N_2$and water vapours mainly. When a part of this exhaust gas is re-circulated to the cylinder, it acts as diluent to the combusting mixture. This also reduces the $O_2$ concentration in the combustion chamber. The specific heat of the EGR is much higher than fresh air, hence EGR increases the heat capacity (specific heat) of the intake charge, thus decreasing the temperature rise for the same heat release in the combustion chamber.

Three popular explanations for the effect of EGR on $NO_x$ reduction are increased ignition delay, increased heat capacity and dilution of the intake charge with inert gases. The ignition delay hypothesis asserts that because EGR causes an increase in ignition delay, it has the same effect as retarding the injection timing. The heat capacity hypothesis states that the addition of the inert exhaust gas into the intake increases the heat capacity (specific heat) of the non-reacting matter present during the combustion. The increased heat capacity has the effect of lowering the peak combustion temperature. According to the dilution theory, the effect of EGR on $NO_x$ is caused by increasing amounts of inert gases in the mixture, which reduces the adiabatic flame temperature [10].

## 3.4 Operating Condition of the EGR:

The amount of re-circulated gas in the combustion chamber is dependent on the following operating conditions: [9]

1) High EGR flow is necessary during cruising and mid-range acceleration, when combustion temperatures are very high.

2) Low EGR flow is needed during low speed and light load conditions.

3) No EGR flow should occur when it could adversely affect engine operating efficiency or vehicle drivability (engine warm up, idle open throttle, and act).

## 3.5 Classification of EGR Systems:

Various EGR systems have been classified on the basis of EGR temperature, configuration and pressure. [10]

3.5.1 Classification Based On Temperature.

3.5.2 Classification Based On Configuration.

3.5.3 Classification Based On Pressure.

## 3.6 Types of EGR Valve:

3.6.1 Ported EGR valves (1973 to 1980s).

3.6.2 Positive backpressure EGR valves (1973 & up).

3.6.3 Negative backpressure EGR valves (1973 & up).

3.6.4 Pulse-width modulated electronic EGR valves (early 1980s & up).

3.6.5 External Sensor.

## 3.7 Advantages of EGR:

1) The main objective of the EGR system lowering NOx.

2) The EGR system also helps control detonation *(*knock). Occurs when high pressure and heat cause the air-fuel mixture to ignite.

3) Using the EGR system allows for greater ignition timing advance and for the advance to occur sooner without detonation problems, which increases power and efficiency. [10]

## 3.8 Disadvantages and Difficulties of EGR:

1) Since EGR reduces the available oxygen in the cylinder, the production of particulates. Is increased when EGR is applied.

2) The deliberate reduction of the oxygen available in the cylinder will reduce the peak power available from the engine.

3) The EGR valve cannot respond instantly to changes in demand, and the exhaust gas takes time to flow around the EGR circuit.

4) The recirculated gas is normally introduced into the intake system before the intakes divide in a multi-cylinder engine. Despite this, perfect mixing of the gas is impossible to achieve at all engine speeds / loads and particularly during transient operation.

## 3.9 EGR Operating Concept:

1 Fresh air intake

2 Throttle valve

3 Recirculated exhaust gas

4 Engine ECU

5 EGR valve

6 Exhaust gas

*n* Engine rpm

*rl* Relative air charge

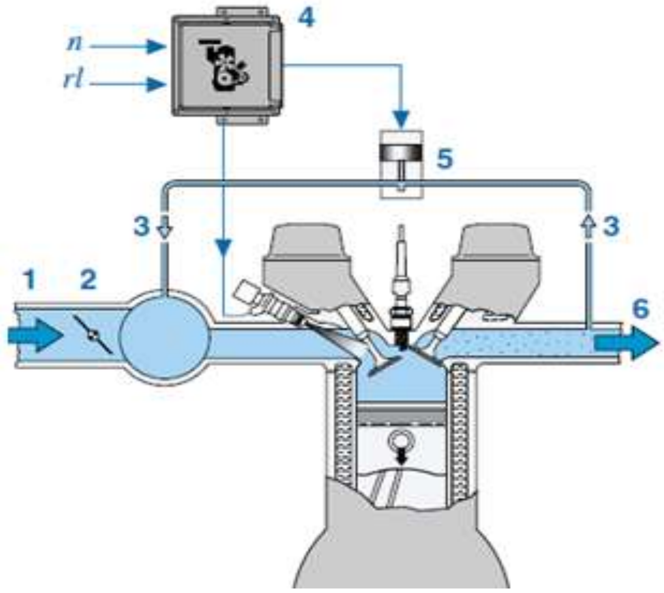


Figure 3.1: Structure of EGR system. [12]

# Chapter Four

## Design & Installation of EGR

- Introduction.
- Mechanical EGR Designing.
- The Equipments.
- Engine Parameter.

## 4.1 Introduction:

This chapter discusses the design of mechanical EGR and installation the test equipments intended to be used in the experiments.

## 4.2 Mechanical EGR Designing:

The proposed design of EGR system by the team research is illustrated in figure (4.1).

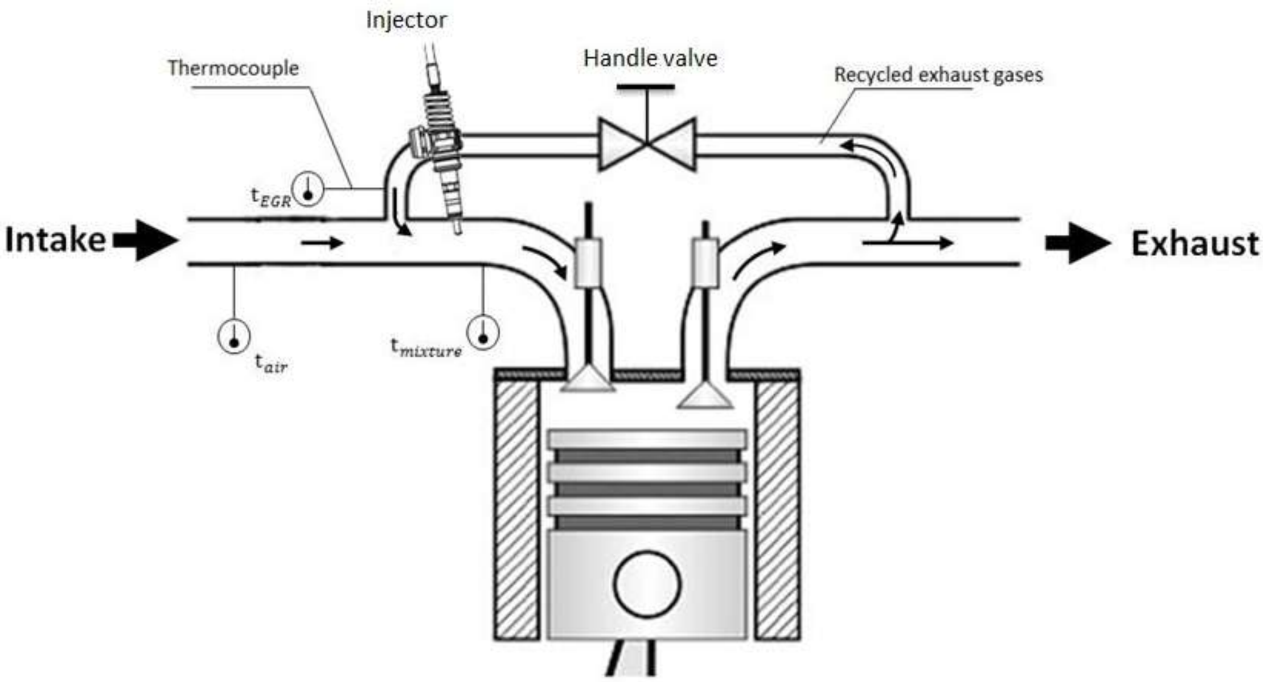


Figure 4.1: Structure of design and installation the EGR

Figure (4.1) shows how the exhaust gases will be adjusted by the handle valve and directly set to the inlet manifold.

This design contains three thermocouples; the function of the first one is to measure the exhaust gases temperature before entering the inlet manifold. The second one is used to measure the air temperature, while the function of the third thermocouple is to measure the mixture gases temperature (EGR, air and fuel) after injector.

## 4.3 The Equipments:

- Mazda 323i Engine.
- Engine Performance Test Stand (EPTS) with Vertical Instrument Panel.
- Exhaust Gas Analyzers.
- Fuel Tank with Glass Tube Scale.
- EGR Mechanical Control.
- Thermo Couple Sensors.

### 4.3.1 Mazda 323i Engine:

The Table (4.1) shows the engine technical specification.

Table 4.1: Engine Technical Specification. [13]

| Engine (general) | | |
|---|---|---|
| Item | Values | Units |
| Engine code | Z5 | |
| Capacity | 1489 | (cc) |
| Idle speed | 700 - 800 | (rpm) |
| Valve clearance | | |
| Hydraulic | | |
| Compression Pressure | | |
| Normal | 12.8 | (bar) |
| Minimum | 10.1 | (bar) |
| Oil pressure | 3.4 - 4.4/3000 | (bar / rpm) |
| Fuel system (make & type) | Mazda EGI | |
| Firing order | 1-3-4-2 | |
| Timing stroboscopic (before TDC) | $5\pm1$/700 - 800 | (° / rpm) |
| Ignition coil resistance, primary | 0.49 - 0.73 | (ohms) |
| Ignition coil resistance, secondary | 20000 - 31000 | (ohms) |
| Spark plugs (make & type) | NGK BKR5E11<br>Champion RC9YCC4 | |
| Spark plug gap | 1.0 - 1.1 | (mm) |
| Injection pressure / system pressure | 2.7 - 3.2 | (bar) |
| CO exhaust gas | < 0.5 | (%) |
| CO2 | 14.5 - 16.0 | (%) |
| HC | 100 | (ppm) |
| O2 | 0.1 - 0.5 | (%) |
| Lambda | 0.97 - 1.03 | |
| Lambda change (Delta Lambda) | 0.03 | |
| Oil temperature during test | 60 | (℃) |
| Fast-idle speed | 2500 - 2800 | (rpm) |
| CO at fast-idle speed | < 0.3 | (%) |

### 4.3.2 EPTS with Vertical Instrument Panel:

The THEPRA Engine Performance Test Stand with vertical Instrument Panel shown in Figure 4.2, has been developed for instructional use and performance tests.

The unit is light, compact and easy to install and is a most versatile instrument. The self-contained design of the engine performance Test Stand permits quick reinstallation from engine to engine by bolting the unit the crankcase of the engine to be tested.

Beyond this, the test stand is used for the measurement of forces and torques in engine suspensions,

Figure 4.2: Engine Performance Test Stand with Vertical Instrument Panel

The engine performance Test stand consists of turbine, bearing block arm of wag, water inlet pipe, water outlet pipe, torque meter, tachometer (revolution counter) and a load /unload valve.

Since the unite was old and there were manuals for the dynamometer which belong to. Our Knowledge of the system was also very limited .so we decided to fix the unit and to search in the internet to get more information about it. After that, we found that the technical name of the unit is THEPRA Engine performance Test Stand with vertical Instrument Panel and we get a little information about it.

The instrumentation of console: Tachometer and Torque meter (Nm). [14]

#### 4.3.2.1Engine Parameters:

The method most commonly employed to measure torque is show in the figure (4.3). The dynamometer is supported by bearing and restrained from rotation only by a strut Connected to a load cell. Whether the dynamometer is absorbing or providing power, a reaction torque is applied to the dynamometer. Hence, if the force is applied to the strut is F, and then the torque applied to the engine is: [15]

Engine torque (T): [N.m]

$$\mathrm{T} = \mathrm{F} \times \mathrm{R} \tag{4.1}$$

The power delivers from the engine and absorbed by the dynamometer is called break power, this power is the usable delivered by the engine to the load, and it is equal the product of torque and angular speed as:

$$\mathrm{bp} = \frac{2\pi NT}{60} \times 10^{-3} \tag{4.2}$$

Where:

T: engine torque [N.m]

N: engine speed [rpm]

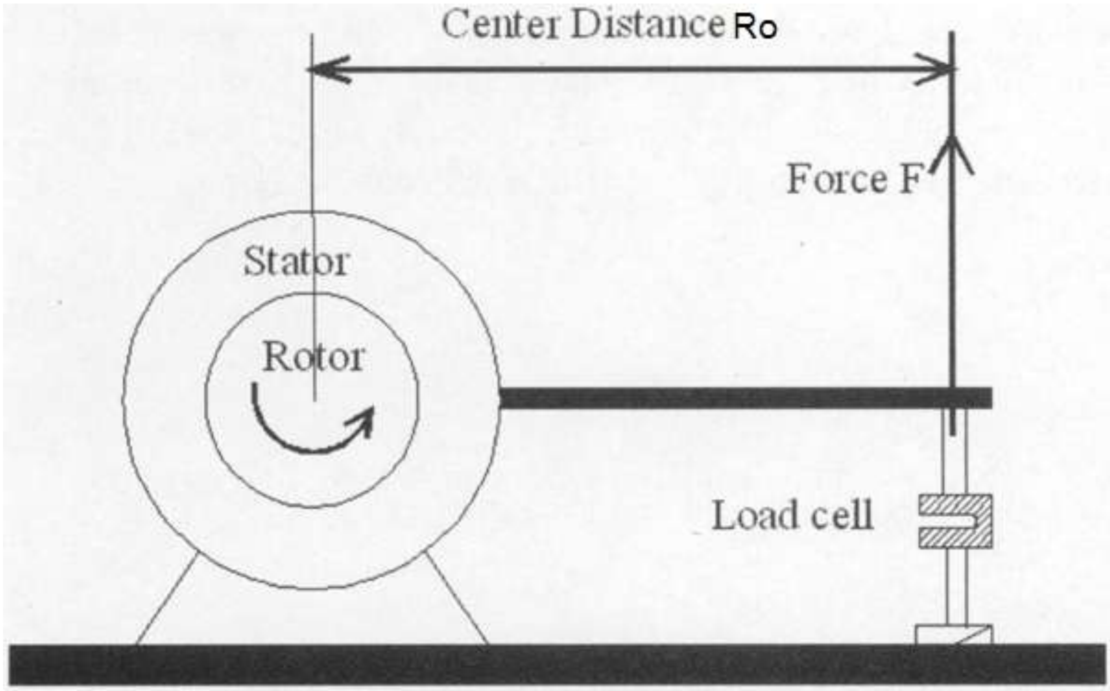


Figure 4.3: Measuring engine torque method

Note that torque is a measure of an engine ability to do work, power is the rate at which work is done.

### 4.3.3 Fuel Tank with Glass Tube Scale:

For measuring gasoline fuel consumption, a volumetric measuring method was needed.

Figure 4.4: Fuel Tanks with Glass Tube Scale

### 4.3.5 The SUN Diagnostic Gas Analyzer:

We used the SUN diagnostic gas analyzer, Figure (4.5) to measure:

- Carbone monoxide ($CO$)
- Hydrocarbons (HC)
- Nitrogen oxides ($NO_x$)
- Carbon dioxide ($CO_2$)


Figure 4.5: Gas Analyzer

### 4.3.6 Thermocouples Sensors:

A thermoelectric device was used to measure temperatures accurately, especially one consisting of two dissimilar metals joined so that a potential difference generated between the points of contact is a measure of the temperature difference between the points.

# Chapter Five

## Simulation &Installation of EGR system Components and Challenges through Building EGR system

- Introduction
- The main components of the EGR system
- Steps of work

## 5.1 Introduction:

After conducting the necessary studies of the components that should be available in the system, identify the function of each one of them.

First of all, collecting the ingredients, identify features that should be available in these components, and ability to perform the desired function in the best possible conditions.

The team faced many challenges .The most important of them are Lack of resources in the local market, difficulty in control and implementation of the system. However, the working group is to look for other resources and the use of alternatives as possible to minimize these challenges.

## 5.2 The main components of the EGR system:

1- Connection pipes between intake manifold and exhaust manifold:

Figure 5.1: Connection pipes between intake and exhaust manifold

The main objective of the use of these pipes is the transfer part of the of exhaust gases from exhaust manifold to intake manifold.

At the beginning of work, the team thought about using plastic pipes for the transfer of exhaust, but there was a big challenge that is high temperature in the exhaust gases and the inability of these pipes to with stand this heat.

Then it was proposed to use the aluminum tubes, despite the lack of sufficient flexibility. However, the main drawback is the inability to conduct teething and the inability to weld with iron or aluminum.

The last option is the use of iron pipes. Although the lack of flexibility and the difficulty of control, they bear the high temperature. They can be welded and teething.

2- EGR manual Control valve:

Figure 5.2: EGR manual Control valve

The objective of the use of valve is to control the amount of exhaust gas that enters to intake manifold through the scale located on the valve.

The search for a suitable value for use has been difficult. Because the difficulty of providing valve that bear the high temperatures, most valves contain parts that can melt at temperatures of exhaust. After a long search, the team found the valve thermal that bear this heat, in spite of the relatively high cost.

- Features of this valve:

A- To bear the high temperature.

B- To contain a scale that determine the amount of cross area required.

3- Thermocouples Sensors:

A

B

C

Figure 5.3: Thermocouple Sensors (A: to measure exhaust recirculation temperature,
B: to measure mix. of exhaust recirculation and air temperature,
C: to measure intake air temperature)

The function of these sensors is to measure temperatures of air, EGR, and mixture of the air and EGR. the type of this sensor is (thermocouple).

- Features of these sensors:
  1- Relatively high accuracy.
  2- Bear the high temperature.

Used in system device to reading the temperature from the senores

Figure 5.4 device to reading the temperature.

## 5.3 Steps of work:

1- Collecting the needed parts and components.
2- Taking the measures of the needed pipes.
3- Holing in the cover of take manifold.
4- Holing in the exhaust manifold.
5- Connecting the pipes between intake and exhaust manifold.
6- Install of the valve in the suitable location.

# Chapter Six

## Performance Comparison of Mazda 323i Engine Powered by LPG and Gasoline as Fuel without opening EGR

- Introduction
- Mounting Test Stand (EPTS) to the Engine
- Operation
- Shaft Power
- Measure the Performance of the Engine Powered by LPG and comparing it with the Same Engine Powered by Gasoline
- The results and Discussions
- Engine Dynamometer Method
- The Ratio of Engine Power
- Conclusion

## 6.1 Introduction

To measure the performance of Mazda 323i engine powered by LPG and gasoline, engine Performance Test Stand (EPTS) with Vertical Instrument Panel was used and an experimental procedure was designed, after fixing its problems and adjusts its design to get the data practically.

## 6.2 Mounting Test Stand (EPTS) to the Engine

The THEPRA Engine Performance Test Stand with vertical Instrument Panel was bolted to the engine crankcase by using an adapter flange as shown in Figure 6.1. The adapter flange has to be made in accordance with the bell housing of the engine. The bell housing has to be centered to the Engine Performance Test Stand by means of the adapter flange as shown in Figure 6.2.The rotor shaft of the Test Stand was connected to the engine clutch disc by the interchangeable connection shaft shown in Figure 6.3.

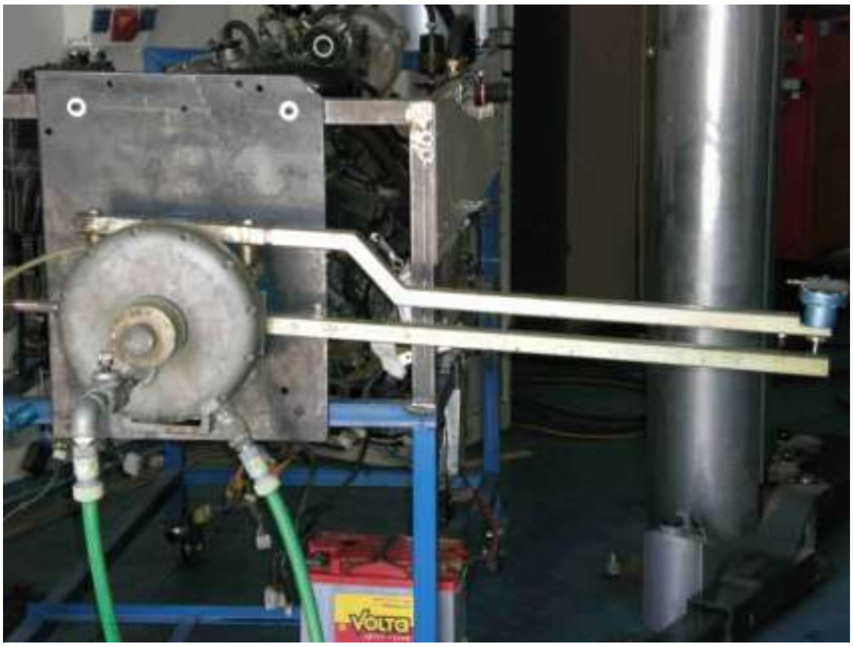

**Figure 6.1: Bolting the (EPTS)   to the Engine Crankcase**

**Figure 6.2: Adapter Flange**

**Figure 6.3: The Interchangeable Connection Shaft**

## 6.3 Operation

The THEPRA EPTS is a hydraulic brake retarded. The rotating torque of the engine is converted to a stationary torque that will be measured.

The turbulent action of the water absorbs the power of the engine. The load is controlled by the water inlet. The power is converted into heat which is carried away by the continually flowing water.

EPTS with vertical Instrument Panel measures engine torque and power continuously from an absorption brake and produces value of torque and power for various RPM bands. Torque and power values are integrated during each shaft revolutions as the engine is slowly accelerated through a range of interest. The data are accumulated such that for each 500 RPM wide band in the range, there is a statistical mean value produced of torque and of power.

Water required: Each 75 kW require 40 L/min. of water with a minimum pressure of 4 bars. The Engine Performance Test Stand will not suffer any damages when overcharged in the torque and performance range.

## 6.4 Shaft Power

On a rotating shaft, the torque is doing the work, and the shaft's rotational speed is time-dependent, so shaft power is the product of its rotational speed and its torque. Using arbitrary units, the power formula for a rotating shaft is: [16]

$$\text{Power Shaft} = \text{Rotating Speed} \times 2\pi \times \text{Torque} \tag{6.1}$$

- **Units of Shaft Power**

When using Newton-meters for torque, revolutions per minute (RPM) for shaft speed, and kilowatts for power, shaft power can be expressed with the following formula: [16]

1 [W] = 1 [N.M/sec]

1 [kW] = 1 [W] × [1kW/1000W] × [1min/60 sec]× [2 π rad/1 rev]

$$P_{\text{Shaft}}[\text{kW}] = \frac{\text{T Q [N. M]} \times \text{Rev's [RPM]}}{9550}$$

## 6.5 Performance Measurements of the Engine Powered by LPG and comparing them with the Same Engine Powered by Gasoline without opening EGR

**Experimental Procedure**

1. Run the engine and wait until reaches its normal operating temperature.
2. Connect tachometer to measure the RPM.
3. Connect torque meter to measure the torque.
4. Activate the cooling water.
5. Activate the load /unload valve 5 min, to get the warm-up time.
6. Open throttle valve until reaching full load, at the same time activate brake torque at higher case.
7. Fixed throttle valve at full load or (at the RPM you want) and activate the load/unload valve to measure the torque at various engine speeds.
8. Record the results.
9. Calculate and draw the results. [17]

### 6.5.1 The Results and Discussions

First, the engine was run with gasoline fuel and recorded the data as shown in table 6.1, and then with LPG fuel and also recorded the data as shown in Table 6.1.

**Table 6.1: The Recorded Data and calculated power for the engine running on gasoline and LPG without opening EGR**

| | | **Gasoline Fuel** | | LPG Fuel | | |
|---|---|---|---|---|---|---|
| **No.** | **Engine speed (RPM)** n | **Torque (Nm)** $TQ_1$ | **Power $P_1$ (kW)** $P_1 = TQ_1 * n/9550$ | **Torque (Nm)** $TQ_2$ | **Power $P_2$ (kW)** $P_2 = TQ_2 * n/9550$ | **$P_2/P_1$** |
| 1 | 1000 | 200.0 | 20.94 | 173.3 | 18.15 | 0.87 |
| 2 | 1500 | 183.3 | 28.80 | 143.3 | 22.51 | 0.78 |
| 3 | **2000** | 150.0 | 31.41 | 126.7 | 26.53 | 0.84 |
| 4 | 2500 | 100.0 | 26.18 | 73.3 | 19.20 | 0.73 |
| 5 | 3000 | 63.3 | 19.90 | 46.7 | 14.66 | 0.74 |
| | | | | | **∑P2/P1=** | **3.96** |
| | | | | | **The average** | **0.793** |

#### 6.5.1.1 Engine Dynamometer Method

The mean of power measurements shall be calculated as follows: [8]

$$\text{Power}_{petrol} = \frac{1}{n}\sum_{i=1}^{n} \text{Power}_{petrol.i} \quad (6.2)$$

$$= 127.23$$

$$\text{Power}_{LPG} = \frac{1}{n}\sum_{i=1}^{n} \text{Power}_{LPG.i} \quad (6.3)$$

$$= 101.05$$

**6.5.1.2 The Ratio of Engine Power** [8]

$$\text{K}_{\text{power}} = \text{Power}_{\text{ LPG}}/\text{Power}_{\text{ petrol}} \quad (6.4)$$

$$= 101.05/127.23 = 0.79$$

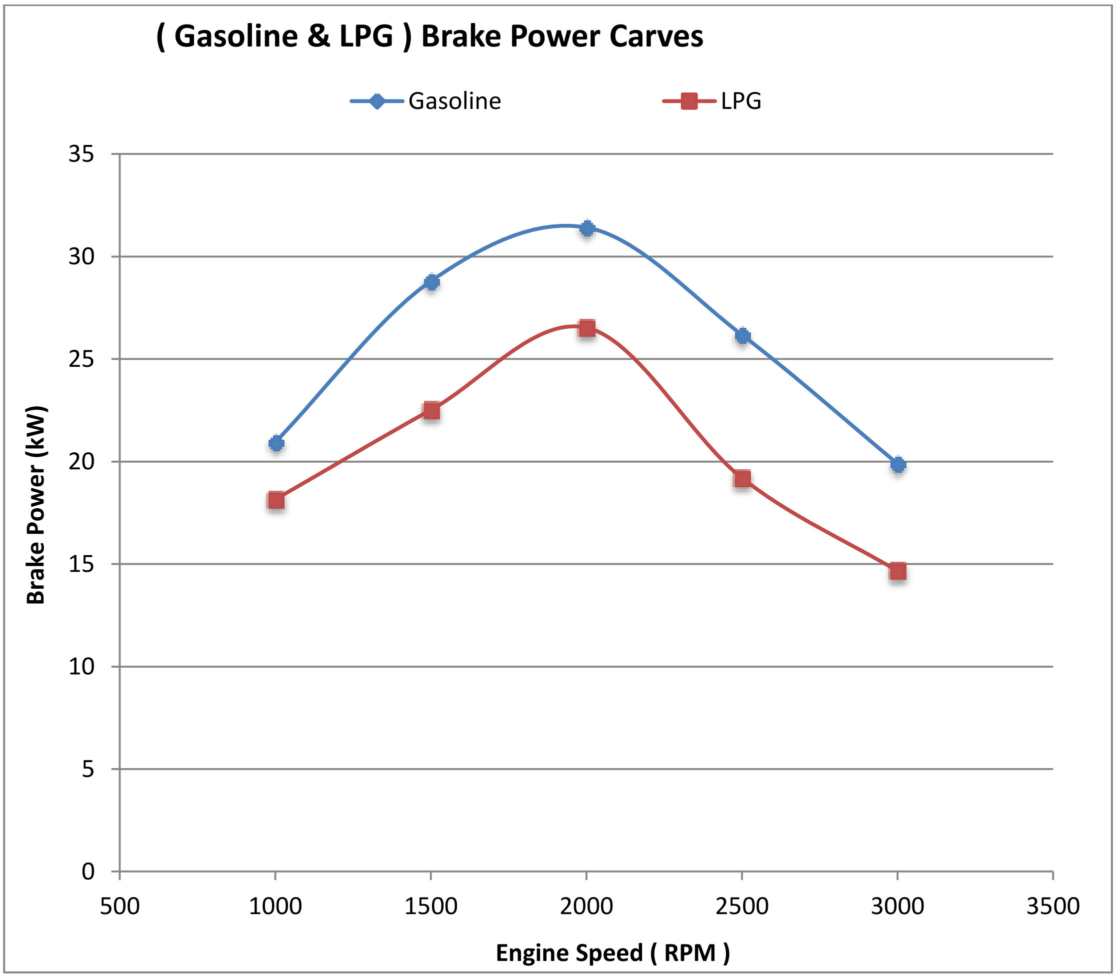


**Figure 6.4: Comparisons between Gasoline and LPG Power Diagram**

Table 6.1 shows the engine output torque and power produced from both fuels (Gasoline and LPG) under the same test sets. Test results were represented graphically for direct comparison in figure 6.4. In addition, figure 6.6.

Just like expected the engine powered by gasoline produced more power than the engine powered by LPG fuel, the results show that gasoline engine produces 21% more power than LPG engine.

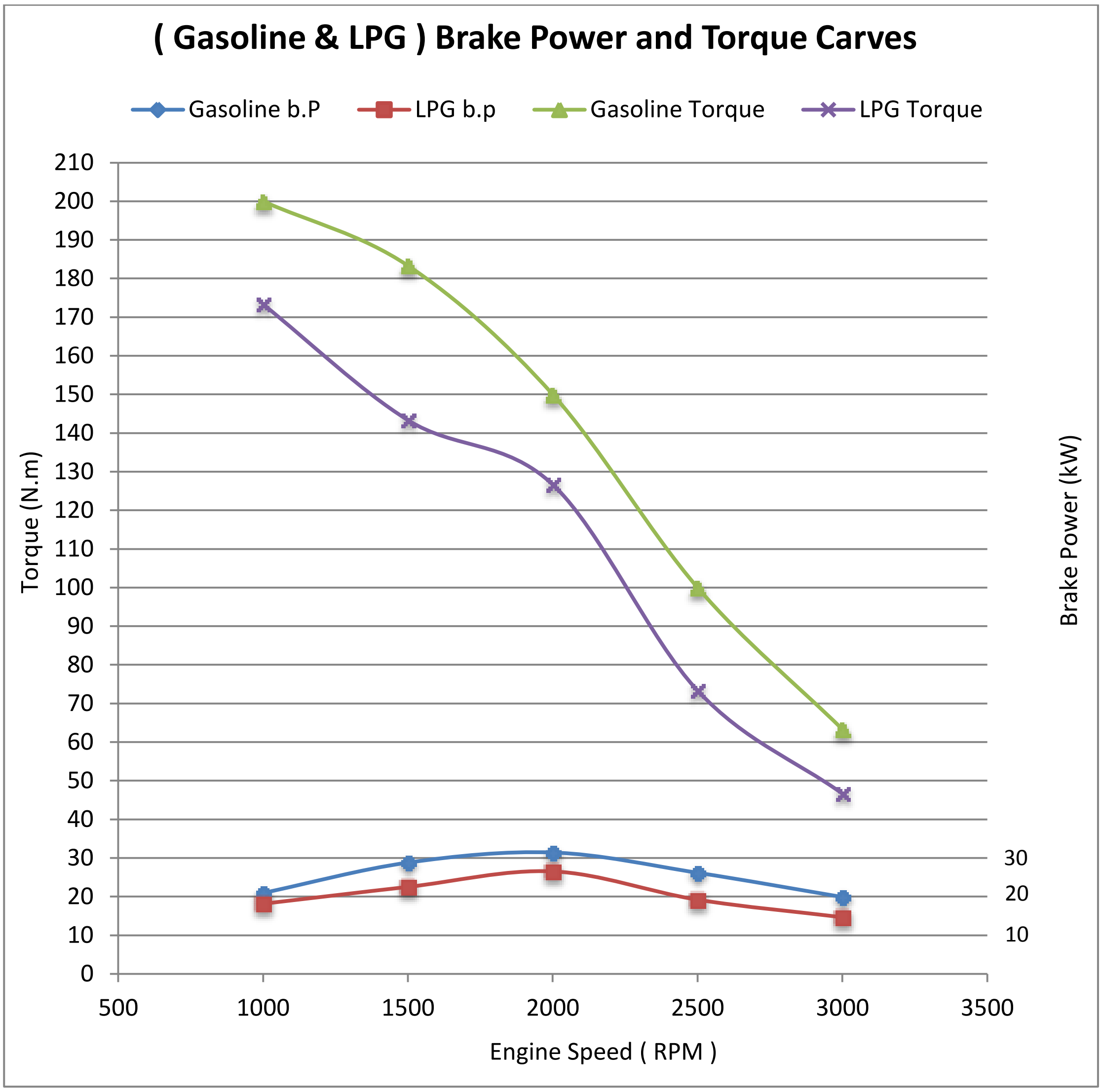


**Figure 6.5: Gasoline & LPG Torque and Brake Power Diagram**

## 6.6 Performance Measurements of the Engine Powered by LPG and comparing them with the Same Engine Powered by Gasoline with opening EGR

**Experimental Procedure**

1. Run the engine and wait until reaches its normal operating temperature.
2. Connect tachometer to measure the RPM.
3. Connect torque meter to measure the torque.
4. Activate the cooling water.
5. Activate the load /unload valve 5 min, to get the warm-up time.
6. Open handle valve of installed EGR system to various percentage.
7. Open throttle valve until reaching full load, at the same time activate brake torque at higher case.
8. Fixed throttle valve at full load or (at the RPM you want) and activate the load/unload valve to measure the torque at various engine speeds.
9. Record the results.
10. Calculate and draw the results.

### 6.6.1 The Results and Discussions

After run the engine and wait until reaches its steady state, opening the handle valve of EGR system.

First, the engine was run with gasoline fuel and recorded the data and then with LPG fuel and also recorded the data with opening EGR valve ( 5,10,…,30%) as shown in Table 6.2.

**Table 6.2: The Recorded Data and the Calculating Gasoline and LPG Power with opening EGR (5 – 30)%**

**With open 5%**

| No. | Engine speed (RPM) n | Gasoline Fuel: Torque (Nm) $TQ_1$ | Gasoline Fuel: Power $P_1$ (kW) $P_1 = TQ_1 * n / 9550$ | Temperature (℃) $T_1$ EGR | $T_2$ Air | $T_3$ Mix. |
|---|---|---|---|---|---|---|
| 1 | 1000 | 196.7 | 20.59 | 33.30 | 26.18 | 30.32 |
| 2 | 1500 | 166.7 | 26.18 | 34.60 | 26.27 | 32.30 |
| 3 | 2000 | 140.0 | 29.32 | 38.20 | 26.52 | 36.52 |
| 4 | 2500 | 86.7 | 22.69 | 38.70 | 26.41 | 38.42 |
| 5 | 3000 | 50.0 | 15.71 | 40.20 | 26.50 | 39.40 |

| | | **LPG Fuel** | | | | |
|---|---|---|---|---|---|---|
| **No.** | **Engine speed (RPM)** | **Torque (Nm)** | **Power $P_1$ (kW)** | **Temperature (℃ )** | | |
| | **n** | **$TQ_1$** | **$P_1 = TQ_1 * n/9550$** | **$T_1$ EGR** | **$T_2$ Air** | **$T_3$ Mix.** |
| 1 | 1000 | 166.7 | 17.45 | 41.30 | 27.40 | 44.00 |
| 2 | 1500 | 140.0 | 21.99 | 40.50 | 28.20 | 45.40 |
| 3 | 2000 | 113.3 | 23.73 | 45.10 | 28.60 | 46.21 |
| 4 | 2500 | 63.3 | 16.58 | 46.60 | 28.80 | 48.48 |
| 5 | 3000 | 36.7 | 11.52 | 47.50 | 29.20 | 50.30 |

**With open 10%**

| | | **Gasoline Fuel** | | | | |
|---|---|---|---|---|---|---|
| **No.** | **Engine speed (RPM)** | **Torque (Nm)** | **Power $P_1$ (kW)** | **Temperature (℃ )** | | |
| | **n** | **$TQ_1$** | **$P_1 = TQ_1 * n/9550$** | **$T_1$ EGR** | **$T_2$ Air** | **$T_3$ Mix.** |
| 1 | 1000 | 183.3 | 19.20 | 43.40 | 26.55 | 40.13 |
| 2 | 1500 | 153.3 | 24.08 | 47.10 | 26.51 | 41.60 |
| 3 | 2000 | 123.3 | 25.83 | 51.80 | 26.82 | 42.35 |
| 4 | 2500 | 76.7 | 20.07 | 53.30 | 26.48 | 44.75 |
| 5 | 3000 | 43.3 | 13.61 | 54.10 | 27.10 | 45.64 |

| | | **LPG Fuel** | | | | |
|---|---|---|---|---|---|---|
| **No.** | **Engine speed (RPM)** | **Torque (Nm)** | **Power $P_1$ (kW)** | **Temperature (℃ )** | | |
| | **n** | **$TQ_1$** | **$P_1 = TQ_1 * n/9550$** | **$T_1$ EGR** | **$T_2$ Air** | **$T_3$ Mix.** |
| 1 | 1000 | 157 | 16.40 | 51.15 | 28.55 | 50.65 |
| 2 | 1500 | 130 | 20.42 | 53.45 | 29.00 | 50.90 |
| 3 | 2000 | 110 | 23.04 | 60.40 | 29.35 | 53.35 |
| 4 | 2500 | 51.7 | 13.53 | 63.50 | 29.55 | 54.95 |
| 5 | 3000 | 30 | 9.42 | 63.55 | 29.65 | 57.26 |

**With open 15%**

| No. | Engine speed (RPM) n | Gasoline Fuel<br>Torque (Nm) $TQ_1$ | Power $P_1$ (kW) $P_1 = TQ_1 * n/9550$ | Temperature (℃ ) $T_1$ EGR | $T_2$ Air | $T_3$ Mix. |
|---|---|---|---|---|---|---|
| 1 | 1000 | 170.0 | 17.80 | 56.2 | 26.6 | 47.5 |
| 2 | 1500 | 136.7 | 21.47 | 57.3 | 27.3 | 48.6 |
| 3 | 2000 | 116.7 | 24.43 | 59.1 | 27 | 49.8 |
| 4 | 2500 | 63.3 | 16.58 | 60.4 | 27.2 | 50.6 |
| 5 | 3000 | 36.7 | 11.52 | 62.3 | 27.1 | 51.3 |

| No. | Engine speed (RPM) n | LPG Fuel<br>Torque (Nm) $TQ_1$ | Power $P_1$ (kW) $P_1 = TQ_1 * n/9550$ | Temperature (℃ ) $T_1$ EGR | $T_2$ Air | $T_3$ Mix. |
|---|---|---|---|---|---|---|
| 1 | 1000 | 146.7 | 15.36 | 61 | 29.7 | 57.3 |
| 2 | 1500 | 120.0 | 18.85 | 66.4 | 29.8 | 57.4 |
| 3 | 2000 | 96.7 | 20.24 | 74.2 | 30.1 | 61.6 |
| 4 | 2500 | 40.0 | 10.47 | 78.3 | 30.3 | 62.4 |
| 5 | 3000 | 23.3 | 7.33 | 79.6 | 30.1 | 64.4 |

**With open 20%**

| No. | Engine speed (RPM) n | Gasoline Fuel<br>Torque (Nm) $TQ_1$ | Power $P_1$ (kW) $P_1 = TQ_1 * n/9550$ | Temperature (℃ ) $T_1$ EGR | $T_2$ Air | $T_3$ Mix. |
|---|---|---|---|---|---|---|
| 1 | 1000 | 150.0 | 15.71 | 63.5 | 27.1 | 54.1 |
| 2 | 1500 | 113.3 | 17.80 | 64.8 | 27 | 55 |
| 3 | 2000 | 106.7 | 22.34 | 67 | 27.1 | 55.6 |
| 4 | 2500 | 46.7 | 12.22 | 69.2 | 27 | 56.1 |
| 5 | 3000 | 30.0 | 9.42 | 71 | 26.7 | 56.5 |

| | | LPG Fuel | | | | | |
|---|---|---|---|---|---|---|---|
| **No.** | **Engine speed (RPM)** **n** | **Torque (Nm)** **$TQ_1$** | **Power $P_1$ (kW)** **$P_1 = TQ_1 * n/9550$** | **Temperature (℃ )** | | |
| | | | | **$T_1$ EGR** | **$T_2$ Air** | **$T_3$ Mix.** |
| 1 | 1000 | 123.3 | 12.91 | 71.2 | 30.2 | 65.9 |
| 2 | 1500 | 100.0 | 15.71 | 73.8 | 30.41 | 67.3 |
| 3 | 2000 | 73.3 | 15.36 | 78.4 | 31.3 | 69.1 |
| 4 | 2500 | 26.7 | 6.98 | 80.4 | 30.9 | 71.8 |
| 5 | 3000 | 13.3 | 4.19 | 83.2 | 31.5 | 74.2 |

**With open 25%**

| | | Gasoline Fuel | | | | |
|---|---|---|---|---|---|---|
| **No.** | **Engine speed (RPM)** **n** | **Torque (Nm)** **$TQ_1$** | **Power $P_1$ (kW)** **$P_1 = TQ_1 * n/9550$** | **Temperature (℃ )** | | |
| | | | | **$T_1$ EGR** | **$T_2$ Air** | **$T_3$ Mix.** |
| 1 | 1000 | 130.0 | 13.61 | 76 | 27.8 | 61.3 |
| 2 | 1500 | 100.0 | 15.71 | 81.3 | 27.8 | 62.8 |
| 3 | 2000 | 80.0 | 16.75 | 92.5 | 28.1 | 68.5 |
| 4 | 2500 | 36.7 | 9.60 | 97.1 | 28.4 | 71.7 |
| 5 | 3000 | 20.0 | 6.28 | 99.3 | 28.6 | 73.4 |

**With open 30%**

| | | Gasoline Fuel | | | | |
|---|---|---|---|---|---|---|
| **No.** | **Engine speed (RPM)** **n** | **Torque (Nm)** **$TQ_1$** | **Power $P_1$ (kW)** **$P_1 = TQ_1 * n/9550$** | **Temperature (℃ )** | | |
| | | | | **$T_1$ EGR** | **$T_2$ Air** | **$T_3$ Mix.** |
| 1 | 1000 | 83.3 | 8.73 | 103.7 | 29 | 75.3 |
| 2 | 1500 | 66.7 | 10.47 | 117.3 | 28.6 | 85 |
| 3 | 2000 | 53.3 | 11.17 | 130 | 28.4 | 92 |
| 4 | 2500 | 30.0 | 7.85 | 138 | 28.6 | 95.4 |
| 5 | 3000 | 10.0 | 3.14 | 143 | 28.8 | 98.3 |

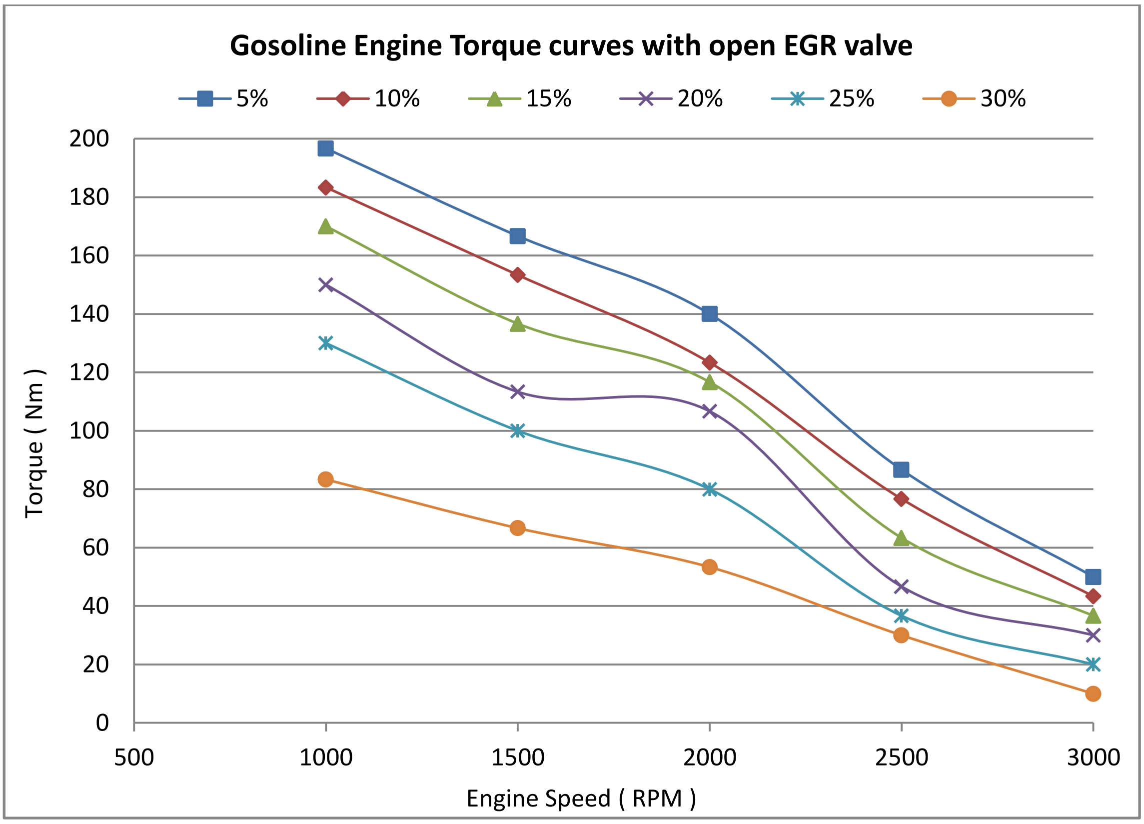


**Figure 6.6: Gasoline Engine Torque with open EGR Diagram**

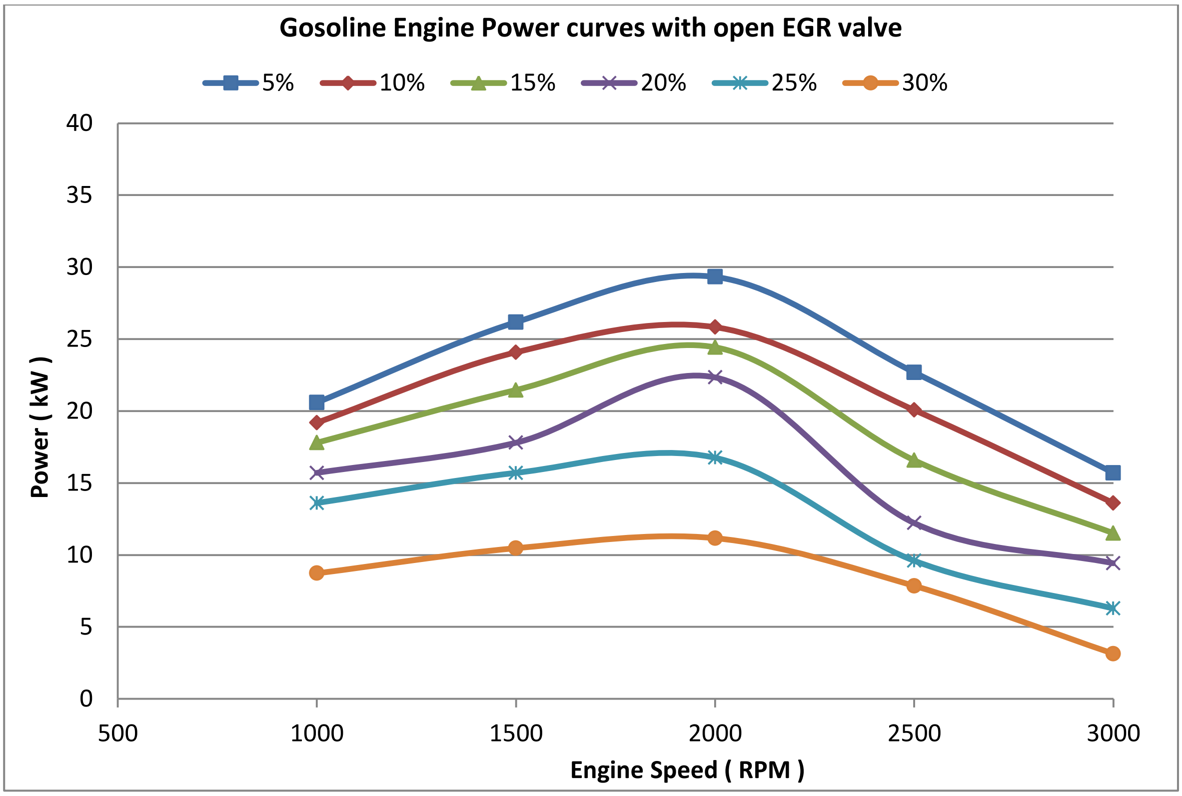


**Figure 6.7: Gasoline Engine Power with open EGR Diagram**

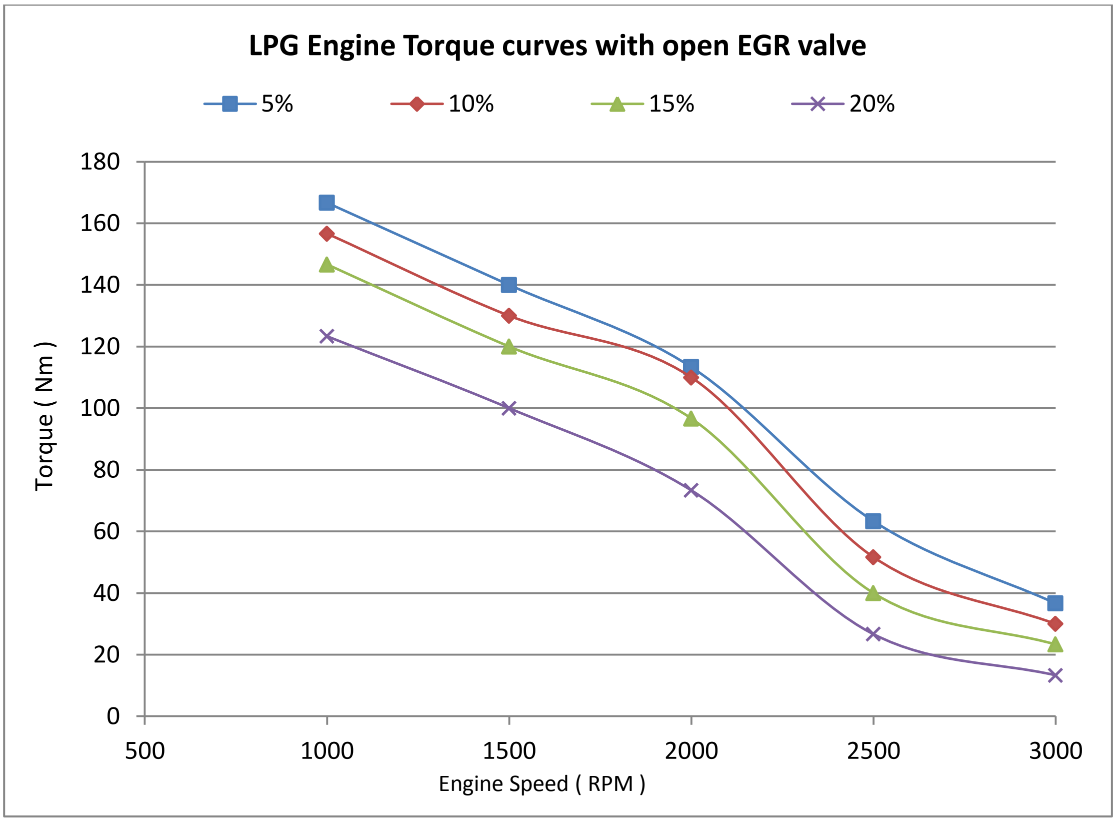


**Figure 6.8: LPG Engine Torque with open EGR Diagram**

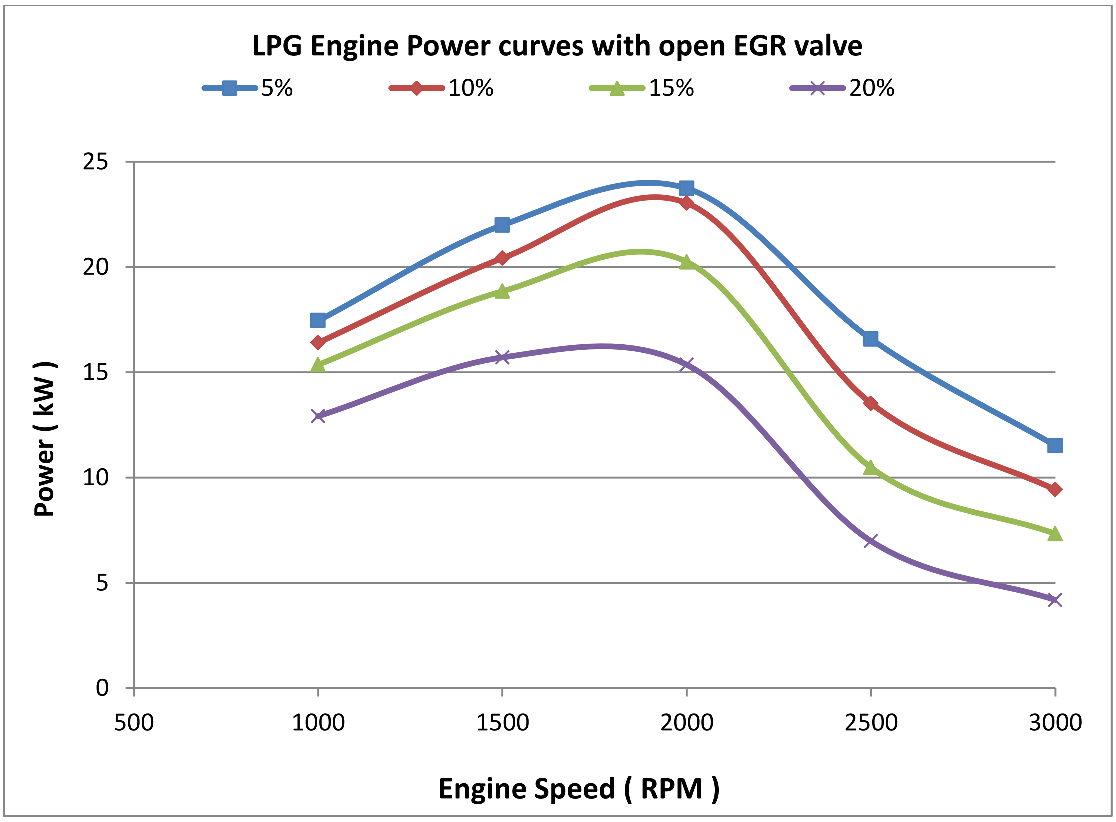


**Figure 6.9: LPG Engine Power with open EGR Diagram**

## 6.7 Conclusions

### Torque and brake power

- The torque and brake power test results for Mazda 323 MPI engine fuelled with either gasoline or LPG without opening EGR show that the torque and brake power of the LPG fuel is less about 21% than that of gasoline fuel, but with opening EGR, the torque and brake power of the LPG fuel are less about 27% than that of gasoline fuel, at different engine loads and speeds. As it is known that, the density of the LPG is lower than gasoline density, so the injected mass of the LPG to the combustion chamber is lower than gasoline.

- The torque and brake power for engine fuelled with either gasoline or LPG is decrease with increase open percentage of EGR valve.

- When opening EGR valve more than 20% while engine powered by LPG fuel, then engine was stop running due to engine reach lowest possible power.

# Chapter Seven

## Fuel consumption and cost comparison of LPG and gasoline as fuel for Mazda 323i engine

- Brake Specific Fuel Consumption without EGR

  Calculation and Results

  The Ratio of Engine bsfc Between LPG and Gasoline Fuel

- Brake Specific Fuel Consumption with open EGR

- Conclusion

## 7.1 Brake Specific Fuel Consumption without EGR

The engine compares the fuel consumption of different engines or different fuels by the amount of fuel used in a period of one hour for each kilowatt developed. This is called *brake specific fuel consumption* (bsfc), and depends on the calorific value of the fuel used.

The specific fuel consumption stated for the brake power of an engine [8].

Thus:

$$\text{bsfc [g/kWh]} = \frac{\text{Fuel consumed in (g/h)}}{\text{Brake Power in (kW)}} \qquad (7.1)$$

### 7.1.1 Calculation and Results

A set of tests were made at different engine speeds and loads to calculate the brake specific fuel consumption rates. The recorded data are given in tables 7.1 and 7.2 along with the calculated brake specific fuel consumption rates and calculated developed engine power, and the results are illustrated in Figure 7.1 and Figure 7.2.

Digital balance is used to measure the gasoline and LPG consumed mass

Example:

Gasoline fuel Consumption in (g/h) =

= g/min* 60 (min/h)

= 20 (g/min) *60 (min/h)

= <u>1200 g/h</u>

Gasoline break specific fuel consumption (g / kWh) =

= ṁ(g /h) / Break Power (kW)

= 1878.6 / 7.0= <u>268.37g / kWh</u>

Table 7.1: Gasoline Brake Specific Fuel Consumption

| Engine Speed ( RPM ) | Torque ( Nm ) | Brake Power ( kW ) | Gasoline Fuel Consumption ( g/min ) | Gasoline Fuel Consumption ( g/h ) | Break Specific Fuel Consumption ( g / kWh ) |
|---|---|---|---|---|---|
| 1000 | 67 | 7.0 | **31.31** | **1878.6** | 268.37 |
| | 133 | 14.0 | **40.52** | **2431.2** | 173.66 |
| | 167 | 17.5 | **46.22** | **2773.2** | 158.47 |
| 1500 | 67 | 10.5 | **44.24** | **2654.4** | 252.80 |
| | 133 | 20.9 | **58.17** | **3490.2** | 167.00 |
| | 167 | 26.2 | **70.34** | **4220.4** | 161.08 |
| 2000 | 67 | 14.0 | **57.43** | **3445.8** | 246.13 |
| | 133 | 27.9 | **75.61** | **4536.6** | 162.60 |
| | 167 | 34.9 | **91.62** | **5497.2** | 157.51 |
| 2500 | 67 | 17.5 | **75.89** | **4553.4** | 260.19 |
| | 133 | 34.9 | **98.16** | **5889.6** | 168.76 |
| | 167 | 43.6 | **116.3** | **6978** | 160.05 |
| 3000 | 67 | 20.9 | **90.26** | **5415.6** | 259.12 |
| | 133 | 41.9 | **116.42** | **6985.2** | 166.71 |
| | 167 | 52.4 | **145.17** | **8710.2** | 166.23 |

Table 7.2: LPG Brake Specific Fuel Consumption

| Engine Speed (RPM) | Torque (Nm) | Brake Power ( kW ) | LPG Fuel Consumption (g / min) | LPG Fuel Consumption g/h | Break Specific Fuel Consumption ( g / kWh ) |
|---|---|---|---|---|---|
| 1000 | 67 | 7.0 | 30.38 | 1822.8 | 260.40 |
| | 133 | 14.0 | 42.86 | 2571.4 | 183.69 |
| | 167 | 17.5 | 51.41 | 3084.6 | 176.26 |
| 1500 | 67 | 10.5 | 38.71 | 2322.6 | 221.20 |
| | 133 | 20.9 | 41.38 | 2482.8 | 118.79 |
| | 167 | 26.2 | 55.81 | 3348.8 | 127.81 |
| 2000 | 67 | 14.0 | 32.88 | 1972.6 | 140.91 |
| | 133 | 27.9 | 37.50 | 2250.0 | 80.65 |
| | 167 | 34.9 | 68.57 | 4114.3 | 117.89 |
| 2500 | 67 | 17.5 | 42.11 | 2526.3 | 144.38 |
| | 133 | 34.9 | 63.16 | 3789.5 | 108.58 |
| | 167 | 43.6 | 77.42 | 4645.2 | 106.54 |
| 3000 | 67 | 20.9 | 48.98 | 2938.8 | 140.61 |
| | 133 | 41.9 | 77.42 | 4645.2 | 110.86 |
| | 167 | 52.4 | 88.89 | 5333.3 | 101.78 |

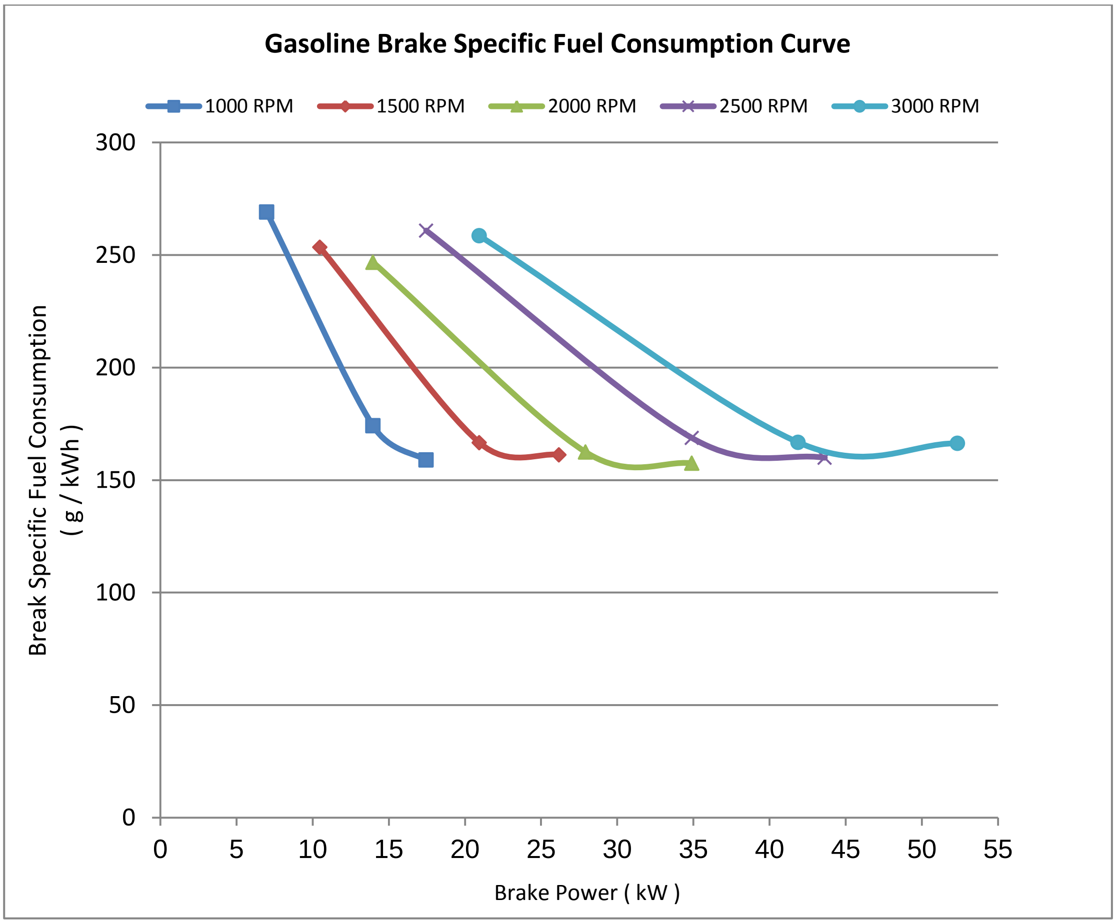

Figure 7.1: Gasoline bsfc (g / kWh) and bp (kW) Diagram

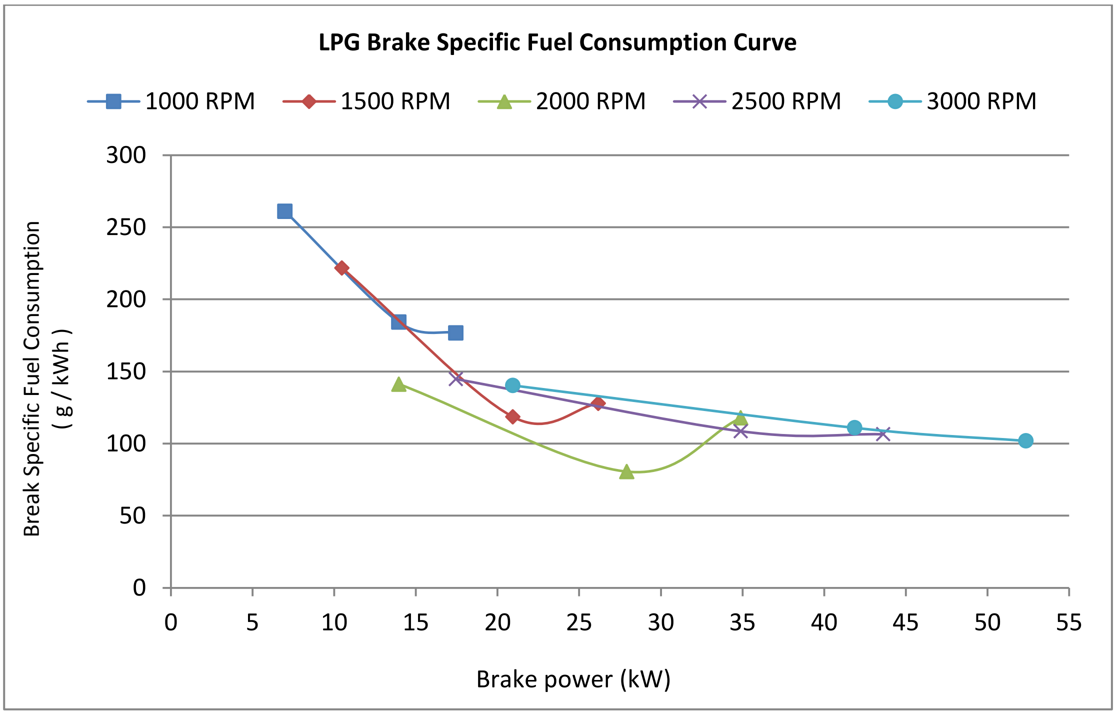

Figure 7.2: LPG bsfc (g / kWh) and bp (kW) Diagram

### 7.1.2 The Ratio of Engine bsfc between LPG and Gasoline Fuel

Statistically we can compare between gasoline and LPG brake specific fuel consumption listed in tables 8.3. The ratio of engine bsfc was calculated with the following formula:

bsfc of gasoline Fuel = $\sum$ bsfc= 9772.00 g / kWh

bsfc of LPG Fuel = $\sum$ bsfc = 7143.18 g / kWh

The ratio of engine bsfc between LPG and gasoline Fuel ( $K_{bsfc}$ )

$$K_{bsfc} = \sum bsfc_{LPG} / \sum bsfc_{gasoline} \qquad (7.2)$$

= 2140.36 /2928.67 = 0.73

The bsfc of LPG fuel is less about 27% than that of bsfc gasoline fuel, at different engine loads and speeds as shown in Table 7.3 and Figure 7.3.

Table 7.3: Comparison between Gasoline and LPG Brake Specific Fuel Consumption

| Engine Speed ( RPM ) | Torque ( Nm ) | Brake Power ( kW ) | Gasoline Break Specific Fuel Consumption ( g / kWh ) | LPG Break Specific Fuel Consumption ( g / kWh ) |
|---|---|---|---|---|
| 1000 | 67 | 7.0 | 268.37 | 260.40 |
| | 133 | 14.0 | 173.66 | 183.69 |
| | 167 | 17.5 | 158.47 | 176.26 |
| 1500 | 67 | 10.5 | 252.80 | 221.20 |
| | 133 | 20.9 | 167.00 | 118.79 |
| | 167 | 26.2 | 161.08 | 127.81 |
| 2000 | 67 | 14.0 | 246.13 | 140.91 |
| | 133 | 27.9 | 162.60 | 80.65 |
| | 167 | 34.9 | 157.51 | 117.89 |
| 2500 | 67 | 17.5 | 260.19 | 144.38 |
| | 133 | 34.9 | 168.76 | 108.58 |
| | 167 | 43.6 | 160.05 | 106.54 |
| 3000 | 67 | 20.9 | 259.12 | 140.61 |
| | 133 | 41.9 | 166.71 | 110.86 |
| | 167 | 52.4 | 166.23 | 101.78 |
| | | $\sum$ **bsfc** | **2928.67** | **2140.36** |

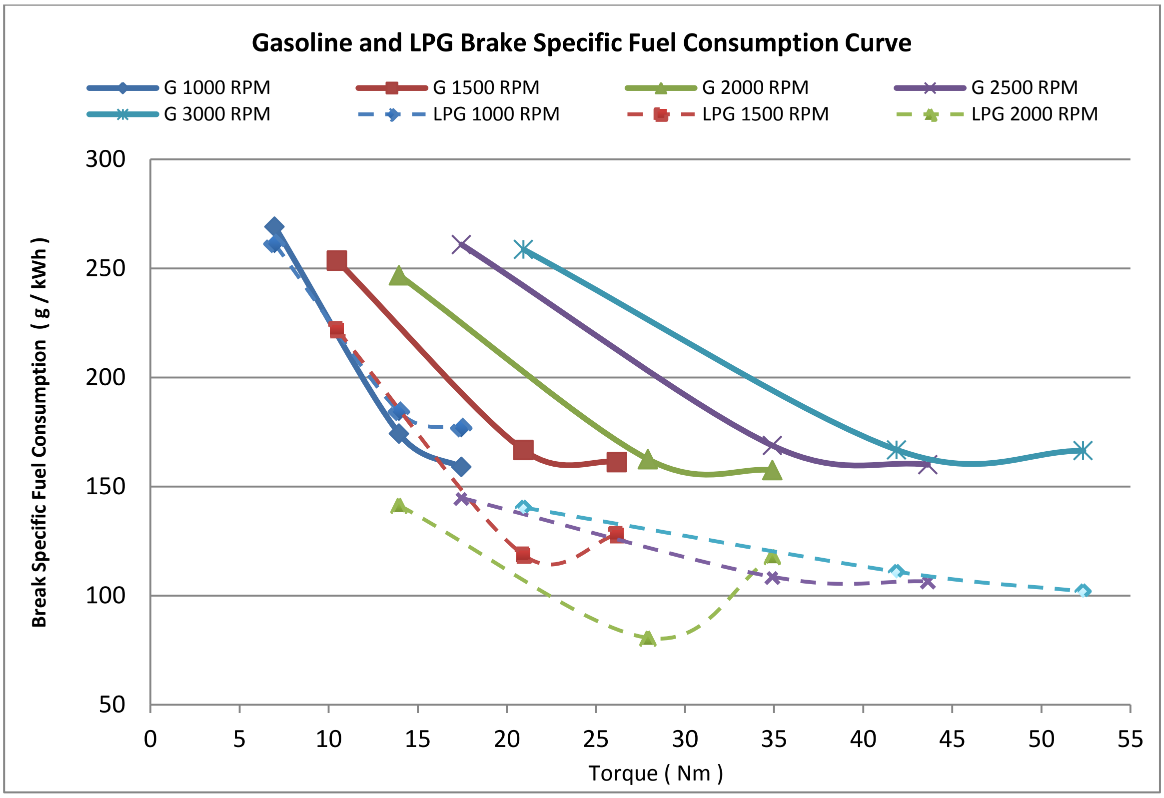


Figure 7.3: The Comparison between Gasoline and LPG Brake Specific Fuel Consumption

## 7.2 Brake Specific Fuel Consumption with open EGR

### 7.2.1 Gasoline Brake Specific Fuel Consumption

**Table 7.4: Gasoline Brake Specific Fuel Consumption with open (5 - 30 %) of EGR**

With open 5% EGR

| No. | Engine speed (RPM) n | Torque (Nm) $TQ_1$ | Power $P_1$ (kW) $P_1 = TQ_1 * n/9550$ | Gasoline Fuel Consumption g/min | Gasoline Fuel Consumption g/h | Break Specific Fuel Consumption ( g / kWh ) |
|---|---|---|---|---|---|---|
| 1 | 1000 | 100 | 3.14 | 35.78 | 2146.8 | 205.02 |
| 2 | 1500 | 100 | 4.71 | 48.42 | 2905.2 | 184.96 |
| 3 | 2000 | 100 | 6.28 | 64.12 | 3847.2 | 183.70 |
| 4 | 2500 | 100 | 7.85 | 81.90 | 4914 | 187.71 |
| 5 | 3000 | 100 | 9.42 | 100.12 | 6007.2 | 191.23 |

With open 10% EGR

| No. | Engine speed (RPM) n | Torque (Nm) $TQ_1$ | Power $P_1$ (kW) $P_1 = TQ_1 * n/9550$ | Gasoline Fuel Consumption g/min | Gasoline Fuel Consumption g/h | Break Specific Fuel Consumption ( g / kWh ) |
|---|---|---|---|---|---|---|
| 1 | 1000 | 100 | 3.14 | 38.08 | 2284.8 | 218.20 |
| 2 | 1500 | 100 | 4.71 | 51.66 | 3099.6 | 197.34 |
| 3 | 2000 | 100 | 6.28 | 67.23 | 4033.8 | 192.61 |
| 4 | 2500 | 100 | 7.85 | 88.90 | 5334 | 203.76 |
| 5 | 3000 | 100 | 9.42 | 111.27 | 6676.2 | 212.53 |

With open 15% EGR

| No. | Engine speed (RPM) n | Torque (Nm) $TQ_1$ | Power $P_1$ (kW) $P_1 = TQ_1 * n/9550$ | Gasoline Fuel Consumption g/min | Gasoline Fuel Consumption g/h | Break Specific Fuel Consumption ( g / kWh ) |
|---|---|---|---|---|---|---|
| 1 | 1000 | 100 | 3.14 | 40.02 | 2401.2 | 229.31 |
| 2 | 1500 | 100 | 4.71 | 54.90 | 3294 | 209.72 |
| 3 | 2000 | 100 | 6.28 | 70.23 | 4213.8 | 201.21 |
| 4 | 2500 | 100 | 7.85 | 93.14 | 5588.4 | 213.48 |
| 5 | 3000 | 100 | 9.42 | 116.35 | 6981 | 222.52 |

With open 20% EGR

| No. | Engine speed (RPM) n | Torque (Nm) $TQ_1$ | Power $P_1$ (kW) $P_1 = TQ_1 * n/9550$ | Gasoline Fuel Consumption g/min | Gasoline Fuel Consumption g/h | Break Specific Fuel Consumption ( g / kWh ) |
|---|---|---|---|---|---|---|
| 1 | 1000 | 100 | 3.14 | 42.54 | 2552.4 | 243.75 |
| 2 | 1500 | 100 | 4.71 | 57.90 | 3474 | 221.18 |
| 3 | 2000 | 100 | 6.28 | 73.23 | 4393.8 | 209.80 |
| 4 | 2500 | 100 | 7.85 | 97.14 | 5828.4 | 222.64 |
| 5 | 3000 | 100 | 9.42 | 124.37 | 7462.2 | 237.83 |

With open 25% EGR

| No. | Engine speed (RPM) n | Torque (Nm) $TQ_1$ | Power $P_1$ (kW) $P_1 = TQ_1 * n/9550$ | Gasoline Fuel Consumption g/min | Gasoline Fuel Consumption g/h | Break Specific Fuel Consumption ( g / kWh ) |
|---|---|---|---|---|---|---|
| 1 | 1000 | 100 | 3.14 | 43.73 | 2623.8 | 250.57 |
| 2 | 1500 | 100 | 4.71 | 59.43 | 3565.8 | 227.02 |
| 3 | 2000 | 100 | 6.28 | 76.23 | 4573.8 | 218.40 |
| 4 | 2500 | 100 | 7.85 | 98.14 | 5888.4 | 224.94 |
| 5 | 3000 | 100 | 9.42 | 126.61 | 7596.6 | 242.15 |

With open 30% EGR

| No. | Engine speed (RPM) n | Torque (Nm) $TQ_1$ | Power $P_1$ (kW) $P_1 = TQ_1 * n/9550$ | Gasoline Fuel Consumption g/min | Gasoline Fuel Consumption g/h | Break Specific Fuel Consumption ( g / kWh ) |
|---|---|---|---|---|---|---|
| 1 | 1000 | 100 | 3.14 | 45.86 | 2751.6 | 262.78 |
| 2 | 1500 | 100 | 4.71 | 65.43 | 3925.8 | 249.94 |
| 3 | 2000 | 100 | 6.28 | 80.23 | 4813.8 | 229.86 |
| 4 | 2500 | 100 | 7.85 | 101.14 | 6068.4 | 231.81 |
| 5 | 3000 | 100 | 9.42 | 132.48 | 7948.8 | 253.86 |

### 7.2.2 LPG Brake Specific Fuel Consumption

**Table 7.5: LPG Brake Specific Fuel Consumption with open (5 - 20%) of EGR**

With open 5% EGR

| No. | Engine speed (RPM) n | Torque (Nm) $TQ_1$ | Power $P_1$ (kW) $P_1 = TQ_1 * n/9550$ | Gasoline Fuel Consumption g/min | Gasoline Fuel Consumption g/h | Break Specific Fuel Consumption ( g / kWh ) |
|---|---|---|---|---|---|---|
| 1 | 1000 | 100 | 10.47 | 35 | 2077.1 | 198.36 |
| 2 | 1500 | 100 | 15.71 | 38 | 2282.7 | 145.33 |
| 3 | 2000 | 100 | 20.94 | 43 | 2580.0 | 123.20 |
| 4 | 2500 | 100 | 26.18 | 51 | 3037.9 | 116.05 |
| 5 | 3000 | 100 | 31.41 | 61 | 3672.0 | 116.89 |

With open 10% EGR

| No. | Engine speed (RPM) n | Torque (Nm) $TQ_1$ | Power $P_1$ (kW) $P_1 = TQ_1 * n/9550$ | Gasoline Fuel Consumption g/min | Gasoline Fuel Consumption g/h | Break Specific Fuel Consumption ( g / kWh ) |
|---|---|---|---|---|---|---|
| 1 | 1000 | 100 | 10.47 | 38 | 2257.1 | 215.55 |
| 2 | 1500 | 100 | 15.71 | 39 | 2342.7 | 149.15 |
| 3 | 2000 | 100 | 20.94 | 46 | 2760.0 | 131.79 |
| 4 | 2500 | 100 | 26.18 | 57 | 3397.9 | 129.80 |
| 5 | 3000 | 100 | 31.41 | 69 | 4152.0 | 132.17 |

With open 15% EGR

| No. | Engine speed (RPM) n | Torque (Nm) $TQ_1$ | Power $P_1$ (kW) $P_1 = TQ_1 * n/9550$ | Gasoline Fuel Consumption g/min | Gasoline Fuel Consumption g/h | Break Specific Fuel Consumption ( g / kWh ) |
|---|---|---|---|---|---|---|
| 1 | 1000 | 100 | 10.47 | 42 | 2497.1 | 238.47 |
| 2 | 1500 | 100 | 15.71 | 43 | 2582.7 | 164.43 |
| 3 | 2000 | 100 | 20.94 | 52 | 3120.0 | 148.98 |
| 4 | 2500 | 100 | 26.18 | 65 | 3877.9 | 148.14 |
| 5 | 3000 | 100 | 31.41 | 71 | 4272.0 | 135.99 |

With open 20% EGR

| No. | Engine speed (RPM) n | Torque (Nm) $TQ_1$ | Power $P_1$ (kW) $P_1$= $TQ_1$*n/9550 | Gasoline Fuel Consumption g/min | Gasoline Fuel Consumption g/h | Break Specific Fuel Consumption ( g / kWh ) |
|---|---|---|---|---|---|---|
| 1 | 1000 | 100 | 10.47 | 44 | 2617.1 | 249.93 |
| 2 | 1500 | 100 | 15.71 | 47 | 2822.7 | 179.71 |
| 3 | 2000 | 100 | 20.94 | 58 | 3480.0 | 166.17 |
| 4 | 2500 | 100 | 26.18 | 66 | 3937.9 | 150.43 |
| 5 | 3000 | 100 | 31.41 | 75 | 4512.0 | 143.63 |

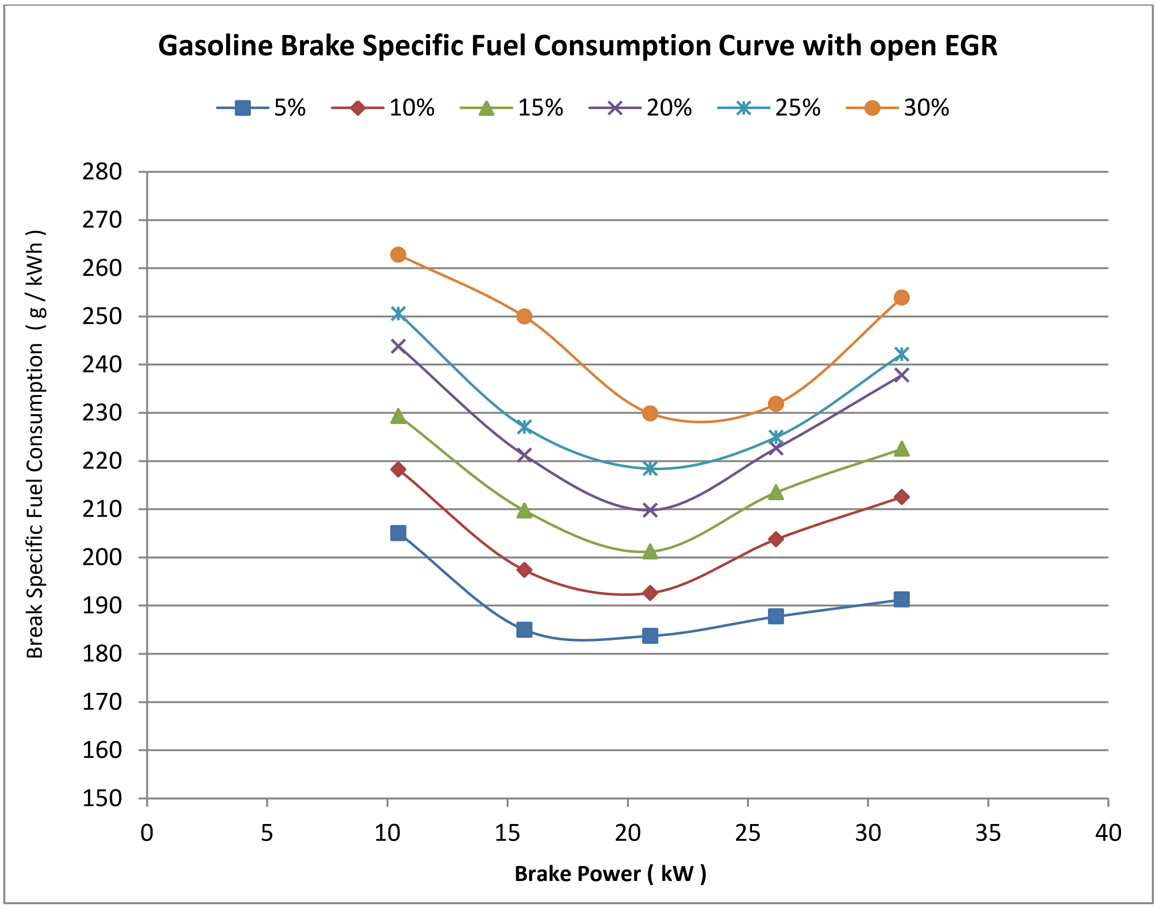


Figure 7.4: Gasoline bsfc (g / kWh) and bp (kW) Diagram

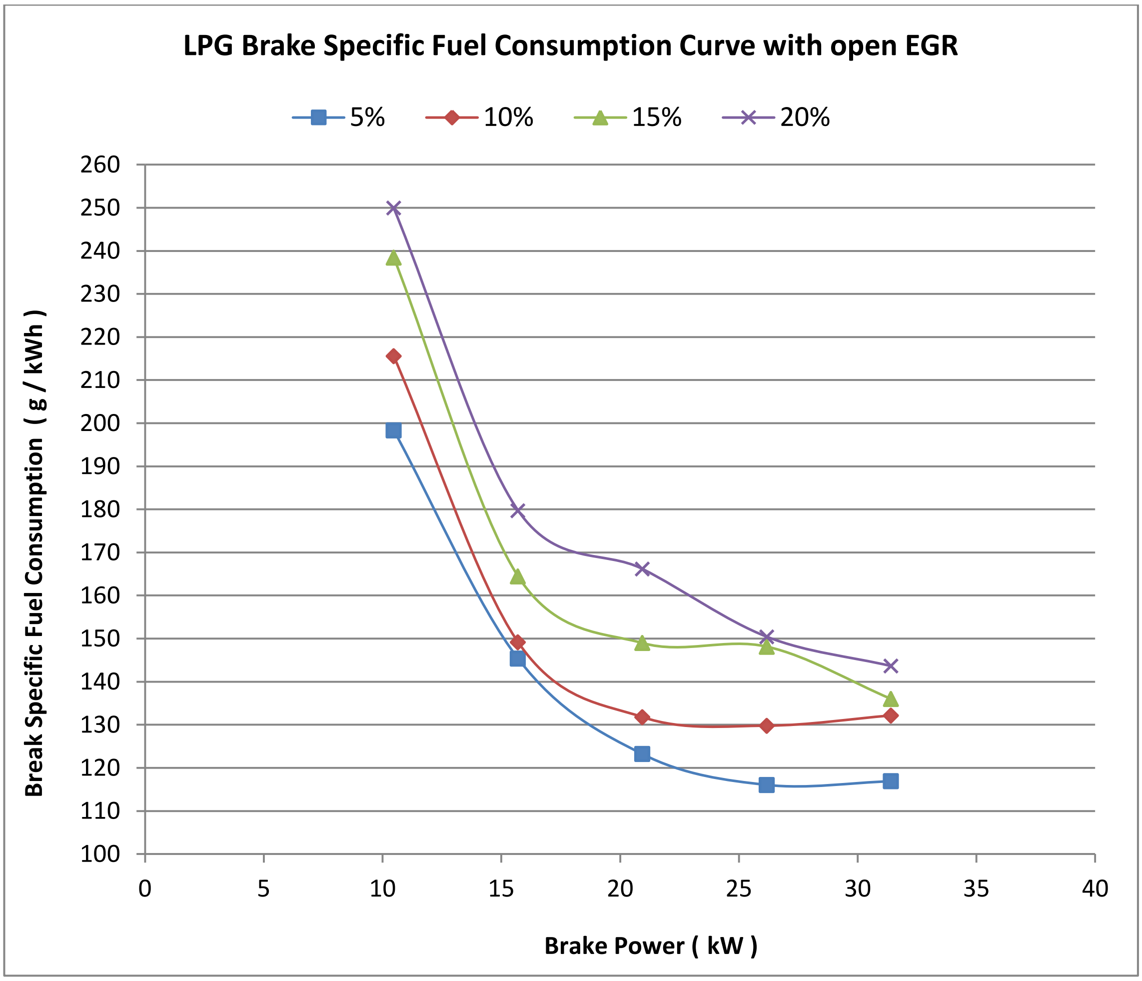

Figure 7.5: LPG bsfc (g / kWh) and bp (kW) Diagram

## 7.3 Conclusion

Brake specific Fuel consumption

- The comparison between the bsfc of LPG and gasoline for Mazda 323 MPI engine fuelled with either gasoline or LPG without open EGR show that the bsfc of LPG fuel is less about 27% than that of bsfc gasoline fuel, but with open EGR show that the bsfc of LPG fuel is less about 24.1% than that of bsfc gasoline fuel at different engine loads and speeds, at different engine loads or speeds.

- Brake specific Fuel consumption of LPG and gasoline for Mazda 323 MPI engine fuelled with either gasoline or LPG increasing with increase open percentage of EGR valve.

# Chapter Eight

## Emissions of gasoline and LPG as fuel for Mazda 323i Engine

- Introduction
- The values of the emissions without and with EGR at different speed

  The rate of emission of gasoline Engine

  The rate of emission of LPG Engine

  When engine powered by gasoline fuel

  When running by LPG fuel
- Results
- Conclusion

## 8.1 Introduction:

A gas analyzer to measure the rate of emission in the exhaust gases. The rate of emission is taking through the rod is placed in exhaust manifold, this rod is connect with gas analyzer, and all the values appear on the screen of the device after a relatively long period of operation of the device about 30 min, at air fuel ratio constant.

## 8.2 The values of the emissions without and with EGR at different speed:

8.2.1 The rate of emission of gasoline Engine:

Table 8.1: The rate of emission without open EGR (Gasoline)

| No. | Engine speed (RPM) n | $CO_2$ % | $NO_x$ Ppm | HC ppm | CO % |
|---|---|---|---|---|---|
| 1 | 1000 | 7.98 | 2967 | 82 | 0.3 |
| 2 | 1500 | 7.73 | 2956 | 84 | 0.32 |
| 3 | 2000 | 7.69 | 2955 | 84 | 0.33 |
| 4 | 2500 | 7.5 | 2950 | 83 | 0.35 |
| 5 | 3000 | 7.62 | 2951 | 83 | 0.35 |

Table 8.2: The rate of emission with open (5 - 30%) of EGR (Gasoline)

With open EGR 5%

| No. | Engine speed (RPM) n | $CO_2$ % | $NO_x$ Ppm | HC ppm | CO % |
|---|---|---|---|---|---|
| 1 | 1000 | 11.18 | 977 | 159 | 0.43 |
| 2 | 1500 | 10.9 | 954 | 153 | 0.55 |
| 3 | 2000 | 12.5 | 941 | 156 | 0.66 |
| 4 | 2500 | 12.66 | 907 | 154 | 0.68 |
| 5 | 3000 | 12.46 | 908 | 169 | 1.1 |

With open EGR 10%

| No. | Engine speed (RPM) n | $CO_2$ % | $NO_x$ Ppm | HC ppm | CO % |
|---|---|---|---|---|---|
| 1 | 1000 | 9.87 | 192 | 215 | 0.31 |
| 2 | 1500 | 12.02 | 168 | 208 | 0.33 |
| 3 | 2000 | 10.98 | 166 | 242 | 0.31 |
| 4 | 2500 | 10.3 | 132 | 255 | 0.34 |
| 5 | 3000 | 12.21 | 133 | 253 | 0.66 |

With open EGR 15%

| No. | Engine speed (RPM) n | $CO_2$ % | $NO_x$ Ppm | HC ppm | CO % |
|---|---|---|---|---|---|
| 1 | 1000 | 10.05 | 109 | 290 | 0.32 |
| 2 | 1500 | 11.73 | 123 | 265 | 0.31 |
| 3 | 2000 | 12.53 | 98 | 275 | 0.29 |
| 4 | 2500 | 12.64 | 80 | 279 | 0.34 |
| 5 | 3000 | 12.6 | 88 | 284 | 0.33 |

With open EGR 20%

| No. | Engine speed (RPM) n | $CO_2$ % | $NO_x$ Ppm | HC ppm | CO % |
|---|---|---|---|---|---|
| 1 | 1000 | 10.86 | 153 | 261 | 0.58 |
| 2 | 1500 | 12.55 | 131 | 248 | 0.47 |
| 3 | 2000 | 12.68 | 113 | 258 | 0.54 |
| 4 | 2500 | 12.9 | 106 | 261 | 0.63 |
| 5 | 3000 | 13.05 | 102 | 268 | 0.66 |

With open EGR 25%

| No. | Engine speed (RPM) n | $CO_2$ % | $NO_x$ ppm | HC ppm | CO % |
|---|---|---|---|---|---|
| 1 | 1000 | 8.98 | 39 | 281 | 0.44 |
| 2 | 1500 | 12.34 | 57 | 285 | 0.66 |
| 3 | 2000 | 12.41 | 57 | 309 | 0.77 |
| 4 | 2500 | 12.66 | 60 | 325 | 0.89 |
| 5 | 3000 | 12.89 | 60 | 331 | 0.94 |

With open EGR 30%

| No. | Engine speed (RPM) n | $CO_2$ % | $NO_x$ ppm | HC ppm | CO % |
|---|---|---|---|---|---|
| 1 | 1000 | 8.22 | 25 | 450 | 1.1 |
| 2 | 1500 | 11.68 | 33 | 456 | 1.2 |
| 3 | 2000 | 11.94 | 38 | 499 | 1.05 |
| 4 | 2500 | 12.08 | 40 | 528 | 1.15 |
| 5 | 3000 | 12.1 | 42 | 548 | 1.25 |

### 8.2.2 The rate of emission of LPG Engine:

Table 8.3: The rate of emission without open EGR (LPG)

| No. | Engine speed (RPM) n | $CO_2$ % | $NO_x$ ppm | HC ppm | CO % |
|---|---|---|---|---|---|
| 1 | 1000 | 10.6 | 950 | 309 | 2.07 |
| 2 | 1500 | 10.4 | 976 | 319 | 2.23 |
| 3 | 2000 | 10.4 | 851 | 317 | 2.77 |
| 4 | 2500 | 10.3 | 887 | 333 | 2.95 |
| 5 | 3000 | 9.7 | 818 | 340 | 3.8 |

Table 8.4: The rate of emission with open (5 - 20%) of EGR (LPG)

With open EGR 5%

| No. | Engine speed (RPM) n | $CO_2$ % | $NO_x$ ppm | HC ppm | CO % |
|---|---|---|---|---|---|
| 1 | 1000 | 10.76 | 120 | 449 | 2.62 |
| 2 | 1500 | 10.25 | 90 | 483 | 3.66 |
| 3 | 2000 | 11.16 | 94 | 430 | 3.72 |
| 4 | 2500 | 10.75 | 101 | 495 | 3.96 |
| 5 | 3000 | 9.87 | 86 | 518 | 4.44 |

With open EGR 10%

| No. | Engine speed (RPM) n | $CO_2$ % | $NO_x$ ppm | HC ppm | CO % |
|---|---|---|---|---|---|
| 1 | 1000 | 10.54 | 92 | 471 | 2.79 |
| 2 | 1500 | 10.13 | 87 | 493 | 3.34 |
| 3 | 2000 | 10.02 | 82 | 508 | 4.29 |
| 4 | 2500 | 9.89 | 75 | 524 | 4.52 |
| 5 | 3000 | 9.75 | 72 | 553 | 4.86 |

With open EGR 15%

| No. | Engine speed (RPM) n | $CO_2$ % | $NO_x$ ppm | HC ppm | CO % |
|---|---|---|---|---|---|
| 1 | 1000 | 10.31 | 64 | 492 | 2.95 |
| 2 | 1500 | 10.37 | 57 | 515 | 3.05 |
| 3 | 2000 | 11.33 | 52 | 510 | 3.18 |
| 4 | 2500 | 10.48 | 46 | 553 | 4.61 |
| 5 | 3000 | 9.63 | 43 | 587 | 5.26 |

With open EGR 20%

| No. | Engine speed (RPM) n | $CO_2$ % | $NO_x$ ppm | HC ppm | CO % |
|---|---|---|---|---|---|
| 1 | 1000 | 10.07 | 38 | 511 | 3.1 |
| 2 | 1500 | 9.88 | 32 | 544 | 3.57 |
| 3 | 2000 | 9.67 | 26 | 571 | 4.43 |
| 4 | 2500 | 9.41 | 24 | 592 | 4.93 |
| 5 | 3000 | 9.35 | 20 | 608 | 5.34 |

## 8.3 Results:

Four types of emissions can be measure by gas analyzer:

### 8.3.1 When engine powered by gasoline fuel

#### 8.3.1.1 Nitrogen oxides ($NO_x$):

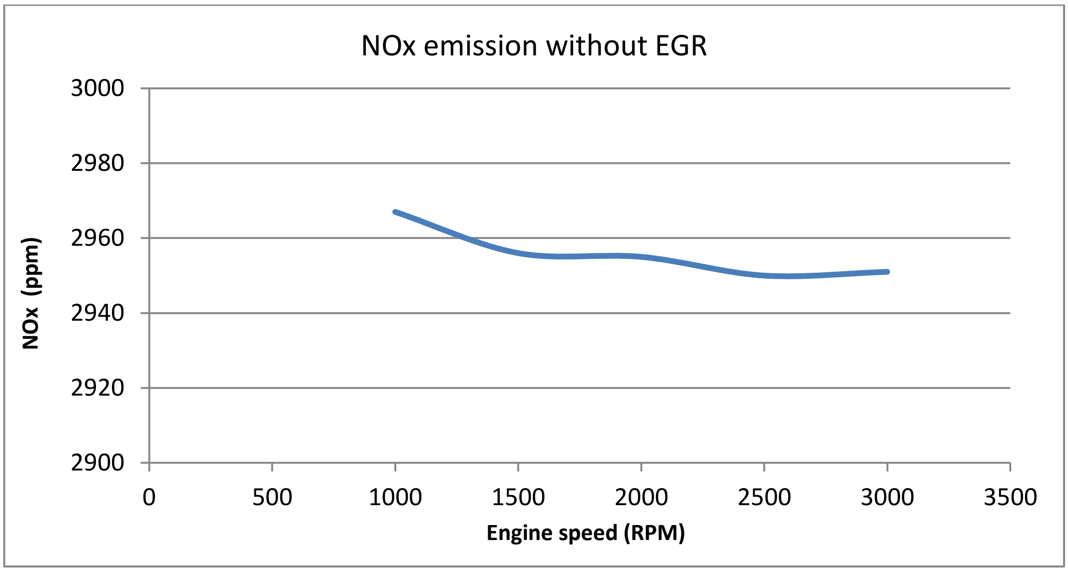


Figure 8.1: Rate of $NO_x$ when engine powered by gasoline without EGR

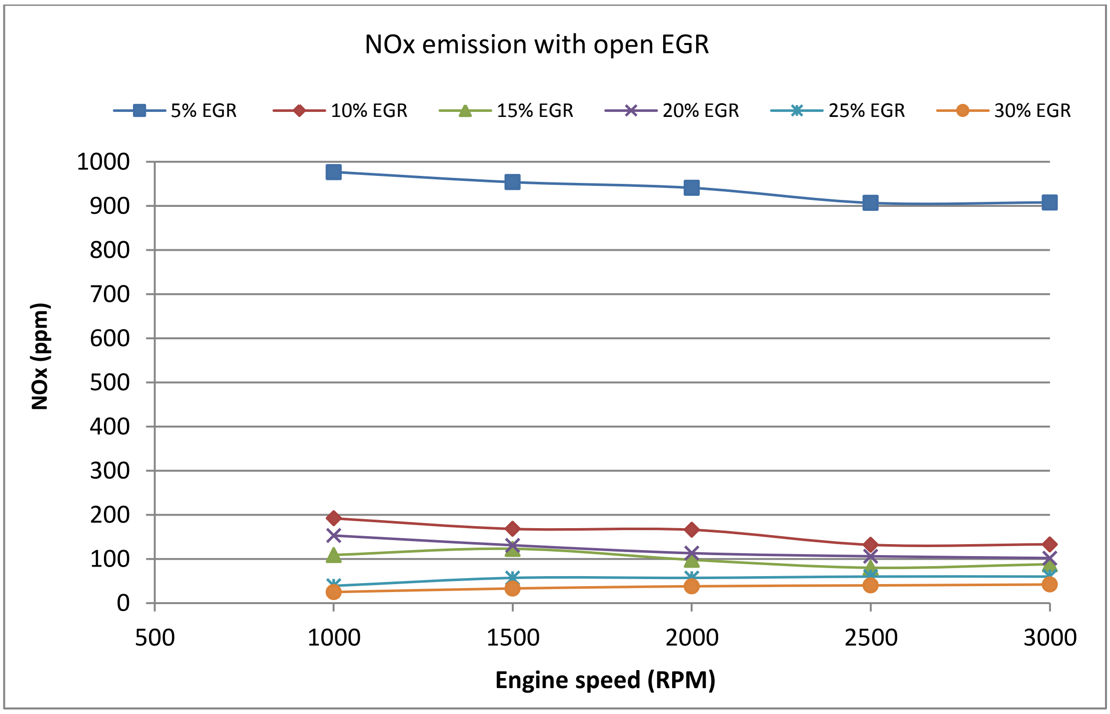


Figure 8.2: Rate of $NO_x$ when powered by gasoline fuel with open EGR

8.3.1.2 Hydrocarbons (HC)

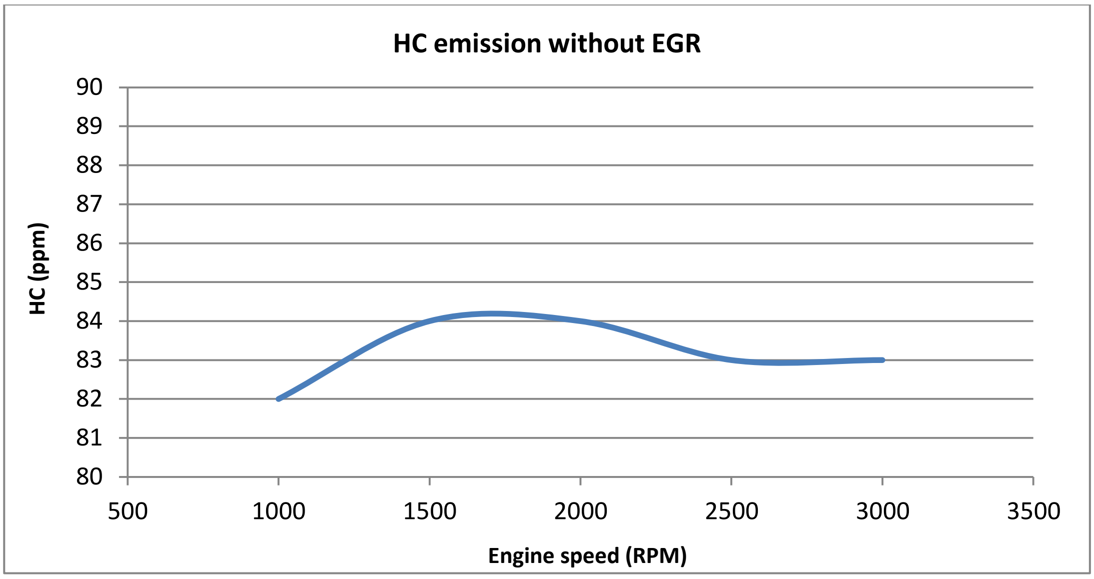


Figure 8.3: Rate of HC when engine powered by gasoline without open EGR

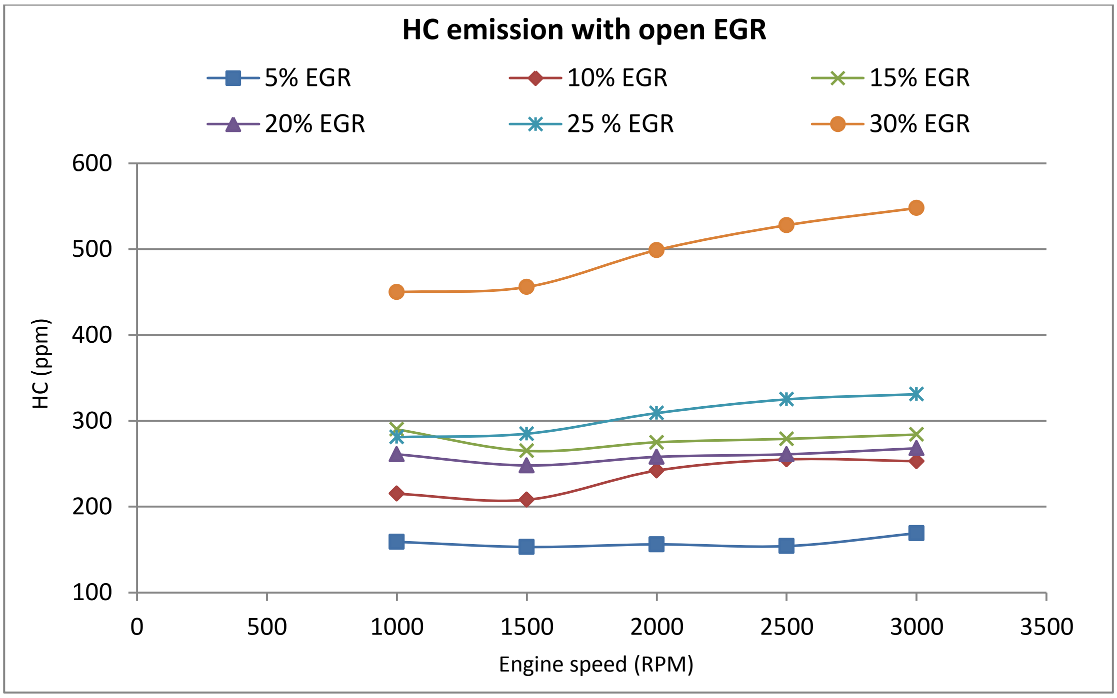


Figure 8.4: Rate of HC when engine powered by gasoline with open EGR

8.3.1.3 Carbone monoxide (CO)

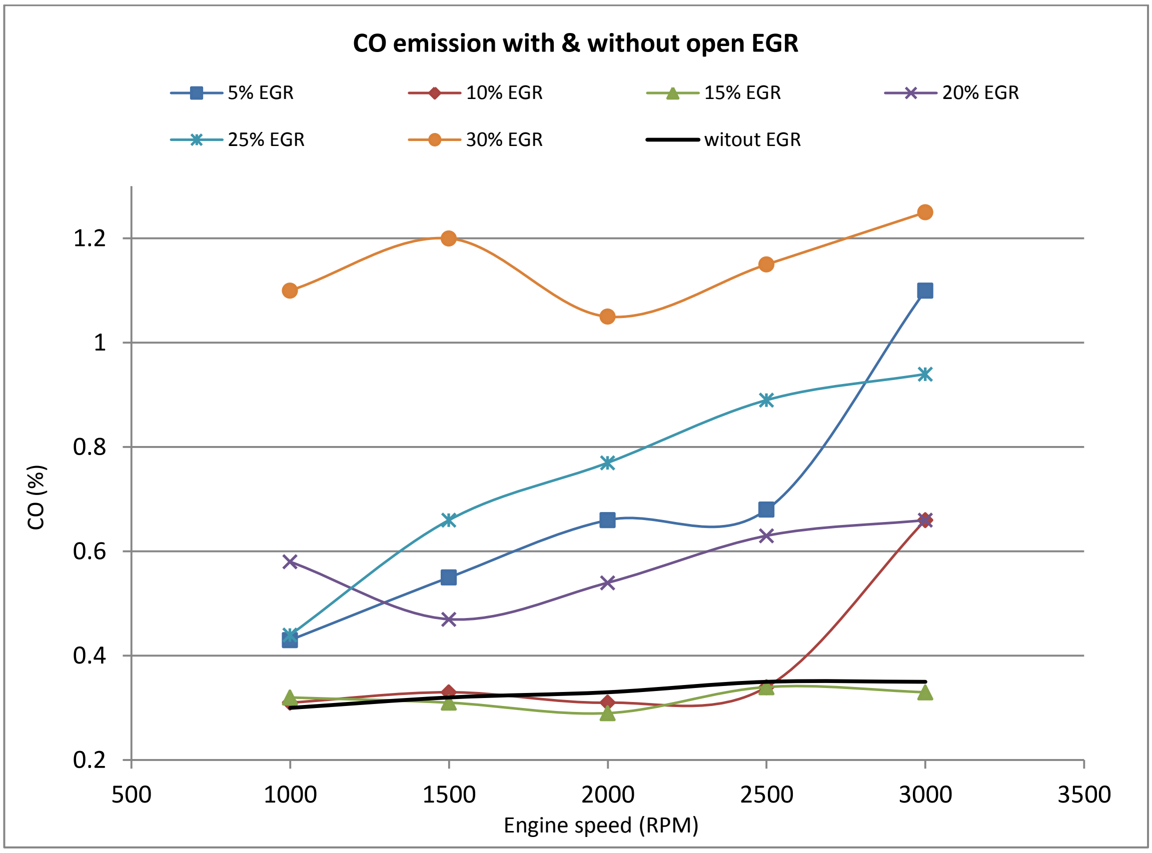


Figure 8.5: Rate of CO when engine powered by gasoline with and without opening EGR

8.3.1.4 Carbon dioxide ($CO_2$)

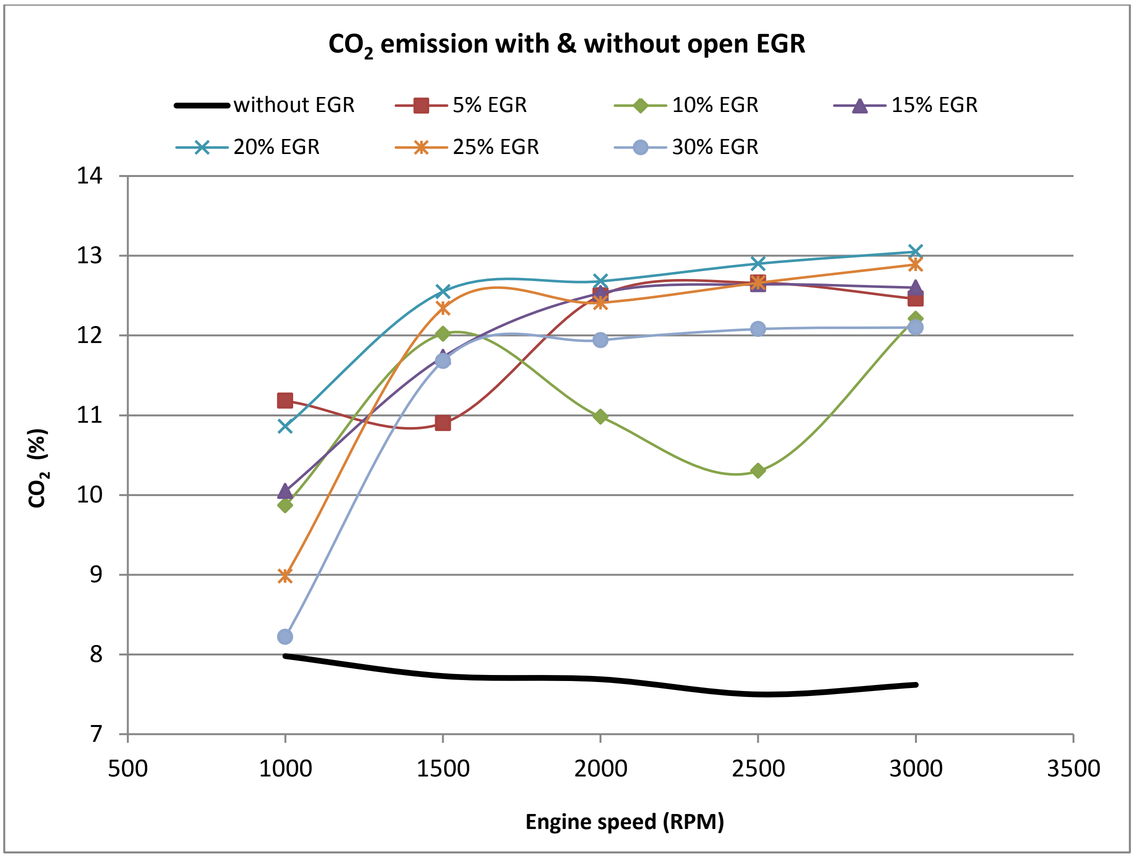


Figure 8.6: Rate of $CO_2$ when engine powered by gasoline with and without open EGR

## 8.3.2 When running by LPG fuel

8.3.2.1 Nitrogen Oxides ($NO_x$):

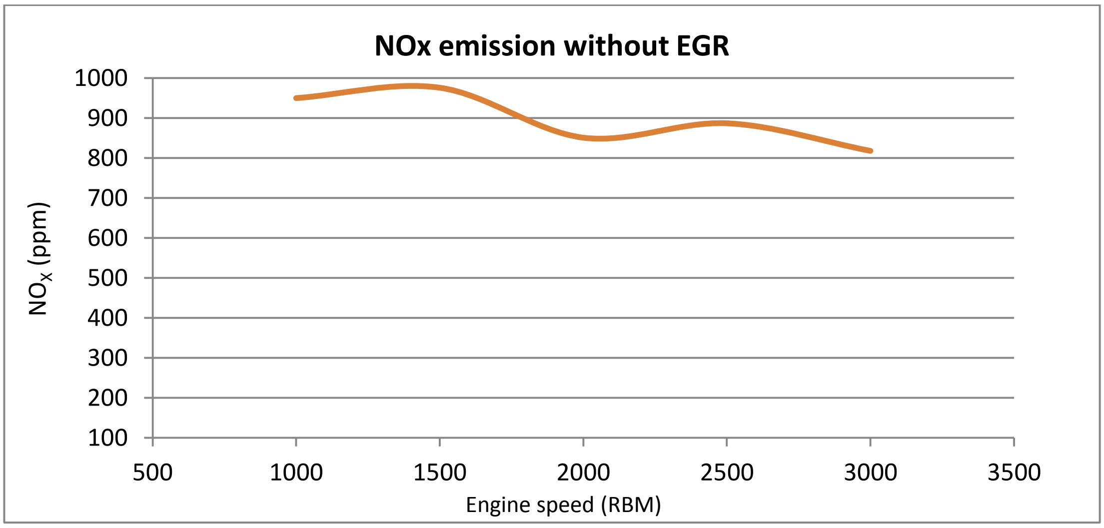


Figure 8.7: Rate of the $NO_x$ when engine powered by LPG without open EGR

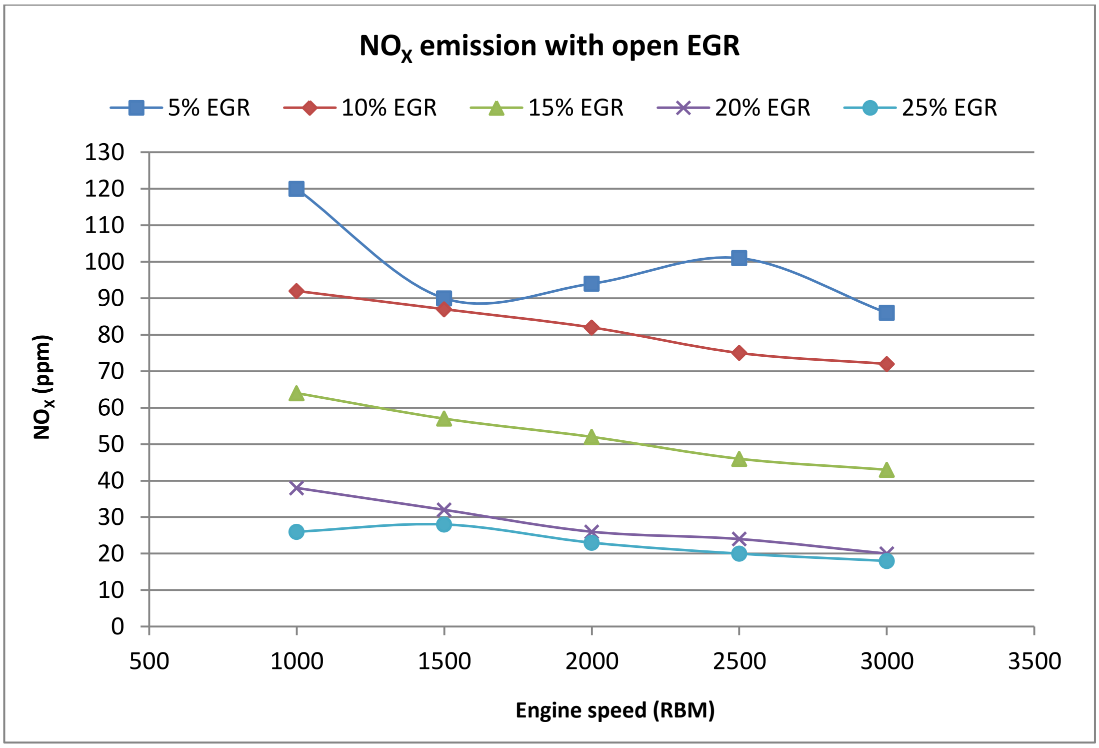

Figure 8.8: Rate of the $NO_x$ when engine powered by LPG with open EGR

8.3.2.2 Hydrocarbons (HC)

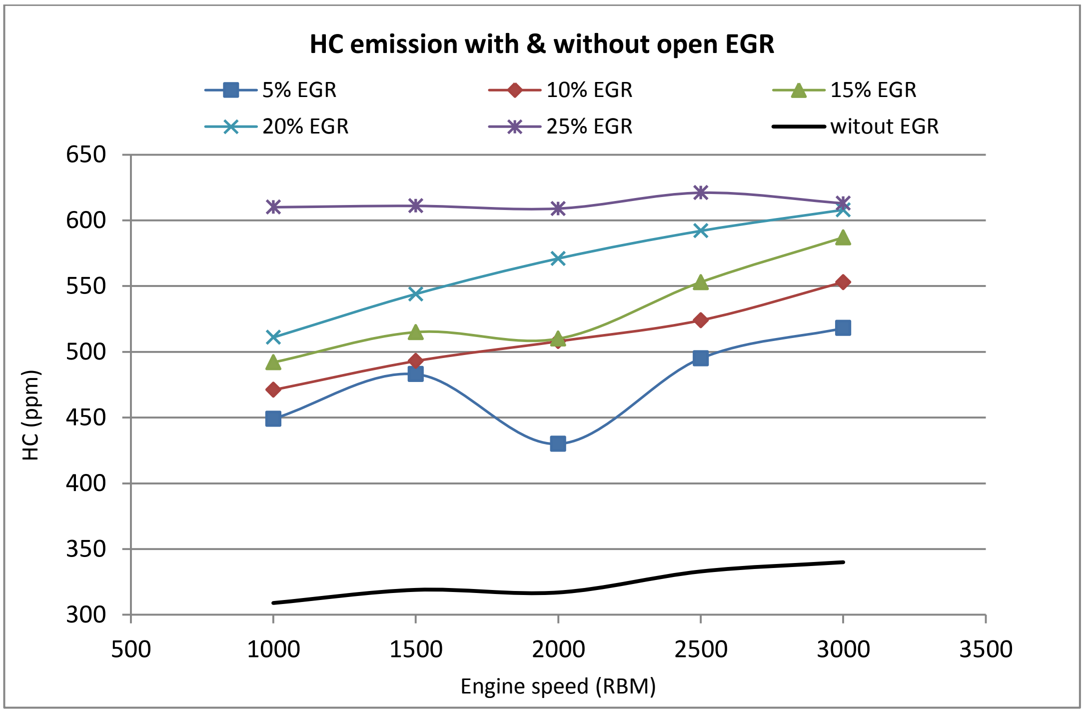

Figure 8.9: Rate of the HC when engine powered by LPG with and without EGR.

8.3.2.3 Carbone monoxide (CO)

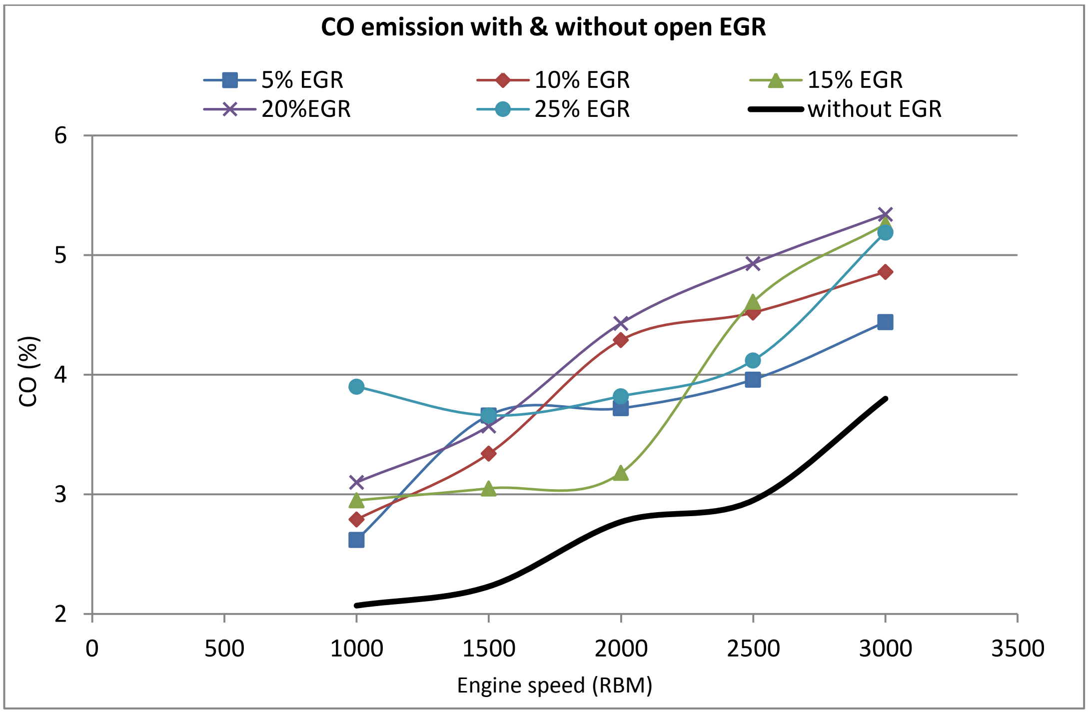


Figure 8.10: Rate of the CO when engine powered by LPG with and without open EGR

8.3.2.4 Carbon dioxide ($CO_2$)

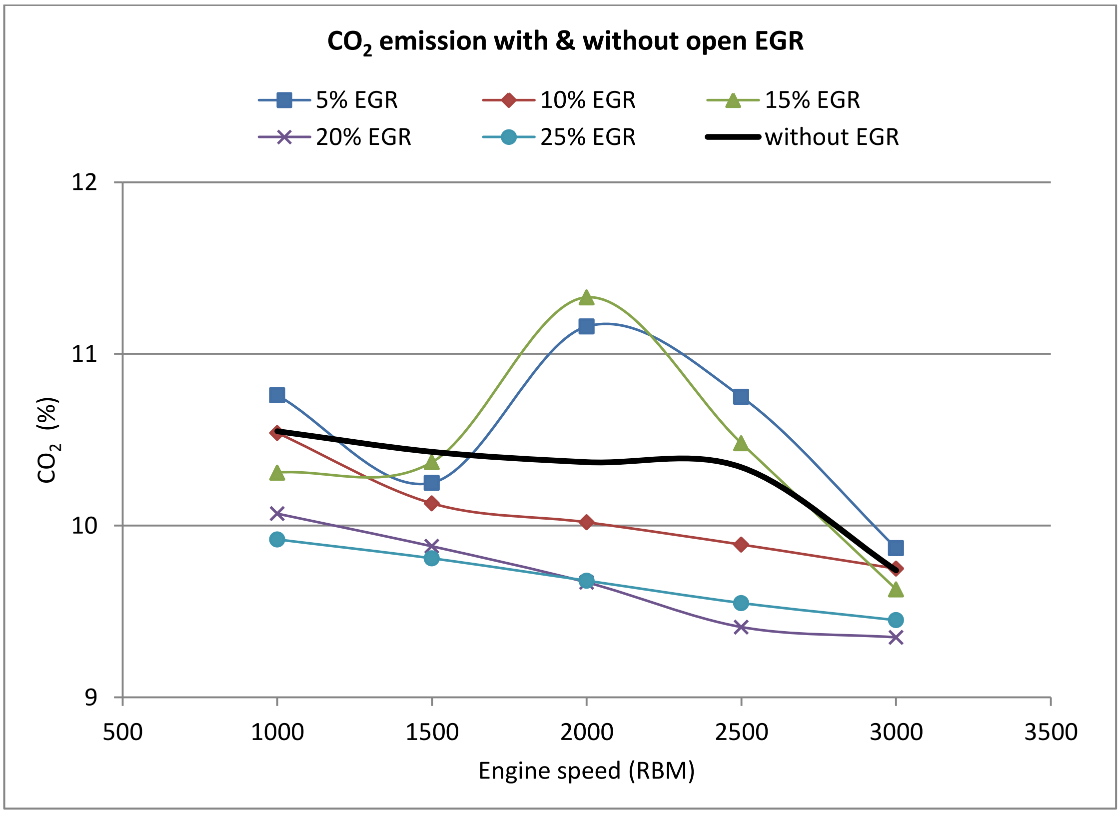


Figure 8.11: Rate of $CO_2$ when engine powered by LPG with and without open EGR.

## 8.4Conclusion :

### 1- Nitrogen oxides (NOx):

- The comparison between with and without opening EGR valve for NOx when engine running by gasoline fuel, show that the NOx with open EGR is less about 92.1% than that of NOx without open EGR.

- The comparison between with and without opening EGR valve for NOx when engine running by LPG fuel, show that the NOx with open EGR is less about 93.7% than that of NOx without open EGR.

- The comparison between the NOx of LPG and gasoline for Mazda 323 MPI engine fuelled with either gasoline or LPG without open EGR show that the NOx of LPG fuel is less about 69.7% than that of NOx gasoline fuel, because the combustion temperature of LPG fuel lower than gasoline.

- The comparison between the NOx of LPG and gasoline for Mazda 323 MPI engine fuelled with either gasoline or LPG with open EGR show that the NOx of LPG fuel is less about 75.8% than that of NOx gasoline fuel, because the combustion temperature of LPG fuel lower than gasoline.

### 2- Hydrocarbons (HC):

- The comparison between with and without opening EGR valve for HC when engine running by gasoline fuel, show that the HC with open EGR is increase about 71.2% than that of HC without open EGR.

- The comparison between with and without opening EGR valve for HC when engine running by LPG fuel, show that the HC with open EGR is increas about 66.5% than that of HC without open EGR.

- The comparison between the HC of LPG and gasoline for Mazda 323 MPI engine fuelled with either gasoline or LPG without open EGR show that the HC of gasoline fuel is less about 74.3% than that of HC LPG fuel, because the combustion temperature of LPG fuel lower than gasoline.

- The comparison between the HC of LPG and gasoline for Mazda 323 MPI engine fuelled with either gasoline or LPG with open EGR show that the HC of gasoline fuel is less about 86.6% than that of HC LPG fuel, because the combustion temperature of LPG fuel lower than gasoline.

### 3- Carbone monoxide (CO):

- The comparison between with and without opening EGR valve for CO when engine running by gasoline fuel, show that the CO without open EGR is less about 48.7% than that of CO with open EGR.

- The comparison between with and without opening EGR valve for CO when engine running by LPG fuel, show that the CO without open EGR is less about 43.7% than that of CO with open EGR.

- The comparison between the CO of LPG and gasoline for Mazda 323 MPI engine fuelled with either gasoline or LPG without open EGR show that the CO of gasoline fuel is less about 88.1% than that of CO LPG fuel, because the combustion temperature of LPG fuel lower than gasoline.

- The comparison between the CO of LPG and gasoline for Mazda 323 MPI engine fuelled with either gasoline or LPG with open EGR show that the CO of gasoline fuel is less about 83.8% than that of CO LPG fuel, because the combustion temperature of LPG fuel lower than gasoline.

### 4- Carbon dioxide ($CO_2$)

The rate of $CO_2$ remains nearly constant whether at running the engine by gasoline or LPG fuel.

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