Palestine Polytechnic University

**College of Engineering and Technology**

**Mechanical Engineering Department**

**Graduation Project**

# ENGINE PERFORMANCE POWERD BY BIOGAS

## (BRAKE POWER, FUEL CONSUMPTION, AND EMISSIONS FOR MAZDA 323I ENGINE)

**Project teams**

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Supervisor:

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Submitted to the College of Engineering in Partial Fulfillment of the requirements for the Degree of Bachelor of Mechanical Engineering

Palestine Polytechnic University

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# Abstract

This research tests the performance of internal combustion engines (braking power, fuel consumption and emissions) using biogas after filtration. The results showed that biogas generates less torque and less braking power than gasoline and liquefied petroleum gas (LPG). The test rates were about 20% and 8%, respectively, and in terms of fuel consumption was lower than gasoline and LPG by 50% and 30% . The research concludes that the engine supplied with biogas found to be economical, and at a much lower cost than gasoline and LPG, where the proportion of them to more than 80%.

In terms of emissions, the results were mixed, a carbon dioxide in biogas higher than gasoline and LPG, in terms of nitrogen oxides is less than gasoline and higher than LPG, and the opposite of carbon monoxide were in biogas lower than gasoline and higher than LPG, finally hydrocarbons were found in biogas less than gasoline and LPG.

هذا البحث يختبر أداء محركات الاحتراق الداخلي (قوة الكبح للمحرك، استهلاك الوقود والانبعاثات) باستخدام الغاز الحيوي بعد الفلترة . وأظهرت نتائج الاختبارات أن الغاز الحيوي يولد أقل عزم وأقل في قدرة الكبح من البنزين وغاز البترول المسال و قد كانت نسب الاختبار حوالي 20% و 8% على التوالي ومن حيث استهلاك الوقود كانت اقل من البنزين وغاز البترول المسال بسبة 50% و 30 % تقريبا. ويلخص البحث إلى أن محرك المزود بالغاز الحيوي وجد أنه اقتصادي، و بكلف اقل بكثير من البنزين و غاز البترول المسال حيث وصلت النسبة بينهم الى اكثر من 80% .

بالنسبة الى الانبعاثات كانت النتائج متضاربة حيث كان الغاز الحيوي اعلى في ثاني اكسيد الكربون من البنزين وغاز البترول المسال, وكان اقل من البنزين من حيث أكاسيد النيتروجين و اعلى من غاز البترول المسال و المثل في أول اكسيد الكربون فقد كان في الغاز الحيوي اقل من البنزين و اعلى من غاز البترول المسال و أخيرا الهيدروكربون وجد انه في الغاز الحيوي اقل من البنزين و غاز البترول المسال.

**الإهداء**

إلى فلسطين ودُرَتها القُدس وَ تاجُها الأقصى

وَ لِمَن افتَداها بِروحِهِ فارتَقى شَهيدا

وَ لِمَن ضَحى لَها بِسنين عُمرهِ فَغدى أَسيرا

وَ لِكل المُرابِطين على ثَراها الطاهِر.

إلى مَن قَضى اللهُ تَعالى في كِتابِهِ الإحسان إلَيهِما

مَع تَوحيده بِالعُبودية فَلا نَستَطيع رَد نزر مِن إحسانِهم إلَينا

" أَبي وأُمي"

أَنتُما حَياتي كُلها, لَكُم مِني فُؤادي فاقبَلوه ....

إلى مَن وَقَفَ على المَنابِر وَ أَعطى مِن حَصيلة فِكره لِيُنير دُربنا ...

إلى الأساتِذَةِ الكِرام ...

لِكُل مَن دَعمَنا وَ وَقَفَ بِجانِبِنا...

لِزَميلاتِنا وَ زُمَلائِنا مُهَندِسي وَ مُهَندِسات المُستَقبَل ....

إليكُم جَميعاً نُهدي فاتِحَة العَطاء ....على أَملِ البَقاء بِإذنِ الله تَعالى

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## 1.1 Overview

Biogas found its way from developing countries to developed countries . In 2008 the biogas production in Europe exceeded 7.5 million tons of oil equivalent . Germany is this respect a leading country in Europe with 4500 biogas plants and 1650 MW installed electric power in 2009 and expanding for more capacity [1].

Biogas fuels usually cause low pollution to the atmosphere and because they come from renewable energy resources, they have a great potential for future use. For the last decade the use of biogas coming from sewage collection, farms and industrial treatment has risen constantly. Nowadays biogas plants are easily available in the market, and biogas constructions have been installed all over Europe. The upgraded biogas is mainly used for heat and electricity production. However more and more projects using biogas as vehicle fuel are set up in European cities. Indeed, this vehicle fuel is the best way to upgrade waste. Nevertheless a governmental support is needed in order to make the biogas market attractive because of its high investment costs [2].

Producing biogas means enhancing the value of a renewable natural gas and reducing greenhouse gas. Whatever its origin, the non-upgraded biogas contributes to the greenhouse effect. Nevertheless the carbon dioxide liberated by the combustion of the biogas has no impact on the greenhouse effect. This $CO_2$ comes from the carbon dioxide stocked into the organic substance during the photosynthesis. Therefore there is no “additional” gas freeing, as it is the case for the fossil deposit[2]. Using biogas in internal combustion engines started from 1940 and till now a lot of progress has been made to cope with biogas specifications [3].

However , In this project, we will test the performance of internal combustion engines that operate on biogas and compare the results we will obtain with other results for gasoline and natural gas.

## 1.2 What is Converted Gasoline Vehicle?

Biogas is combustible in internal combustion engines, with simple modifications necessary on basic spark as their actual designs can accommodate the burning of biogas as a fuel to produce the energy required. Biogas, can attain higher compression ratios without knocking, allowing better engine performance .

In an aftermarket conversion, equipment is added to a vehicle that was originally designed for one fuel to allow it to operate on an alternative fuel. Converting gasoline vehicles to compressed natural gas (CNG) or Biogas operation is common. Converting diesel vehicles is less common.

Typically the conversion company adds a fuel tank or tanks, fuel lines, a pressure regulator (vaporizer) to reduce the pressure of the fuel to usable levels, and a mixer or carburetor to mix the CNG or Biogas with the incoming air. In addition, most modern conversions have an electronic control system to control the fuel/air ratio to the precise levels required by today's vehicles. A switch and related hardware are also installed to switch from one fuel to the other. All existing emissions-related equipment must be left on the vehicle because they are required for proper emissions control, and emissions regulations[4].

Palestine is an important site for the production of biogas because of the quality of its geographical location and the diversity of its topography from the plains and mountains of the valley, and also the difference in climate from one place to another and the presence of many species of animals in them.

## 1.3 Potential of Biogas in Palestine:

The percentage of livestock in Palestine varies from city to city as shown in Fig (1.1) [5].

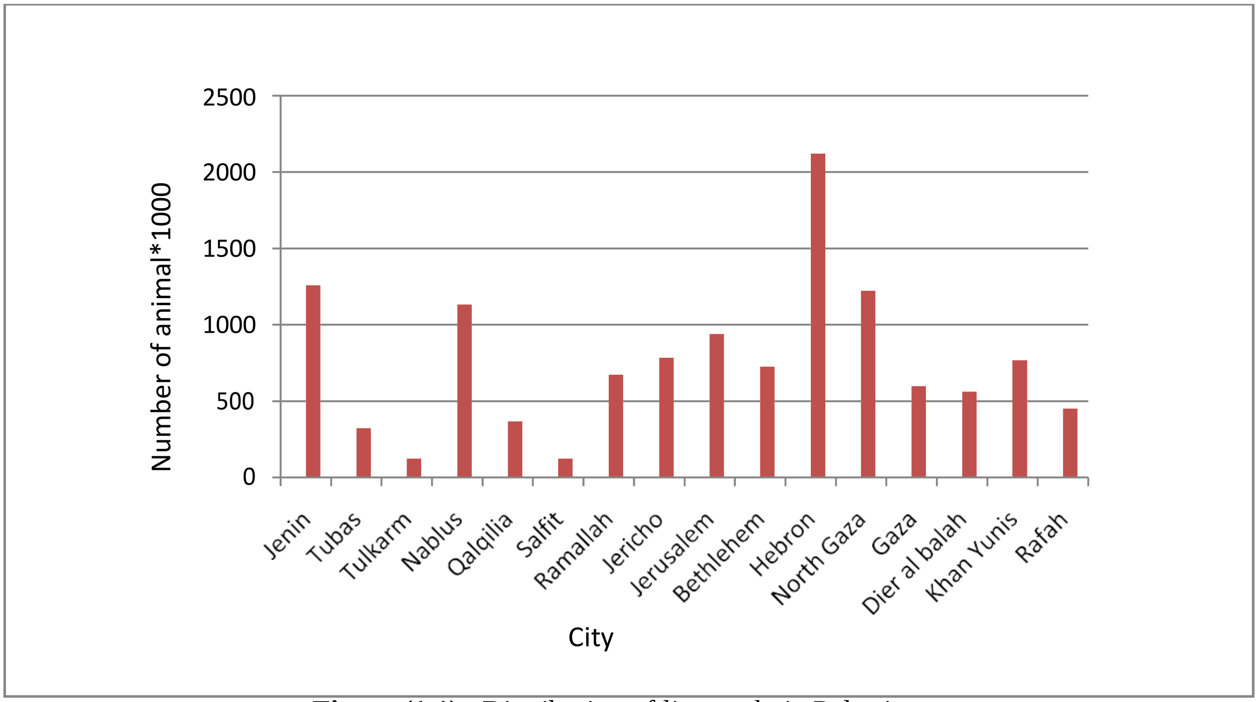


**Figure (1.1)** : Distribution of livestock in Palestine

These livestock are distributed as Figure (1.2) [5] :

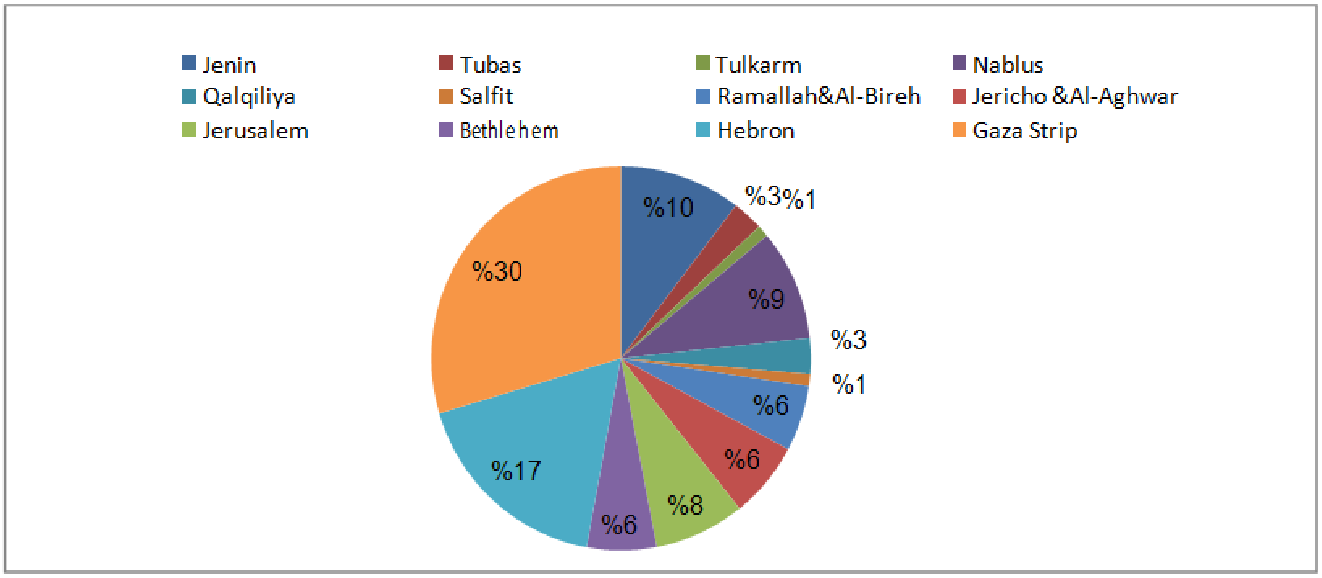


**Figure (1.2)** : Distribution of livestock in Palestine

Considering the number of livestock minted above, and estimating the human and other organic wastes in the Palestinian rural community, the yearly amount of dry organic wastes can be estimated as in the table (1.1) and Figure (1.3 ) [6].

| Waste type | Yearly amount |
|---|---|
| Animal wastes | 22000 tons |
| Chicken waste | 17000 tons |
| Goats and sheep wastes | 105000 tons |
| Kitchen wastes | 8000 tons |

**Table (1.1)** : Type of wastes in the West Bank and Gaza strip

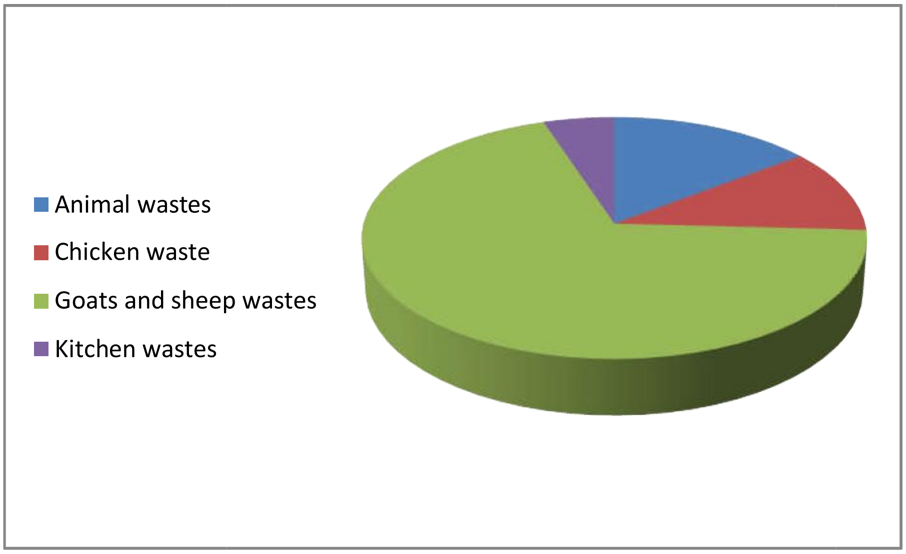


**Figure (1.3 ):** Shares of local wastes sources

According to the statistics and the values we have, the same output of biogas amounts in Palestine 32 million m3/year, and this equivalent of 46 million NIS, which accounts 13% of Palestine spending on oil product [6].

However, the ratio of methane production to animal residue is different as shown in the Figure (1.4 ) [7].

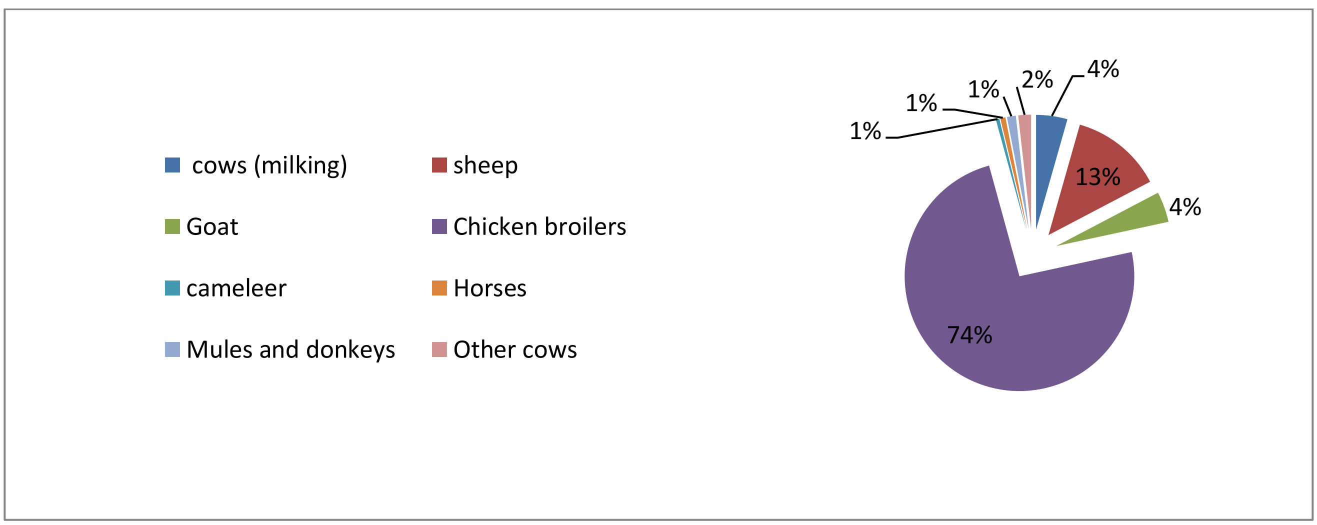


**Figure (1.4 )** : Percentage of methane production from animals

The process of producing and extracting bio is done in two different ways and will be explained as follows:

### 1.3.1 Production of biogas:

Biogas is produced in two ways:

First way :

Fermentation: in this way , the biogas production in four step :

1. Hydrolysis : hydrolysis is the first step in which AD facultative and obligatory microorganisms tend to convert insoluble complex organic material to soluble compound (monomers)using specialized hydrolytic exoenzymes (hydrolase)[8].

2. Acidogenesis :In this stage, the hydrolyzed compounds are fermented into volatile fatty acids (VFA) (acetic, propionic, butyric, valeric acids etc.), neutral compounds (ethanol, methanol), ammonia, and the pH falls as the levels of these compoundsincreases[8].

3. Acetogenesis : The third step is acidogenesis. Obligatory $H_2$ producers microorganisms (acetones microorganisms whichhave ability to produce acetate)further degraded VFA, alcohol, $CO_2$ and $H_2$that produced in acetogenesis step to acetic acid[8].

4. Methanogenesis :The Last stage in anaerobic degradation of biomass is methanogenesis where methane production proceeded by obligatory anaerobic bacteria. The Substance acceptable to methanogen to produce methane would be classified to three category depend ontheirdegradation path way and number of microorganisms that able to handle degradation process[8].

Sec**o**nd way :

Anaerobic digestion : in this way , the biogas production in four step :

**1.** Hydrolysis:

Some of microorganisms are responsible for hydrolysis*Bacteroides.*They take substrate as carbohydrates and metabolic products of other microorganisms like sugar, amino acids, and organic acids. The metabolic products of the *Bacteroides*are succinate, acetate, formate, lactate, and propionate[8].

**2.** Acidogenesis:

Species of the *Ruminococcus*such as *R.hydrogenotrophicus*; degrades fatty acids and aromatics in symbiosis with obligate syntrophic organism, which ferment carbohydrates to acetate, formate, succinate, lactate, ethanol, $H_2$ and$CO_2$[8].

**3.** Acetogenesis

In this step enrichment of butyric acid, degrading acetogenic bacterium by butyric acid in symbiosis with *Methanobacteriumhungatii*takes 120 h at 35°C. Acetogenic bacteria, *Aminobacteria*ferment amino acids and produce acetate[8].

**4.** Methanogenesis

The main species of bacteria in this step *Methanobacterium, Methanospirillumhungatii, and Methanosarcina*[8].

There is a practical experience on the production and use of biogas in Palestine, the station of Aljibreeni (EFG), where the plant contains 1000 heads of cows where these cows produce 20 tons of manure and this amount produced daily 370 kW, and this plant contains a filter, This filter produces 65% of methane, This plant is capable of producing 1 MW but produces 370 KW because the existing generator is capable of producing this quantity only. If the plant increases production, they must add another generator.

## 1.3.2 Chemical construction of biogas:

Biogas is a mixture of different gases produced from organic material in the absence of oxygen. Biogas can be produced from raw materials such as agricultural waste, manure, municipal waste, plant material, sewage, green waste or food waste.

The main component gases of Biogas are:

| Substances | Symbol | Percentage |
|---|---|---|
| Methane | $CH_4$ | 50-70 |
| Carbon dioxide | $CO_2$ | 30-40 |
| Hydrogen | $H_2$ | 5-10 |
| Nitrogen | $N_2$ | 1-2 |
| Water vapor | $H_2O$ | 0.3 |
| Hydrogen sulphide | $H_2S$ | Traces |

Methane is virtually odorless and is invisible in bright daylight . It burns with a clear blue flame without smoke and is non-toxic .

Methane is produced by the following equations

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O \qquad (1.1)$$

$$CH_3OH + H_2 \longrightarrow CH_4 + H_2 \qquad (1.2)$$

$$CH_3COOH \longrightarrow CH_4 + CO_2 \qquad (1.3)$$

But when the combustion of methane it produces carbon dioxide and water gas according to the following equation:

$$CH_4+2O_2 \longrightarrow 4CO_2+ 2H_2O \qquad (1.4)$$

## 1.4 Project theory:

Biogas can be used in combustion engines as fuel-effective alternative to gasoline and LPG. In spite of the soft nature of, a low-density and compact size, there must be some fundamental changes necessary to accommodate the fuel and these modifications are present at relatively low cost, and if the engine was better. These amendments is to change the ignition properties and increased compression ratio by adding hydrogen .

Biogas in its purer state (more than 95% methane) has calorific values similar to that of natural gas and can be used in all existing natural gas applications .
Comparisons have been drawn in the performances of enriched biogas and natural gas at constant speed internal combustion engines with the experiments reporting similar engine performance in terms of brake power output, specific gas volume, thermal efficiency, fuel economy and emissions [9].

## 1.5 Project Objectives:

The main objective of the project is to test the performance of internal combustion engines (break power, fuel consumption and emissions) and the use of biogas after filtering .

The sub objectives of this project was to find out the followings:

- Power a Mazda engine by Biogas fuel.
- Test the suitability of Biogas as fuel for engine.
- Measure the performance of the engine powered by Biogas, LPG and gasoline.
- Compare the gasoline, LPG and Biogas fuel consumption.
- Compare the gasoline, LPG and Biogas emissions.

## 1.6 Literature review:

There are many previous studies on the use of biogas for energy production and its effects. These studies include:

Huang J, Crookes RJ: A single cylinder engine was used to compare the performance and emissions of gasoline, natural gas and biogas, and gas fuel had lower limits than gasoline. The brake power was even lower at a higher compression ratio compared with the gasoline process at normal value. The thermal efficiencies of the brakes were lower than the gasoline at the same pressure ratio and decreased with increased carbon dioxide ratio. In high pressure and moderate speeds [10].

A recent study developed a biogas-petrol blend and used the resulting mixture to run a spark ignition test bed. Parameters such as torque, specific fuel consumption, brake power, brake thermal efficiency, brake mean effective pressure, mechanical efficiency, indicated thermal efficiency, and exhaust temperature at different speeds were compared with that run on petrol . It can therefore be concluded that biogas-petrol blend is a veritable and viable alternative for standalone spark ignition engine. A spark ignition engine fuelled with biogas-petrol fuel of proportion 20:80 generates more torque, brake power, indicated power, brake thermal efficiency and more brake mean effective pressure but with less fuel consumption and exhaust temperature [11].

Study was to investigate the influence of dual fuel combustion on the engine performance and exhaust emission in SI engine fuelled with biogas-petrol dual fuel. For this reason engine test were carried out on SI engine using neat petrol as fuel and biogas-petrol as dual fuel. Different percentages of biogas substitution were used to compare the performances and exhaust emission. Performance Testing revealed that Brake specific fuel consumption and Brake thermal efficiency were improved with increases in gas substitution [12].

Power generation in Colombari farm, Paraná, Brazil : The Colombari farm, located in the municipality of São Miguel do Iguaçu, also in western Paraná, Brazil, has a pilot production of electricity from biogas. This pilot, technically managed by Itaipu, configured as reference prior to the generation of electricity in Ajuricaba[13].

## 1.7 Project schedule:

| **TASKS** | 1$^{st}$Month | | | | 2$^{nd}$Month | | | | 3$^{rd}$Month | | | | 4$^{th}$Month | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wk$_1$ | Wk$_2$ | Wk$_3$ | Wk$_4$ | Wk$_1$ | Wk$_2$ | Wk$_3$ | Wk$_4$ | Wk$_1$ | Wk$_2$ | Wk$_3$ | Wk$_4$ | Wk$_1$ | Wk$_2$ | Wk$_3$ | Wk$_4$ |
| Identification of Project Idea | ■ | ■ | | | | | | | | | | | | | | |
| Literature Review | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |
| Preparation of equipment | | | ■ | ■ | ■ | ■ | | | | | | | | | | |
| Work experiments | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | |

## 1.8 Budget :

| NO | Parts | Cost (NIS ) | Quantity | Total cost |
|---|---|---|---|---|
| **1** | Engine transfer | 200 | 2 | 400 |
| **2** | Maintenance The engine | 700 | 1 | 700 |
| **3** | Motor of water | 200 | 1 | 200 |
| **4** | Tube | 100 | 2 | 200 |
| **5** | Compressor | 50 | 1 | 50 |
| | Total | | | 1550 |

# Chapter2

## PERFORMANCE COMPARISON OF MAZDA 323I ENGINE POWERED BY LPG AND GASOLINE AS FUEL

# CHAPTER 2

# PERFORMANCE COMPARISON OF MAZDA 323I ENGINE POWERED BY LPG AND GASOLINE AS FUEL

## 2.1 Introduction

This chapter discusses the installation of the equipment and the tools used in experiments and how these tools used to measure the performance of gasoline engine powered by gasoline then by LPG. Where a hydraulic dynamometer was used and calibrated properly. Also the chapter discusses the performance comparison of the engine operated by LPG and gasoline. The main purpose of measuring the performances such as brake power, exhaust emissions and fuel consumption of gasoline and LPG fuels is to underline these measurement as comparison base line with performances of biogas fuel as a fuel for ICE.

## 2.2 Experiment Equipment and Devices

### 2.2.1 Mazda 323i engine

The experiments were performed on a gasoline four strokes and pistons Mazda engine with a total capacity of 1489 cc. The engine belongs to Palestine Polytechnic University mechanical department internal combustion Lab. A maintenance made to the engine to insure a good performance during experiments.

The following Table (2.1) shows the engine technical specification**:**

| 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 ± 1/700 - 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 | (°C) |
| Fast-idle speed | 2500 - 2800 | (rpm) |
| CO at fast-idle speed | < 0.3 | (%) |

**Table (2.1)**: Engine Technical Specification

### 2.2.2 The gas analyzers :

Two exhaust analyzers have been used to determine the ratios of different exhaust emission gases.

1. **Testo320 :**

This device shown in Figure (2.1) was used to measure Carbon monoxide (CO) and Carbon Dioxide ($CO_2$) percentages.


**Figure (2.1):** Testo320

Testo320 can measure (CO) and ($CO_2$) with accuracy of ±5% of meas. With Response time less than 40s. The device was calibrated, First, run the device and then choose the fuel that wants to calculate the exhaust gas, then work calibration on the pure external air, and finally put the device in the exhaust entry and press the on button.

2. **Gas analyzer :**

This device shown in Figure(2.2) was used to measure Nitrogen Oxides($NO_x$), Sulfur dioxide ($SO_x$) and Hydrocarbon (HC) percentages.

**Figure (2.2):** Gas analyzer

The gas analyzer detector with 3D sensor detects toxic gases and vapors. with accuracy 10%, two point field calibration of zero and standard reference gas.

### 2.2.3 Hydraulic Dynamometer :

The dynamometer is a hydraulic brake retard the rotating torque of the engine that convert to a stationary torque that will be measure through the power of water. The engine power is absorbed which is controlled through the water input on the dynamometer. The dynamometer measures the engine torque continuously while increasing the amount of water and produces a torque value for each speed in the engine. Torque and power values were integrated during each shaft revolutions as the engine is slowly accelerate through a range of interest . The data has been taken at 500 RPM of the engine.

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 damage when overcharge in the torque and performance range.

**Calibration of dynamometer**

Maintenance was made to the dynamometer to insure the proper working and the accuracy of the measured engine torque. Then the dynamometer was calibrated, through placing a known different weights on the torque arm of the dynamometer. The actual torque was found by multiplying each weight with the torque arm of 30.5 cm of the dynamometer, while the red torque from the dynamometer was recorded by observing the torque measuring device shown in figure (2.3) of the dynamometer. The results of the calibration process are recorded in table (2.2).

| Mass (kg) | Torque (N.m) Theoretical | Torque (N.m) Experimental |
|---|---|---|
| 5 | 14.96 | 14.5 |
| 6 | 17.95 | 17.5 |
| 11 | 32.9 | 32.5 |
| 12.5 | 37.4 | 37.0 |

**Table (2.2)**: Calibration of dynamometer

The results of the calibration confirms the accuracy of the dynamometer torque measurement.

**Figure (2.3):** The dynamometer is fitted with the measuring torque clock.

### 2.3 Performance Measuring Experiment

The experiment done to measure the torque and the brake power versus the engine speed was performed according to the following steps:

**Step 1**: The engine was operated on gasoline fuel until it reached its operation coolant temperature.

**Step 2**: The engine was accelerated with zero load until the engine speed reached 3500 RPM.

**Step 3**: The load was increased by increasing the water flow of the hydraulic dynamometer gradually such that, the engine speed decreased each time by 500 RPM.

**Step 4**: The measured torque was recorded for each speed reduction.

**Step 5**: The brake power ( bp ) which was developed by an engine at the output shaft of the engine was calculated using Eq.1

$$(bp) = 2\pi NT/60 \quad (1)$$

Where:

bp is $Brake\ power$ in kW

N is engine speed in RPM.

T is engine torque in N.m.

### 2.4 Results and Discussions:

Based on the experiment steps stated on section 2.4 above the results of the brake power and the output torque produced from powering the engine one time using gasoline fuel and another time using LPG are shown in the table (2.3).

| No. | Engine speed (RPM) | Gasoline Fuel | | LPG Fuel | |
|---|---|---|---|---|---|
| | | Torque (Nm) | Break power (kW) | Torque (Nm) | Break power (kW) |
| | N | $TQ_1$ | $bp_1=(2\pi NT/60)/1000$ | $TQ_2$ | $bp_2=(2\pi NT/60)/1000$ |
| 1 | 1000 | 83 | 8.7 | 78 | 8.16 |
| 2 | 1500 | 71 | 11.15 | 66 | 10.36 |
| 3 | 2000 | 55 | 11.5 | 51 | 10.70 |
| 4 | 2500 | 39 | 10.2 | 35 | 9.16 |
| 5 | 3000 | 20 | 6.28 | 18 | 5.65 |
| 6 | 3500 | 8 | 2.93 | 8 | 2.93 |

**Table (2.3):** The Recorded Data and the Calculating Gasoline and LPG Power

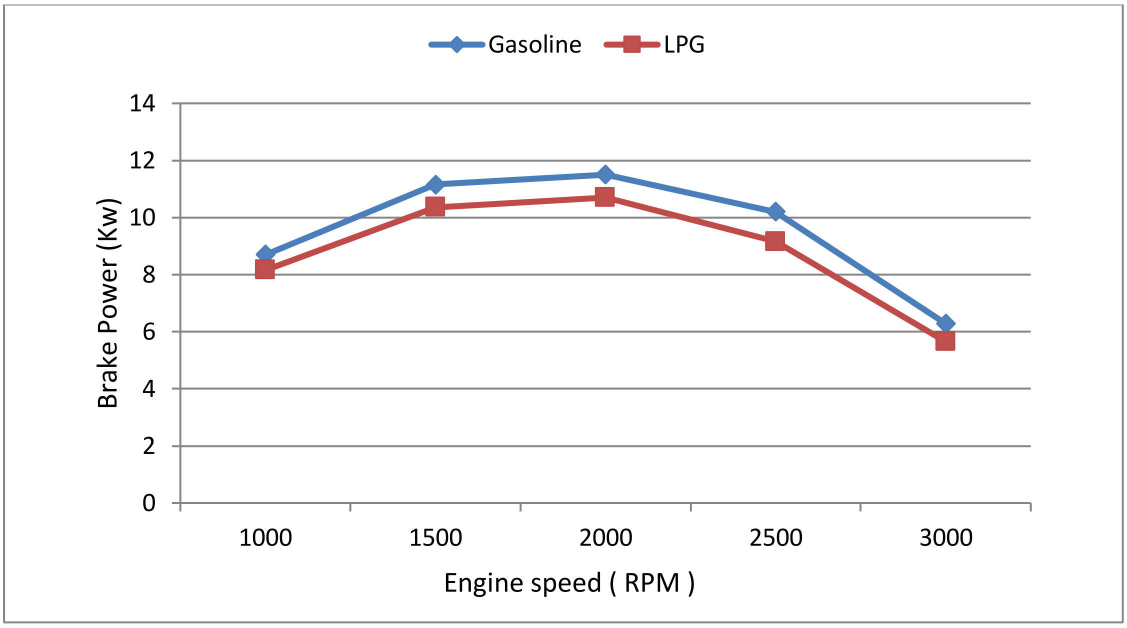


**Figure (2.4):** Gasoline and LPG Brake Power Curve

The last figure show the relation between the brake power of the engine in (kw) on the vertical line and the engine speed in RPM on the horizontal line. The maximum break power in both curves is at 2000 RPM as engine speed.

## 2.5 Brake Specific Fuel Consumption:

Brake Specific Fuel Consumption (bsfc), is defined as the amount of fuel consumed for each unit of brake power developed per hour. It is a clear indication of the efficiency with which the engine develops power from fuel.

$$\text{bsfc [g / kW h]} = \frac{\text{Fuel consumed in g / hour}}{\text{Brake Power in (kW)}} \quad \text{......................... (2)}$$

### 2.5.1 Calculation and Results

A set of tests were made at different engine speeds and loads to measure the brake specific fuel consumption rates. The recorded data are in table (2.4) along with the calculated brake specific fuel consumption rates and calculated developed engine power.

Gasoline fuel density = 0.75 kg / litter

Example:

Gasoline fuel Consumption in (g/h) =

ml/min/1000 * 60 * Gasoline density (kg/ litter) *100

= 54.05(ml/min) /1000 *60 * 0.75(kg/ litter) * 1000

= 2432.25 g/h

Gasoline break specific fuel consumption (g / kWh) =$\dot{m}$(g /h) / Break Power (kW)

= 2432.25 / 3.14 = 774.6 g / kWh

When measuring gas consumption, a digital balance was used. And Before the operation was the mass of the gas tank = 29.45 Kg.

The engine was operated at variable speeds and loads for one minute and then measured the mass of the tank after operation for each case.

Example:

LPG fuel Consumption in (g/h) =

(g /min) * 60

=45 (g /min) * 60

=2700g/h

LPGbreak specific fuel consumption (g / kWh) =

$\dot{m}$(g /h) / Break Power (kW)

= 2700/ 3.14 =859.87g / kWh

| Engine speed (RPM) | Torque (N.m) | Break power (Kw) | Gasoline Fuel Consumption (ml / min) | Gasoline Fuel Consumption g/h | LPG Fuel Consumption g/h | Break Specific Fuel Consumption of gasoline ( g / kw.h ) | Break Specific Fuel Consumption of LPG ( g / kw.h ) |
|---|---|---|---|---|---|---|---|
| 1500 | 20 | 3.14 | 54.05 | 2432.25 | 2700 | 774.6 | 859.87 |
| 1500 | 40 | 6.3 | 69.76 | 3139.2 | 3000 | 498.28 | 476.20 |
| 2000 | 20 | 4.2 | 75 | 3375.00 | 2400 | 803.57 | 571.40 |
| 2000 | 40 | 8.4 | 96.66 | 4354.65 | 2700 | 518.41 | 321.42 |
| 2500 | 20 | 5.2 | 100 | 4500.00 | 3000 | 865.38 | 576.90 |
| 2500 | 40 | 10.5 | 130.4 | 5869.53 | 4200 | 558.98 | 400.00 |

**Table (2.4)**: LPG & Gasoline Brake Specific Fuel Consumption

The next Fegures (2.5) and (2.6) show the relation between Brake Specific Fuel Consumption ( g / kWh ) and the engine speed (RPM) for gasoline and LPG as a fuel, where The blue curve is when the torque is 20 N.m and the red one is when the torque is 40 N.m.

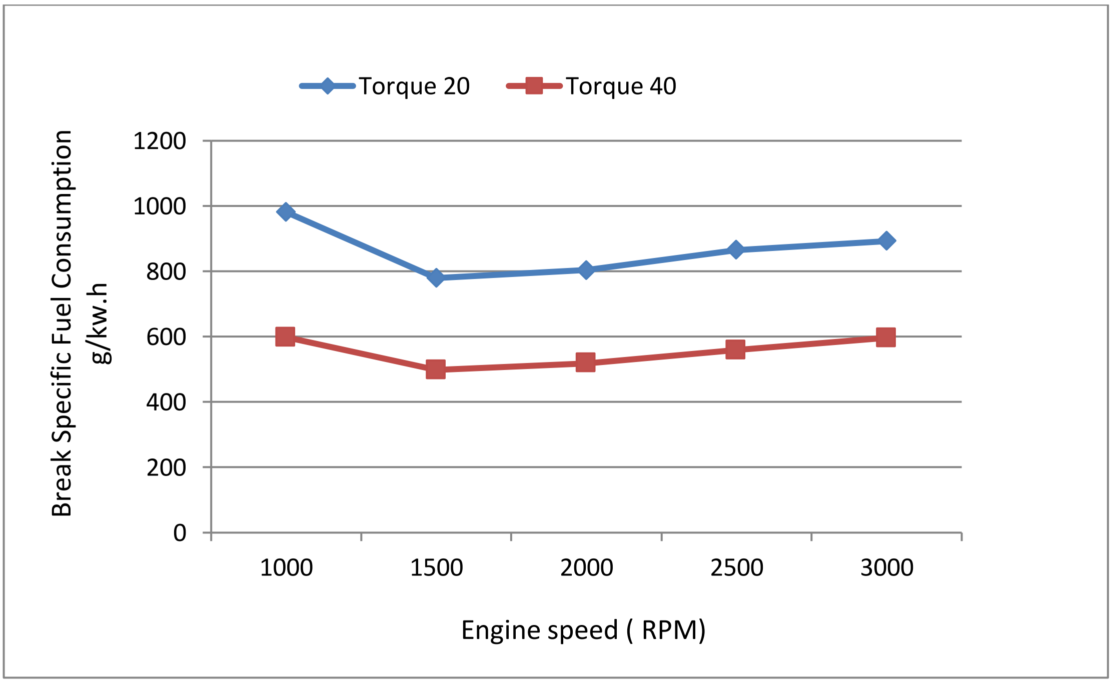


**Figure (2.5)**: Gasoline bsfc in g/Kw.h and RPM

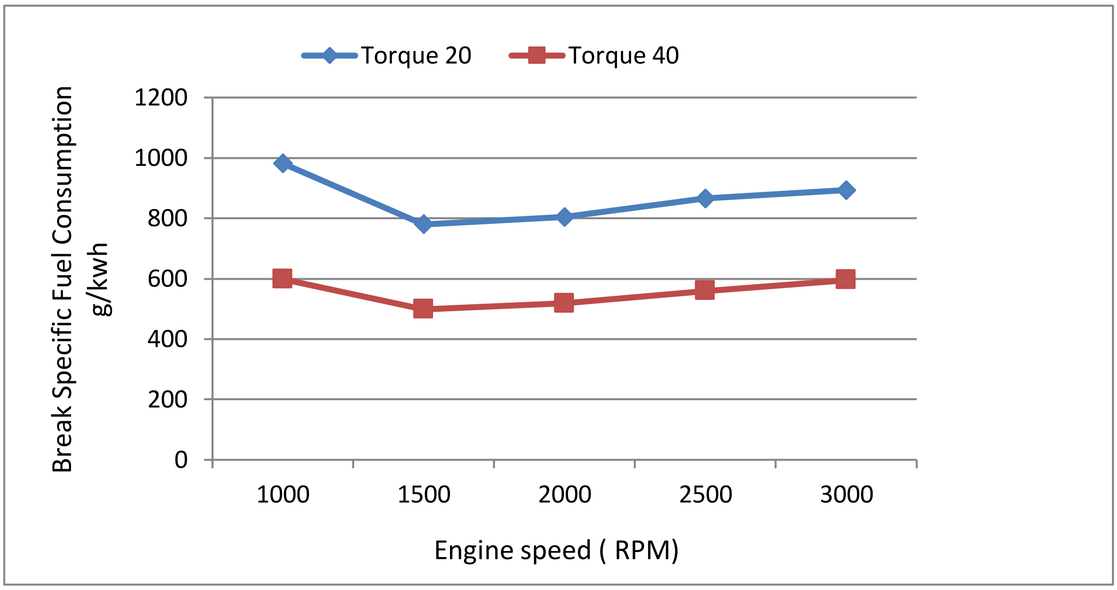


**Figure (2.6):** LPG bsfc in g/KWh and RPM

## 2.6 Emission Measurements

The analysis of CO, HC, $NO_x$,$SO_x$,$NH_3$ and $CO_2$ emissions during emission test on the Gas Analyzer for both gasoline and LPG fuels, The objective was to focused on analyzing the effect of gasoline and LPG fuels upon exhaust emissions aspects of ecological and environmental benefits when alternative fuel is used. The results were as in the table (2.5) .

| | | | Gasoline | | | | LPG | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Engine RPM | Torque Nm | Power (kw) | CO % | HC ppm | $NO_x$ ppm | $CO_2$ % | Power (kw) | CO % | HC ppm | $NO_x$ ppm | $CO_2$ % |
| 1500 | 20 | 3.1 | 0.81 | 113 | 1170 | 12.7 | 3.1 | 2.11 | 320 | 1120 | 11 |
| 1500 | 40 | 6.28 | 1.13 | 110 | 2500 | 14.3 | 6.28 | 1.1 | 128 | 2250 | 12.5 |
| 2000 | 20 | 4.18 | 1.19 | 120 | 2600 | 14.5 | 4.18 | 1.07 | 115 | 2300 | 12.8 |
| 2000 | 40 | 8.37 | 1.31 | 148 | 2650 | 12 | 8.37 | 0.98 | 117 | 2400 | 13 |

**Table (2.5)**: Emissions Comparison of LPG and Gasoline as Fuel

# Chapter3

## Performance Comparison of Mazda 323i Engine Powered by Biogas

# Chapter 3

# Performance Comparison of Mazda 323i Engine Powered by Biogas

## 3.1 Introduction

This chapter will discuss the process of bringing biogas from the station and how to fill it, and power the engine by biogas and compare the results of the performance of the engine with LPG and gasoline.

## 3.2 Bring the gas and its specifications

After agreeing with the engineer of the plant that produces biogas on taking a quantity of gas, we encountered several problems: First, biogas are not compressed, so we cannot take a large amount of it when placed in a gas tank, Secondly, where the gas will be put in this case. After the question and research was found that the best way to fill the gas placed inside the tubes was to use the Compressor as fig (3.1) to work on taking the largest amount of gas, In this way, valves were placed on the two cylinders to accommodate the valves in the station and the appropriate amount of gas was taken.

**Figure (3.1):** Tube & compressor

The chemical components of biogas taken from the plant were as shown in the table (3.1):

| No | Constituent Gas | Percentage |
|---|---|---|
| 1 | $CH_4$ | %65 |
| 2 | $NH_3$ | %5 |
| 3 | $CO_2$ | %33 |
| 4 | $H_2S$ | 10 PPM |

**Table 3.1:** Biogas chemical component

### 3.3 Performance of the engine power by biogas:

#### 3.3.1 Brake power

The brake power calculated for biogas similar to the way LPG gas and gasoline and the result come as in the table 3.2 & figure 3.2

| No. | Engine speed (RPM) | Torque (Nm) | Brake power (kW) |
|---|---|---|---|
| 1 | 1000 | 69 | 7.22<br>2 |
| 2 | 1500 | 55 | 8.65 |
| 3 | 2000 | 44 | 9.2 |
| 4 | 2500 | 29 | 7.58 |
| 5 | 3000 | 15 | 4.71 |
| 6 | 3500 | 7 | 2.56 |

**Table (3.2):** The Recorded Data and the Calculating Biogas Power

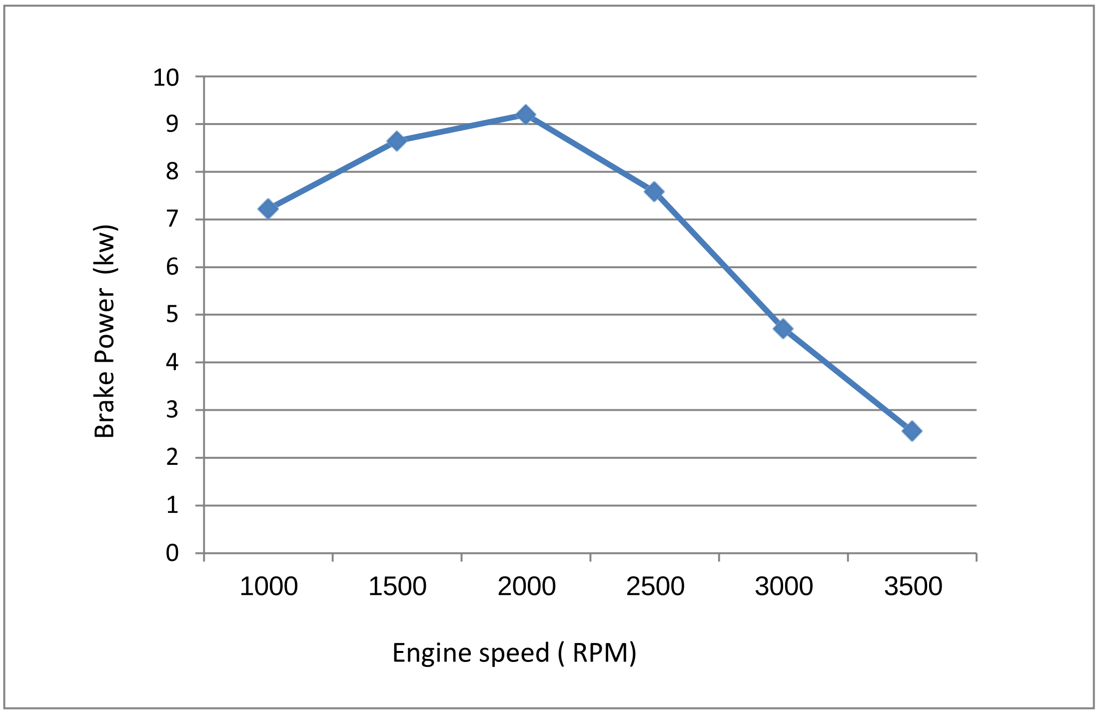


**Figure (3.2):** Biogas brake power

The upper figures show the relationship between the engine speed in ( RPM ) on the horizontal and the brake bower in ( KW ) on the vertical line. The maximum brake power of the engine is when the engine speed is approximately 2000 RPM.

### 3.3.2 Brake Specific Fuel Consumption

A set of tests were made at different engine speeds and loads to measure the brake specific fuel consumption rates. and the results are illustrated in Figure (3.3).

The engine was operated at variable speeds and loads for one minute and then measured the mass of the tube after operation for each case as shown in the table(3.3):

Example:

Biogas fuel Consumption in (g/h) = (g /min) * 60

=30 (g /min) * 60

=<u>1800g/h</u>

Biogas break specific fuel consumption (g / kw.h) =

= m (g /h) / Break Power (kw)

= 1800/ 3.14 =<u>573.24 g / kw.h</u>

| Engine speed | Torque | Break power | Biogas Fuel Consumption g/h | Break Specific Fuel Consumption of Biogas ( g / kw.h ) |
|---|---|---|---|---|
| 1500 | 20 | 3.14 | 1800 | 573.24 |
| 1500 | 40 | 6.28 | 2100 | 334.4 |
| 2000 | 20 | 4.18 | 1533 | 358.85 |
| 2000 | 40 | 8.37 | 1833 | 215.05 |
| 2500 | 20 | 5.2 | 2100 | 403.84 |
| 2500 | 40 | 1304 | 2733 | 259.61 |

**Table (3.3):** Biogas break specific fuel consumption

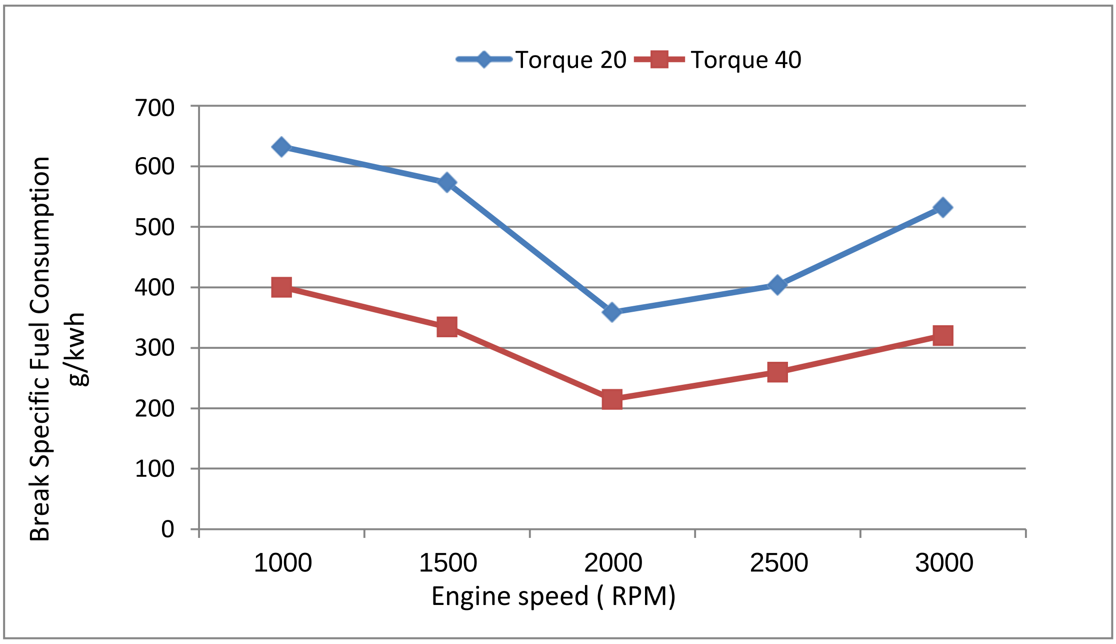


**Figure (3.3):** Biogas Break Specific Fuel Consumption

Figure (3.3) show the relation between the engine speed in RPM on the horizontal and the brake specific fuel consumption for the Biogas in g/kWh on the vertical. This relation show the two results for two different torques. The blue curve is when the torque is 20 N.m and the red one is when the torque is 40 N.m.

### 3.3.3 Emission Measurement

The analysis of CO, HC, NOx , and CO2 emissions during emission test on the Gas Analyzer for biogas , The objective was to focused on analyzing the effect of biogas upon exhaust emissions aspects of ecological and environmental benefits when alternative fuel is used. The results were as in the table (3.4).

| Engine speed RPM | Torque N.M | Power KW | CO % | HC PPM | NOx PPM | CO2 % |
|---|---|---|---|---|---|---|
| 1500 | 20 | 3.1 | 1.6 | 138 | 1130 | 33.2 |
| 1500 | 40 | 6.28 | 1.05 | 98 | 2160 | 39.6 |
| 2000 | 20 | 4.18 | 1.55 | 133 | 2340 | 38.4 |
| 2000 | 40 | 8.37 | 0.95 | 93 | 2320 | 39.3 |

**Table (3.4):** Emissions of Biogas

## 3.4 Comparison of the results of biogas, LPG and gasoline

### 3.4.1 Brake power & Brake Specific Fuel Consumption

Figure (3.4) , (3.5) show the result of comparison Brake power & Break Specific Fuel Consumption between Biogas, LPG and gasoline.

We used the torque =20 N in Brake Specific Fuel Consumption curve.

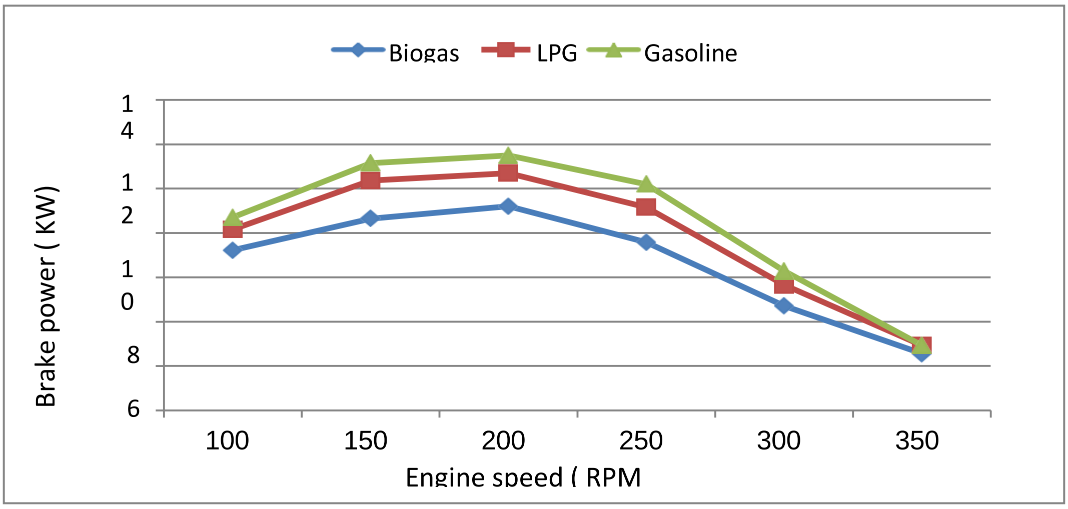


**Figure (3.4):** Comparison of the results of brake power between biogas, LPG and gasoline

The upper figure show the relation between the engine speed in ( RPM ) on the horizontal line and the brake power in ( N.m ) in the vertical line. This experiment show the results for three different kind of gases. The blue curve for biogas, the red curve for the LPG and the green curve for gasoline. The maximum brake power is when the engine works by using gasoline as a fuel and when the engine speed is 2000RPM.

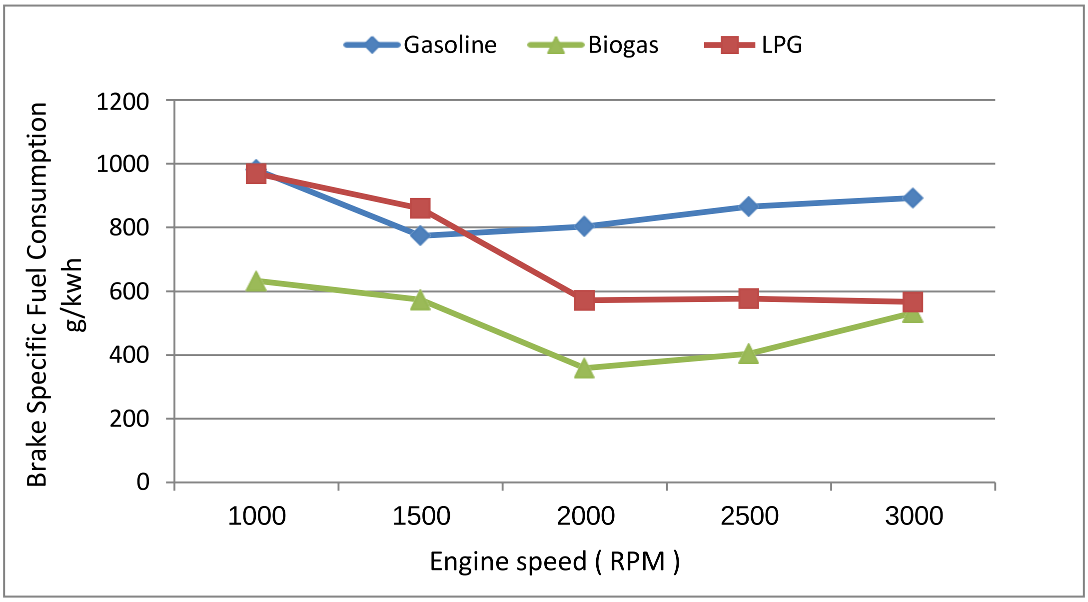


**Figure (3.5):** Comparison of the results of Brake Specific Fuel Consumption between biogas, LPG and gasoline.

The upper figure show the relation between the engine speed in (RPM) on the horizontal line and the brake specific fuel consumption in ( g/kWh) in the vertical line. This experiment show the results for three different kind of gases. The blue curve for gasoline, the red curve for the LPG and the green curve for biogas. The minimum brake specific fuel consumption is when the engine works by using biogas as a fuel and when the engine speed is 2000 RPM.

### 3.4.2 Fuel cost

To measure the fuel cost rates, a set of tests were made at different engine speeds and loads. The recorded data is given in table (3.5) along with the calculated fuel cost rates and calculated developed engine power.

**Calculation and results:**

1 litter of Gasoline price = 5.88 NIS = 1.61 $…….26/4/2017

1 litter of liquid LPG price = 2.62 NIS = 0.72 $

…….26/4/2017 1 litter of Biogas price 1.5 NIS

= 0.413 $ ………26/4/2017

1$ = 3.63 NIS

1. **Gasoline Fuel:**

**Example:**

1 litter = 1000ml =

5.66 NIS = 1.43 $

45.8ml/min = ?

5.66*41.2/1000= 0.26 NIS/min = 0.066 $/min at Engine Speed 1000 RPM and 20 Nm Torque.

2. **LPG fuel:**

Density at 15 $C^{\circ}$, kg/liter = 0.560

**Example:**

1 liter = 0.56 kg

1 liter of LPG liquid = 2.62 NIS

0.56 kg = 2.5 NIS 0.56

* 1000 = 560 g 560 g

= 2.62 NIS

1 g = ?

1 g LPG = 2.62*1/560 = 0.0047 NIS

40.5* 0.0047 NIS = 0.19 NIS/min = 0.052 $/min at Engine Speed 1000 RPM and 20 Nm Torque.

### 3. Biogas fuel:

Density at 15 C°, kg/liter =1.02

**Example:**

1 liter = 1.02 kg

1 liter of Biogas liquid = 1.5 NIS

1.02 kg = 1.5 NIS 1.02

* 1000 = 1020g 1020 g

= 1.5 NIS

1 g = ?

1 g biogas = 1.5*1/1020 = <u>0.0015 NIS</u>

30* 0.0015NIS = 0.045 NIS/min = 0.012 $/min at Engine Speed 1500 RPM and 20 Nm Torque.

| Engine speed (RPM) | Torque (Nm) | Brake Power (kW) | Gasoline Cost $/min | LPG Cost $/min | Biogas Cost $/min |
|---|---|---|---|---|---|
| 1500 | 20 | 3.1 | 0.076 | 0.058 | 0.012 |
| 1500 | 40 | 6.3 | 0.098 | 0.064 | 0.014 |
| 2000 | 20 | 4.2 | 0.106 | 0.05 | 0.01 |
| 2000 | 40 | 8.4 | 0.137 | 0.058 | 0.012 |
| 2500 | 20 | 5.2 | 0.142 | 0.064 | 0.014 |
| 2500 | 40 | 10.5 | 0.188 | 0.09 | 0.019 |

**Table(3.5):** Fuel Cost for Gasoline, LPG & Biogas at Different Engine Loads and Speeds.

The next two figures show the relation between the engine speed in ( RPM ) on the horizontal line and the cost in ( $/min. ) on the vertical line. This experiment show the results for three different kind of gases at three different engine speeds. The blue curve for gasoline, the red curve for the LPG and the green curve for biogas. The minimum cost per minute is when the engine works by using biogas as a fuel at 2000 RPM as engine speed. Figure (3.6) show the results at engine torque of 20 N.m and figure (3.7) show the result at engine torque of 40 N.m.

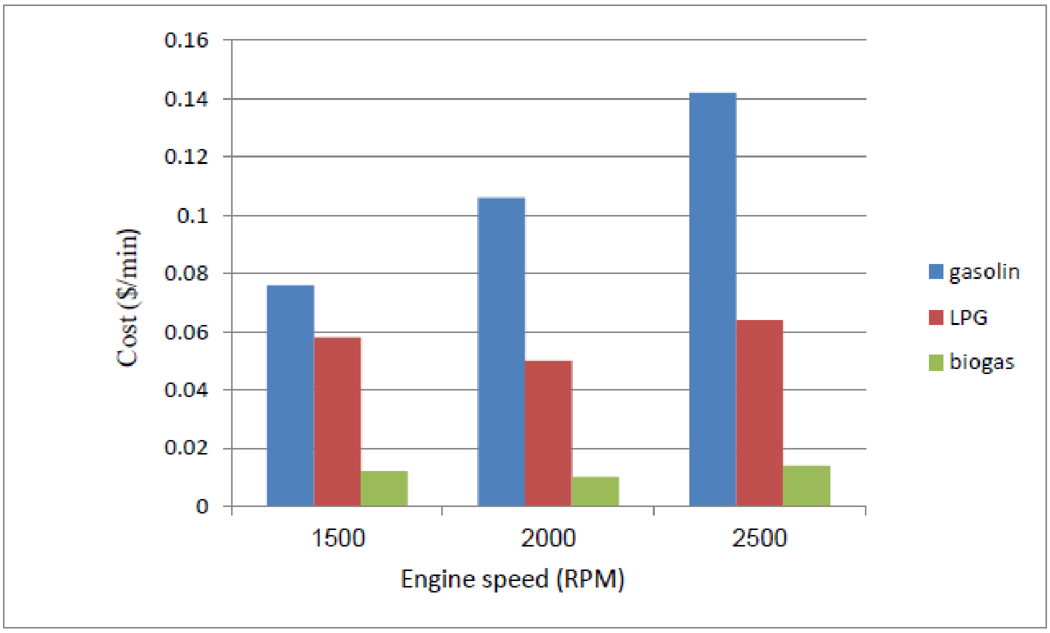


**Figure (3.6):** The Comparison on Fuel Costs in ($/min) at torque of 20 ( N.m )

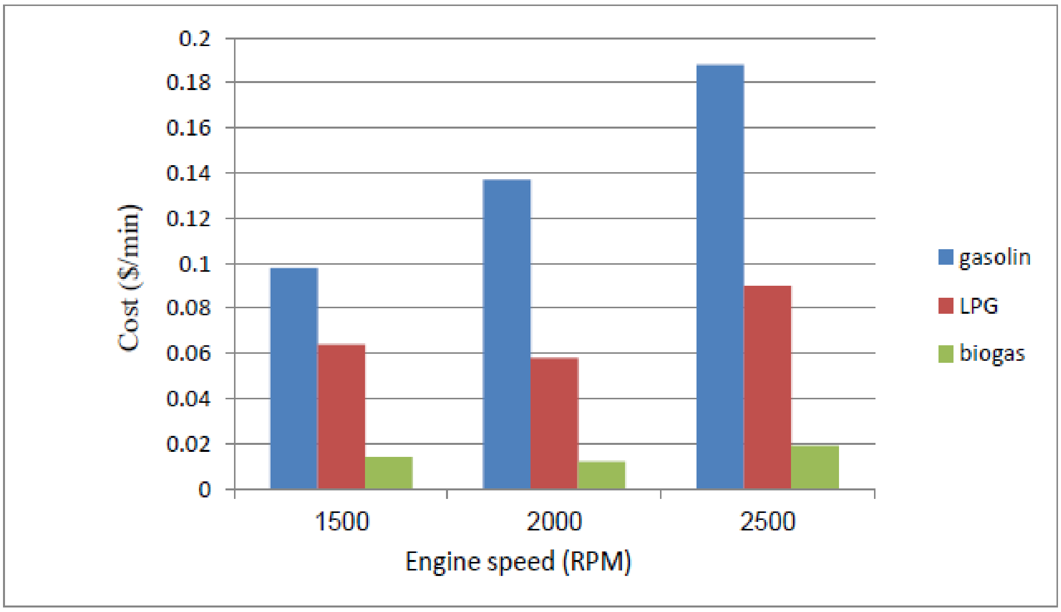


**Figure (3.7):** The Comparison on Fuel Costs in ($/min) at torque of 40 ( N.m )

# Chapter 4

**Test Results and Compare**

# Chapter 4

# Test Results and Compare

## 4.1 Introduction

This chapter will discuss the emission of biogas, and test results, compare the results of our project and other project, problems to use biogas in I.C. engines, conclusion and recommendation.

## 4.2 What are biogas Emissions?

The major harmful emissions from biogas engines are similar to those from other internal combustion engines:

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

**Carbon monoxide** is generated in the exhaust as the result of incomplete combustion of fuel. CO is a very toxic, colorless and odorless gas. LPG emissions may contain considerable amounts of CO. When engines operate in enclosed spaces, such as warehouses, buildings under construction, or tunnels, carbon monoxide can accumulate quickly and reach concentrations, which are dangerous for humans. It causes headaches, dizziness, lethargy, and death. CO is usually the major concern whenever biogas engines are used indoors and out doors.

**Hydrocarbons** are also a product of incomplete combustion of fuel. biogas emissions, because of the composition of fuel, contain only short chain hydrocarbons. They are not likely to contain toxic components, which are found in gasoline HC emissions. Also the environmental impact of biogas hydrocarbon emissions (ozone reactivity contributing to smog) is much smaller than that of gasoline and LPG. However, hydrocarbon derivatives are responsible for the characteristic smell that is often a nuisance when biogas engines operate indoors and out doors .

**Nitrogen oxides** are generated from nitrogen and oxygen under the high temperature and pressure conditions in the engine cylinder. NOx consist mostly of nitric oxide (NO) and some nitrogen dioxide ($NO_2$). Nitrogen dioxide is a reactive gas, very toxic for humans. Accumulation of NOx in a warehouse atmosphere may be also detrimental for the stored goods. For example, only a few ppm of NOx in the ambient air can change the color of paper stock from white to yellowish. NOx emissions are also a serious environmental concern because of their ozone reactivity and important role in smog formation.

**Carbon Dioxide ($CO_2$)** is the principal greenhouse gas emitted as a result of human activity (e.g., burning of coal, oil, and natural gas). $CO_2$ can cause burns, frostbite, and blindness if an area is exposed to it in solid or liquid form. If inhaled, it can be toxic in high concentrations, causing an increase in the breathing rate, unconsciousness, and death.

## 4.3 Test Results

### 1.Emission

Table (2.5) and (3.4) show the emission test results for Mazda 323 MPI engine fueled with either gasoline or LPG or biogas. HC emission of biogas engine at all power range is smaller than gasoline and LPG engine , and this is due to the design of biogas system used in this experiment. but CO emission in biogas is higher than gasoline on low power and smaller than it is on high power and in biogas less than LPG in almost all cases .

$NO_x$ depend on the combustion process. In fact, the interaction between nitrogen and oxygen occurs at high temperatures and high pressure. Experimental results proved that the power produced by biogas and LPG fuel is less than gasoline fuel. This means that maximum pressure and temperature produced in the combustion chamber of biogas and LPG is less than gasoline, so $NO_x$ emission is lower. But in biogas at lower speeds and lower torque, $NO_x$ are higher than LPG but at higher torque at the same speed $NO_x$ are lower.

$CO_2$ in biogas is much higher than LPG and gasoline at all speeds and all the torque due to the components of biogas to contain a large amount of $CO_2$.

**2.Torque**

The torque increases as the speed of the engine decreases as shown in the table (2.3) and (3.2) The torque ranges between 7 and 69 for biogas and between 8 and 83 for gasoline and between 8 and 79 for LPG, gasification due to the fact that gasoline was generates Higher energy than biogas and natural gas when burned and recorded the highest values of torque when 83 for gasoline and 79 for LPG and 69 for Biogas, at speed 1000 rpm.

The results of the torque test with biogas, gasoline or LPG show that the biogas fuel is less than % 20 of gasoline and about 8% of LPG fuel in different engine loads and speeds. It is also known that the density of biogas is less than the density of gasoline and LPG, so the mass of biogas injection into the combustion chamber is lower than gasoline and LPG.

**3. Brake power**

The Engine performance with respect to brake power when run on gasoline and LPG and biogas is shown in table (2.3) and (3.2). gasoline produced slightly greater brake power when compared with LPG fuel and biogas fuel. This can be attributed to the fact that gasoline has a slightly higher heating value [Per cubic meter] than LPG and biogas and therefore produced more energy after combustion at a given speed. From Fig (3.4), brake power increases with an increase in engine speed. The highest brake power of 11.5 kw, 10.70 kw and 9.2 Kw was recorded at speed of 2000 rpm for the gasoline, LPG and biogas respectively.

**4.Brake specific Fuel consumption**

The engine performance with respect to Specific Fuel Consumption is shown in Fig.(2.6) and (3.3). The Specific Fuel Consumption decreased as the engine speed increased. the specific fuel consumption for biogas was less than that of gasoline and LPG. The appreciably higher specific fuel consumption of gasoline could also be explained in terms of higher specific gravity, and higher viscosity of petrol which led to higher fuel consumption per unit of power produced. Also, higher fuel viscosity reduces the quality of fuel atomization and could result in higher gas emission and fuel consumption.

The comparison between the bsfc of biogas and LPG and gasoline for Mazda 323 MPI engine fueled with either biogas or gasoline or LPG show that the bsfc of biogas fuel is less about 50% as an average than that of bsfc gasoline fuel and about 30% as an average than that of bsfc LPG Fuel, at different engine loads or speeds.

**5.Fuel cost**

The comparison between the cost of biogas and LPG and gasoline fuel for Mazda 323 MPI engine fueled with either biogas or gasoline or LPG show that the fuel cost of gasoline is the highest, around 90 % higher than that of biogas and the LPG is the higher than biogas around 80% , at different engine loads and speeds. Because raw materials are free and cost only in the cost of production.

## 4.4 Compare with other project

In this section, a comparison will be made between the practical experiments conducted in our previous study with different projects to perform the internal combustion engine of braking power, fuel consumption and emissions.

This project compare between three types of fuel (gasoline, raw biogas and upgrade biogas), and the content of biogas:[13]

| **Upgrade biogas (%)** | **Raw biogas (%)** | **Biogas contents** |
|---|---|---|
| 71.8 | 50 | $CH_4$ |
| 19.8 | 43 | $CO_2$ |
| 1.04 | 3.94 | $H_2S$ |
| 7.76 | 2.40 | Moisture |

The focus will be on the upgrade biogas because the amount of methane and carbon dioxide is close to biogas which we used.

**Information of engine**

The performance study was performed on Hero Honda Splendor motor cycle engine with following Specification:[13]

Power: 5 kW

Total volume: 100 cc

No. of cylinder: 1

Type: S.I engine

Stroke: 4 Stroke

Type of cooling: Air cooled

Compression ratio: 9.2:1

Control: Throttle valve controlled

**Brake power carve** :

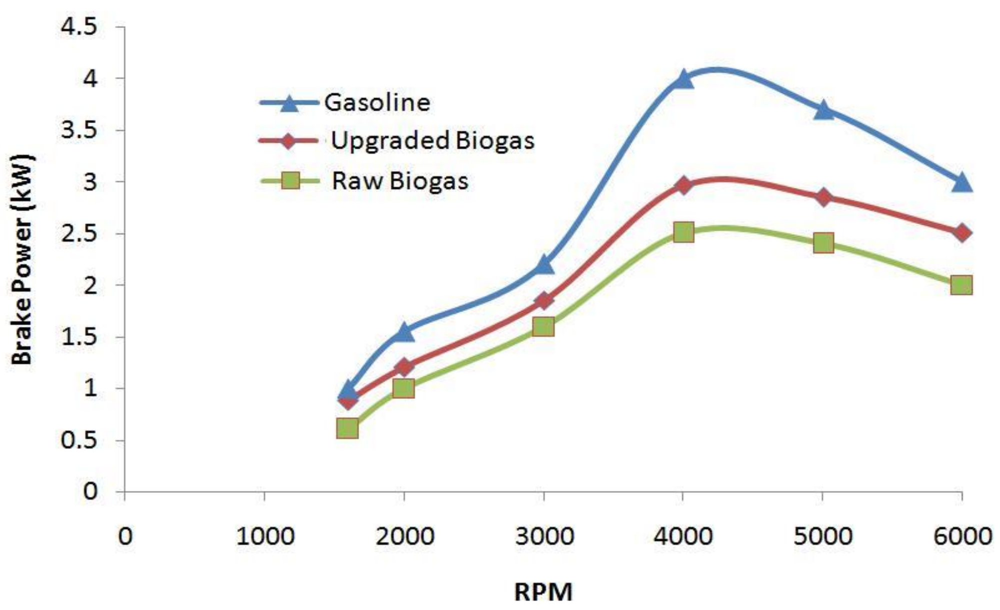


**Figure 4.1**: Engine Brake Power v/s RPM for Honda engine.

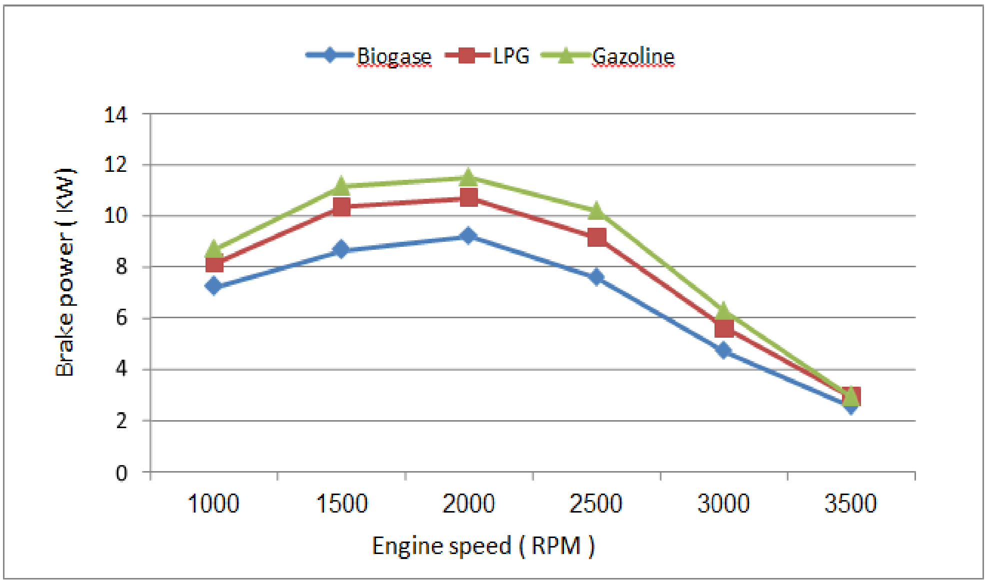


**Figure 4.2**: Engine Brake Power v/s RPM for Mazda engine.

The upper figure shows the relationship between the speed of the Engine in (rpm) on Horizontal line and brake power in (N.m) in vertical line. This experiment Results show three different types of fuel (Gasoline, Raw biogas and upgrade biogas) as shown in fig (4.1). Because of the difference in the design of the two engines worked to give another result to the torque of the engine, thus the curve of the braking power varied, the maximum braking power was at 4000 rpm in honda engine. The figure shows that the braking power curve of the upgrade biogas is less than gasoline about 12% in fig (4.1), and 20% in fig (4.2), This result is synonymous with what we concluded in our previous study in two cases.

**Brake Specific fuel consumption:**

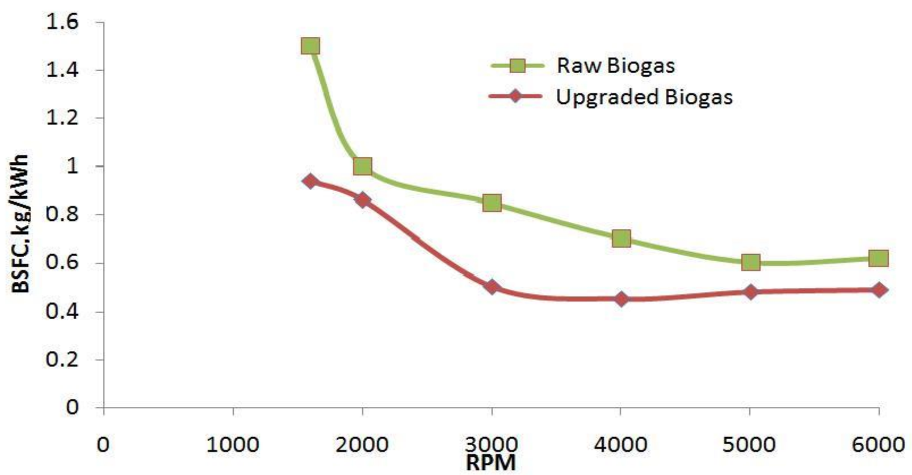


**Figure 4.3**: Brake specific fuel consumption v/s RPM for Honda engine.

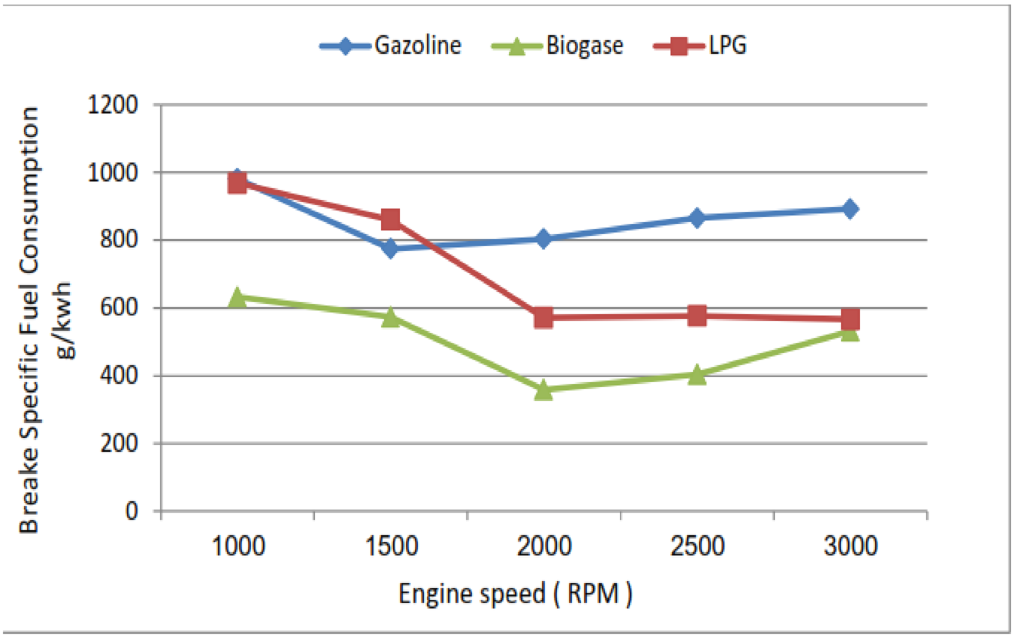

**Figure 4.4**: Brake specific fuel consumption v/s RPM for Mazda engine.

The upper figures shows the relationship between the speed of the Engine in (rpm) on Horizontal line and brake specific fuel consumption in (kg/kwh) in vertical line. The figure (4.3) show experiment Results between raw biogas and upgrade biogas. In terms of curves, the two curves are similar in terms of the starting point which decreases with the increase in engine speed to reach the best point of brake Specific fuel consumption at 4000 rpm, and begins to increase brake specific fuel consumption with the increase in the engine speed.

The best brake specific fuel consumption is around 4,000 rpm, which is about 420 g/Kw.h as shown in fig (4.3), and find the best brake specific fuel consumption at 2000 rpm which is about 358g/Kw.h in ours experiment as shown in fig (4.4). There is a difference between the two results about 70 g / Kw.h due to the difference in the engine and the proportion of methane and carbon dioxide in biogas.

**Emission:**

In the comparable project, the emissions ($CO_2$, $NO_x$, $CO_2$ and HC) were similar to those tested in the previous chapter. increased HC with the speed engine increased to maximum brake power and begin decrease after this point, as well as in NOx. In the case of carbon dioxide, the quantity decrease with the decrease in the engine speed but just the opposite in the case of carbon monoxide, its quantity decreases with the increase in engine speed.

## 4.5 Engine optimization for biogas:

Due to of the different characteristics of biogas from the characteristics of other fuels must make several changes to the internal combustion engine to give the best results in terms of performance, and these changes: [15]

- Using cutting rings insert at the top of cylinder walls prevent deposit forming.
- Use of more corrosion resistance materials for bearings. more dense surface structure will help a lot in a corrosive environment. this also improve the load acceptance of engine bearing therefore higher engine load could be reached.
- For some engine valve recession might be a problem due to abrasive silica particles. reducing the valve temperature by using cooled valve or reducing the valve speed during the seat and valve and valve contact (by changing cam profile) will decrease valve recession.
- Phenol resins could prevent copper heat exchangers corrosion and provide good heat conduction at the same time. If that was insufficient in a very corrosive environment copper could be replace with stainless steel.
- Forged steel pistons are preferred rather than aluminum and then liner should be designed from scratch.

## 4.6 conclusion

In this project the performance of an internal combustion engine using biogas (braking power, fuel consumption and emissions) has been studied and compared with other results for the same engine using gasoline and LPG.

Where was found that the braking power was less in biogas than in gasoline and LPG, as for the brake specific fuel consumption was better in biogas than gasoline and LPG. The emissions in biogas were higher in terms of $CO_2$, less gasoline in the $NO_x$ but higher than LPG, and the HC in biogas was higher than gasoline but less than LPG as well as CO. The cost of biogas is very less compared to gasoline and LPG.

## 4.7 Recommendation

There are many problems to use biogas in I.C. Engine including :

-High $CO_2$ content reduces the power output, making it uneconomical as a transport fuel. It is possible to remove the $CO_2$ by washing the gas with water. The solution produced from washing out the $CO_2$ is acidic and needs careful disposal.

-$H_2S$ is acidic and if not removed can cause corrosion of engine parts within a matter of hours. It is easy to remove $H_2S$, by passing the gas through iron oxide ($Fe_20_3$ -rusty nails are a good source) or zinc oxide (ZnO). These materials can be re-generated on exposure to the air, although the smell of $H_2S$ is unpleasant.

-There is high residual moisture which can cause starting problems.

-The gas can vary in quality and pressure .

-For higher amounts of methane, we recommend installing a biogas filter. This filter purification biogas from harmful gases and extracts high amounts of methane because it contains high energy. Another reason to use this filter is that harmful gases weaken the engine and the filter reduces the amounts of these gases and the amounts of emission.

-From the experiments we can conclude that biogas can be used as a vehicle fuel after purification and can improve results with the best gas purification technology that needs.

# References

[1] : Sebastian Stolpp, European Biogas Association, www.european-biogas.eu

[2] : Landahl, G. (n.d.). Biogas as Vehicle Fuel A European Overview (pp. 1-51, Rep. No. 2003).

[3] : Assadi, M., Mizamohamammad, N., &Razbani, O. (2011). Literature review and road map for using biogas in internal combustion engines (Tech.). Italy : University of stavanger.

[4] : http://www.palestineeconomy.ps/files/server/20142511170905-2.pdf

[5] : Mansour, M. R. (20114). Evaluation of qualitative and quantitave efficiency of small scale biogas units in palestine rural areas (pp. 1-112, Tech.). Nablus.

[6] : http://www.pcbs.gov.ps/Portals/_Rainbow/Documents/EMM-2011-%20A11.htm

[7] : D. Deublein and A. Steinhauser, Biogas from waste and renewable resources: an introduction: John Wiley & Sons, 2011.

[8] : T. O. Kukoyi, E. Muzenda, E. T. Akinlabi, A. Mashamba, C. Mbohwa, T. Mahlats Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa

Environment, and Infrastructure Service Department of the City of Johannesburg, South Africa

[9]: Crookes RJ, H. J. (1998). Spark-ignition engine performance with simulated biogas - a comparison with gasoline and natural gas (pp. 197-203, No. 489). China.

[10] : Babatunde, S., A., O., & A. (2015). Development And Testing Of Biogas-Petrol Blend As An Alternative Fuel For Spark Ignition Engine (pp. 179-186, Working paper).

[11] : Ayade, M., &Latey, D. A. (2006). PERFORMANCE AND EMISSION CHARACTERISTICS OF BIOGAS –PETROL DUAL FUEL IN SI ENGINE (pp. 45-54, Rep.).

[12] : Coimbra-Araújo , C. H., Mariane, L., &Júnior, C. B. (2014). Brazilian case study for biogas energy: Production of electric power,heat and automotive energy in condominiums of agroenergy (pp. 826-839, Rep.).

[13] : Prakash, J., Ranjan, C., & Dhiman, S. K. (2016). ASI Carbon – Science and Technology (pp. 74-85, Rep.).

[14] : RAY, N. H., MOHANTY, M. K., & MOHANTY, R. C. (2013). Biogas alternative fuel in diesel engines :a literature review (pp. 23-28, Rep.). IOSR -JMCE.

[15] : Razbani, O., Mirzamohammad, N., & Assadi, M. (2011). Literature review and road map for using biogas in internal combustion (Rep. No. 4036).