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# IMPROVEMENT THE PERFORMANCE AND EFFICIENCY OF TURBOCHARGING SPARK IGNITION ENGINE BY USING BLENDED BIOETHANOL FUEL

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**Abstract**

Nowadays, the rapid developments in the automobile industry generate a high challenges on the manufacturing companies to find suitable solutions to decrease the amount of fuel consumption and the percentage of pollutants emissions. Bioethanol has greater oxygen content and smaller carbon content comparing with gasoline. Ethanol-gasoline is used as blend fuel for indicating the performance of 1.5 L turbocharged spark ignition engines. The measurements are recorded for several engine equivalence ratios, namely (0.9), (1) and (1.2), respectively. Moreover, it's very important to make comparative analyses between the gasoline proprieties and bioethanol to find the implications on the operation of (SI) engine. It's also a remarkable idea to develop a mathematical model and simulate this thermo-gas-dynamic process inside engine cylinder to enhance the findings through comparison between theoretical and empirical results. The main objective of this research is to improve the thermal efficiency of the supercharged ignition engine and decrease the emission level by using bioethanol fuel. The experimental part includes filling the turbocharged (SI) engine by bioethanol in blend with gasoline. In this research work, an actual state and complex analysis in bioethanol by using a supercharged spark ignition engine was carried out. Also, the commercial software (Unichip Dastek) was used for the analysis and simulation of the electronic control system. The results showed that there's a good improvement in the engine efficiency due to the nature of bioethanol combustion proprieties, and this is considered an important advantage step which leads to improve the total efficiency. Also, the emissions level of (HC) and (CO) decreased with the improvement in the combustion process. Furthermore, the level of ($NO_X$) emissions decreased (50%) at the same engine power at [E20]. It's concluded that the combustion variability will improve by using (E20) fuel, due to the higher limit of in flammability of bioethanol comparing with gasoline, especially at the specific air excess coefficient. Accordingly, bioethanol can be considered as a good alternative fuel.

Keywords: Bioethanol, Cycle heat release, Dosage, Maximum pressure, Turbocharging.

## 1. Introduction

In modern life, it became more urgent to reduce the atmospheric pollution produced by the automotive internal combustion engines and control the devices, which are incorporated on vehicles for to their operating control. In the actual content of the legislation, reduction of the automotive engines pollutant emissions through the use of alternative fuels is a very good solution and becomes a priority. The tightening of the pollution rules and the need of preserving fossil fuels are imposed adopting some efficient solutions for spark ignition engines fuelling with alternative fuels. According to these facts, bioethanol can be considered as a suitable alternative fuel for automotive internal combustion engines through using as single fuel or in blends with gasoline [1].

To reduce the harmful effect on the human health and to protect the harmful environment, researchers are trying hardly to find an alternative fuel for the classical fuel type, other than gasoline. These fuels must have similar technical specifications for the internal combustion engines, and the exhaust gases resulted from its combustion must be less harmful. Using light alcohols in the spark-ignition engines can improve their thermal efficiency and offers the possibility to reduce of the pollutants emissions and the carbon dioxide emission, which is considered as greenhouse gas. The measured level of the carbon dioxide emission was above 400 ppm at April (2014), which is the first time this value has been recorded in history [2].

Nowadays, in many development countries, the problems of the environment pollution are considered apriority among others problems, which need to solve urgently. The exhausts from the automotive engines have a main role in the environment pollution, especially in very crowded places. Besides, the other problems are due to the decrease in carbon amount, which leads to use the amount of energy (82%) instead of (85%) [3]. Due to the pollutant emissions problems, such as (NOx) and (CO2) which consider an urgent demand, it is advised to use bioethanol in the supercharged engines as an alternative fuel [4]. Due to a lot of advantages, bioethanol is considered as a suitable alternative fuel [5]. These advantages are included the possibility of storage and distribution with no much danger comparing with the others fuels. Also, bioethanol fuel can be manufactured from the natural plants. Bioethanol is an alcohol made by microbial fermentation, mostly from carbohydrates produced in sugar- or starch-bearing plants, such as corn, sugarcane, sweet sorghum or lignocellulose biomass [6]. And, the properties of bioethanol are completely compatible with the required operated conditions of SI engine. Moreover; bioethanol reduce the fossil fuels consumption by its use.

The rise in the energy need, the stringent emission norms and the oil resources depletion have led the investigators to find alternative fuels for the internal combustion engines [7]. The use of the waste polyethylene oil as an alternative fuel for the diesel engines was evaluated [8]. The resulted oil was tested in a single cylinder air cooled (TS1) direct injection diesel engine at 1500 rpm. The engine performances and the exhaust pollutant emissions from the waste polyethylene oil were analysed and compared with those resulted from the similar engine fuelled with the traditional diesel fuel. The results depicted that the total fuel consumption of this oil is lower than that of neat diesel fuel due to the higher heating value of waste polyethylene oil.

As apart to reduce the engine pollutants emissions, the addition of ethanol to gasoline will change the distillation temperature and increase the octane number [9].

Ethanol fuel should be used directly without any additions after produced from renewable resources, and without any modification in the method of operation for the internal combustion engine. For the spark ignition (SI) engines, bioethanol fuel is the most suitable among many alcohols fuels, and it has been used since the 19th century [10]. Normally, ethanol is produced from the natural resources, like sugar and corn, and this fuel is considered so friendly for the environment and will decrease the dependency on the petroleum fuel [11].

With using bioethanol fuel, the internal combustion engine will run without knocking. Engine will run in the gasoline maximum power at the air excess coefficient ($\lambda = 0.10$) for (E85), ($\lambda = 0.95$) for (E20). The specific energetic consumption will be at lower ratio (9 - 14%) [12]. In the research centres worldwide, many researches are involving with the reduction of pollutant emissions and in the same time improving the combustion process. Form this point of view, bioethanol is considered as a viable alternative fuel [13]. If one is looking toward improving the performance, the efficiency of turbocharged spark ignition engine, power and torque, then the bioethanol fuel will be the better choice, because the proprieties and the high vaporization heat of this fuel is better comparing with gasoline. The performance, exhaust emission and combustion analyses of a single cylinder spark ignition engine fuelled with extended range of ethanol-petrol blends were carried out successfully at full load conditions.

Ethanol produced from raffia trunks was blended with petrol at different proportions by volume. In order to establish a baseline for comparison, the engine was first run on neat petrol. The engine performance parameters (engine torque, brake power, brake specific fuel consumption, brake mean effective pressure and brake thermal efficiency), exhaust emission parameters (CO, HC, $CO_2$ and $O_2$ emissions) and combustion parameters were determined for each blend of fuel at different engine speeds. The test results interestingly revealed that the addition of ethanol to petrol causes an improvement in combustion characteristics and significant reduction in exhaust emissions which in turn improved engine performance. In all, ethanol and its blends with petrol exhibited the performance characteristics trends similar to that of petrol, thus confirming them as suitable alternative fuels for the spark ignition engines [14].

The combustion characteristics and the optimal spark timings of the blended fuels with various blending ratios were investigated to improve the performance of the flexible fuel vehicle engine. The vehicle utilizing blended fuel is called flexible fuel vehicle. As a tool for the prediction of the optimal spark timing for the 1.6L flexible fuel vehicle engine, the empirical equation was proposed. The validity of the equation was studied via a comparison with the predicted optimal spark timings with the stock spark timings throughout the tests of engine. If the stock spark timings of E0 and E100 were optimal, the empirical equation predicted the real optimal spark timings for the blended fuels with a good accuracy. In the whole circumstances, via optimizing the spark timing control, the performance was improved; especially the torque improvements of E30 and E50 fuels were 5.4% and 1.8%, respectively, without affecting the stability of combustion. From these results, it was concluded that the optimal spark timing which reflects the specific octane numbers of gasoline-ethanol blended fuels should be applied to maximize the performance of the flexible fuel vehicle engine [15].

This study examines the influences of the ethanol and the gasoline injection mode on the combustion performance and exhaust emissions of a twin cylinder port fuel injection (PFI) spark ignition (SI) engine. Generally, when using gasoline-ethanol blends, alcohol and gasoline are externally blended with a specified blending ratio. In such activity, ethanol and gasoline were supplied into the intake manifold into two various ways: throughout two separated low pressure fuel injection systems (Dual-Fuel, DF) and in a blend (mix). The ratio between ethanol and gasoline was fixed at 0.85 by volume (E85). The initial reference conditions were set running the engine with full gasoline at the knock limited spark advance boundary, according to the standard engine calibration. Then, E85 was injected, and a spark timing sweep was carried out at rich, stoichiometric, and lean conditions. Engine performance and gaseous and particle exhaust emissions were measured. Adding ethanol could remove the over-fuelling with an increase in the thermal efficiency without the engine load penalties. Both ethanol and charge leaning resulted in a lowering of CO, HC, and PN emissions. DF injection promoted a faster evaporation of gasoline than in blend, shortening the combustion duration with a slight increase in the THC and PN emissions compared to the mix mode [16]. Both ethanol and methanol are good additives to gasoline in vehicles due to the improvements they provide to the combustion characteristics and the engine performance [17].

The influence of Ethanol (ranging from E10 to E30) and Methanol (ranging from M10 to M30) as additives to gasoline were studied to improve the combustion characteristics and the engine performance, a one-cylinder, four stroke, 11 kW output power IC engine. In this work, the performance tests were conducted for brake torque, power, thermal efficiency, and consumption of specific fuels. The flue gases, comprising CO, HC, and $CO_2$ were measured and analysed under various working circumstances with different engine speeds over a range (1500-3000 rpm). Results manifested that the IC engine thermal performance was enhanced in the (E10) combustion state (10% ethanol and 90% gasoline). As well, it was depicted that the concentrations of (HC) and (CO) were considerably decreased with increases in the ethanol concentration in the mixture of fuel. The methanol-gasoline fuels combustion characteristics weren’t as good as those for the ethanol-gasoline fuels. The aim of conducting this research is to enhance the thermal efficiency of the supercharged ignition engine and reduce the emission level by utilizing the bioethanol fuel.

## 2. Theoretical and Empirical Investigations

### 2.1. Thermodynamic model analysis

In this analysis, a thermodynamic model of two zones was used to apply as in one region thermodynamic model. This modeling is adopted through using the commercial software (AVL) List GMBH, Graz. In (AVL) software, the engine components are substituted by elements, and these elements are connected by lines. The software structure is arranged, where (E1) represents the elements that involve all the engine parameters, like engine friction, ignition order and engine speed. Also, (C1, C2, C3, and C4) represent the elements, which involve all the cylinder parameters, like connecting rod length, stroke, bore dimensions, heat transfer parameters and pollutant emissions. Parameters of exhaust and intake manifolds are included in (PL1) and (PL2), respectively, while the turbocharger parameters are included in (TC1). The parameters of intercooler and throttle are contained in (CO1) and (TH1), respectively, while the external boundary parameters are (SB1) and (SB2). In this model, Vibe combustion law is considered for two zones to divide the cylinder space into two zones. One of these zones is with the burn gas, and the other one is for the fresh charge mixture. For each region (two zones), the zone will be filled with (E20) and gasoline with different percentages of spark advances and air excess ratios. Figure 1 illustrates the parameters of the combustion law.

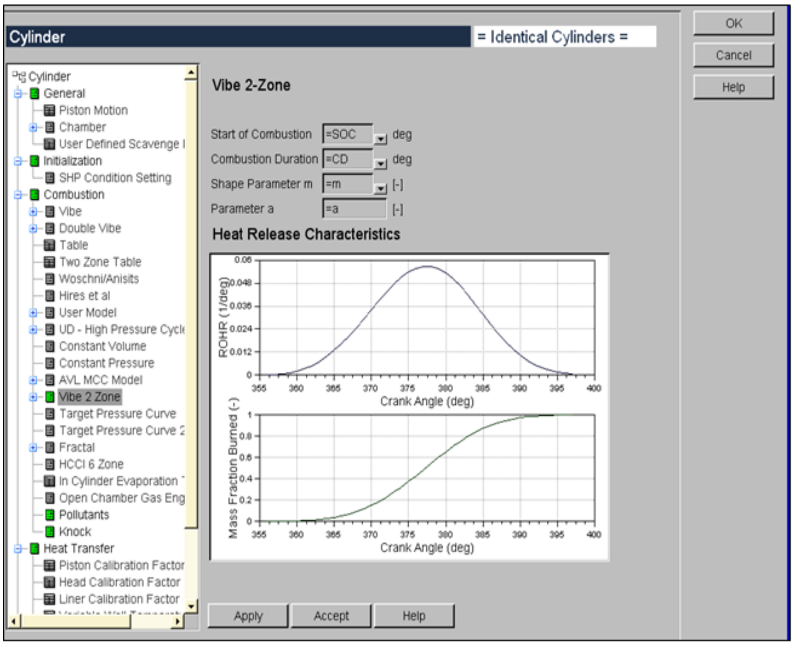


**Fig. 1. Parameters of the combustion law.**

## 2.2. Experimental procedure

The experimental work was conducted on a spark ignition engine (A15MF) type, manufactured by Daewoo Plant for Espero automotive. In the laboratory of the Internal Combustion Engine Thermo Techniques, the engine was turbocharged by using a gas turbine. The main characteristics of the engine are presented in the Table 1.

**Table 1. Daewoo technical engine characteristics [13].**

| | |
|---|---|
| **Number of cylinder and configurations** | 4 in line |
| **Bore** | 76.5 mm |
| **Stroke** | 81.5 mm |
| **Swept volume** | 1.498 $m^3$ |
| **Compression ratio** | 9.2 |
| **Maximum power** | 66 kW |
| **Maximum power speed** | 4800 rpm |
| **Maximum torque** | 137 N.m |
| **Maximum torque speed** | 3600-4800 rpm |
| **Number of valves per cylinder** | 4 |
| **Firing order** | 1-3-4-2 |
| **Fuelling system** | MPI |
| **Cooling** | Liquid |
| **Admission type** | Tturbocharge |

For this test, the engine was mounted in order to study the running at gasoline-bioethanol blend fuelling. This testing stem is equipped with many measurements and control equipment and devices, which are necessary for this type of experimental study. The main equipment and devices in this system are given in

Table 2. All these components are presented in the test bed schema, as shown in Fig. 2. Figure 3 depicts the photograph of the experimental setup.

**Table 2. Types of devices used for the measurements in this work.**

| Device | Measurement |
|---|---|
| **Eddy current electrical dynamo** | Engine torque |
| **Mass flowmeter** | Fuel and air consumption |
| **Thermal resistances measurement, Supercharging pressure** | Manometer |
| **System of data acquisition data acquisition unit, computer with acquisition board** | Recording in-cylinder pressure |
| **Gas analyser** | Pollutants emissions level |

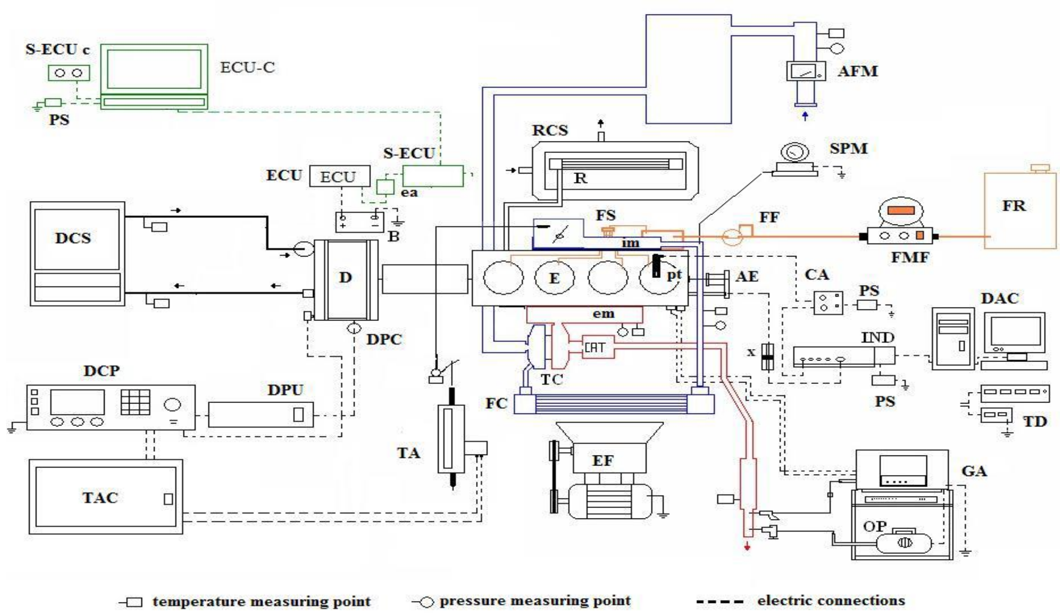


**Fig. 2. A15MF engine test bed schema.**

**Fig. 3. Photograph of the experimental setup.**

## 3. Working Procedure and Engine Operation

By using the equipment, which are presented previously, a set of parameters were registered in order to evaluate the influences of (E20) bioethanol-gasoline blend comparative to gasoline on the Esparto engine performance regarding energetically the efficiency and pollutant emissions. The direct measured parameters are engine torque, engine speed, engine effective power, air and fuel consumptions, engine load (defined in presents from the full load), pressure and temperature inside the test bed, exhaust gases temperature, inlet air temperature, oil temperature, cooling liquid temperature, pollutant emission level and air-fuel ratio value supercharging pressure. In-cylinder pressure diagrams ($p$ - $\alpha$), ($p$ - $V$) and (log $p$ - log $V$); the coordinates are heat release characteristics, maximum pressure and indicated mean effective pressure and were registered for (150) consecutive cycles by using Indimodul software and saved in data files.

In this experimental study, two types of fuel were used: classical gasoline, (E20), and (E50) (gasoline - bioethanol blend: (20%) bioethanol and (80%) gasoline, gasoline - bioethanol blend: (50%) bioethanol and (50%) gasoline, respectively. Table 3 shows the properties of the used E20 blend.

**Table 3. Gasoline and E20 blend properties.**

| Property | Gasoline | E20 |
|---|---|---|
| **Chemical composition: C/H/O[%]** | 85.4/14.2/0.4 | 78/14/8 |
| **Lower heating value [kJ/kg]** | 43500 | 40160 |
| **Stoichiometric ratio (A/F)** | 14.5 | 13.4 |
| **Density at 15 °C[kg/m$^3$]** | 760 | 766 |

The experimental part was accomplished by fully loading the engine at different speeds (2500) rpm and (3000) rpm, respectively. Firstly, the engine was fuelled by different air-fuel mixture dosages (E20). Relative air/fuel ratio ($\lambda$) was defined to avoid the maximum pressure limitation and knocking phenomena. The electric spark was modified, and all the operation parameters of the engine were established accordingly. For gasoline (E20), the engine used ($0.9 \geq \lambda \leq 1.2$). Correctness of air-fuel ratio values indicated by (AVL DiCom 4000) gas analyser for gasoline fuelling was verified by calculus using the air and fuel consumptions.

## 4. Results and Discussion

In this research work, an actual state and deep analysis in bioethanol by using supercharged spark ignition engines was carried out. One of the main findings is confirmed that; for the supercharged SI engines.

### 4.1. Pollutants emission measurement

Exhaust gases (CO), (HC) and ( NOx) are considered as pollutant emissions, and the level of these pollutants can be measured by an (AVL DiCom 4000) gas analyser. Measuring principle of Infrared spectroscopy is used in the gas analyser to measure the level of unburned hydrocarbons (HC), unburned hydrocarbons (HC), carbon monoxide (CO) and electrochemical principle for (Nox). Gas analyser was also used to measure the engine speed, ($CO_2$) gas emission and air-fuel ratio. Table 3 lists the main characteristics of gas analyser.

**Table 3. Characteristics of the AVL DiCom 4000 analyser.**

| Measured parameter | Measuring domain |
|---|---|
| **$\lambda$ [-]** | 0.5-2.0 |
| **CO [% vol]** | 0-10 |
| **$CO_2$ [% vol]** | 0-20 |
| **$O_2$ [% vol]** | 0-25 |
| **HC [ppm]** | 0-20000 |
| **NOx [ppm]** | 0-4000 |
| **Engine speed [rpm]** | 250-8000 |
| **Engine oil temperature [°C]** | 0-120 |

The air excess coefficient for (E20) fuelling was determined by calculus; with the relation that uses the air and fuel consumptions per hour and the value of air-fuel stoichiometric ratio for (E20) and gasoline blend. The reference for the investigated operating engine regimes was established by registering the parameters when the engine is running by using gasoline fuel only. In case of (E20) fuelling, at the dosage ($\lambda$=0.9), the spark ignition timing is greater compared to gasoline to keep the same engine power. At the dosages $\lambda$= (1) and $\lambda$= (1.2), due to better combustion proprieties of the bioethanol, the timing of spark ignition is smaller comparative to gasoline. This will help for obtaining the same output power for both bioethanol and gasoline.

It's found experimentally that the percentage of (NOx) emission with using gasoline fuel is higher than the (E20) emission. Figure 4 reveals the air excess ratio against the nitrogen oxides emission in both gasoline and (E20). At the same maximum power, the NOX emissions level decreases with 50% for E20 fuelled engine at dosage $\lambda$=1.0 compared with the gasoline fuelled engine for $\lambda$=0.9, the spark ignition timing having an important effect on the NOX emissions and engine efficiency increases due to the better combustion proprieties of the bioethanol. And, for the same dosage $\lambda$=1.0, the NOx emissions level is smaller for E20 fuelled engine versus the gasoline fuelled engine, the engine power being greater.

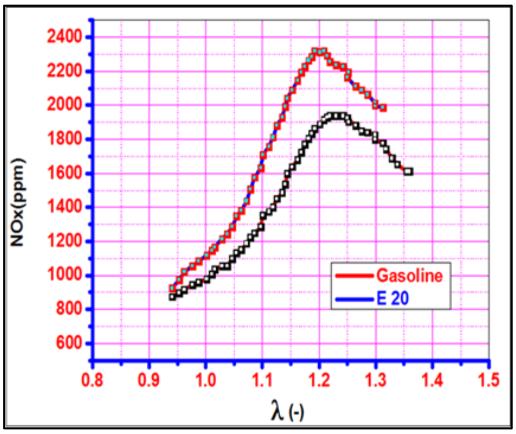


**Fig. 4. The Nitrogen Oxides emission level versus the air excess ratio.**

## 4.2. Knock and carbon monoxide emissions measurement

In supercharging spark ignition engine, knock is considered the most important limiting factor. The optimum correlation between some parameters will lead to avoid the knocking phenomena. These parameters are air supercharger temperature, air supercharger pressure, air fuel mixture, brake specific fuel consumption and exhaust gas temperature.

The concentration of carbon monoxide rate CO% will decrease especially when the percentage of bioethanol fuel with gasoline increase. This due to combustion improvement which resulting from bioethanol proprieties is better comparing with gasoline. Generation of carbon monoxide (CO) is an indication that combustion is not completed due to oxygen deficiency in combustion chamber. Figure 5 shows the (CO) emission level versus substitute ratio of gasoline with bioethanol at different engine speed.

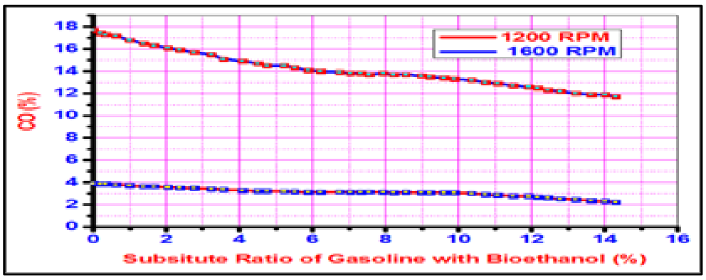


**Fig. 5. CO emission level versus substitute ratio of gasoline with bioethanol.**

## 4.3. Brake thermal efficiency measurement

As a comparison between gasoline and bioethanol-gasoline blends in terms of brake thermal efficiency, it's found that the (E60) fuelling is much higher than gasoline in same conditions like (2400) rpm speed value. In fact it can say that the increase in brake thermal efficiency is involving all tested samples due to combustion improvement and octane number. Figure 6 illustrates a comparison between gasoline and (E50) % in term of brake thermal efficiency at different engine speed.

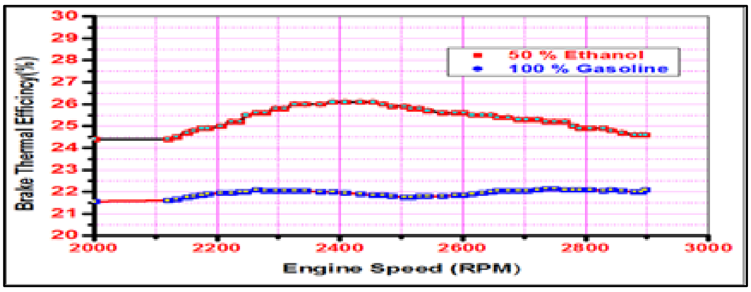


**Fig. 6. Brake thermal efficiency versus engine speed.**

## 4.4. Brake specific fuel consumption (BSFC)

It's found from this study that the brake specific fuel consumption (BSFC) will decrease with the gasoline-ethanol blends. However, when the ethanol percentage was increased, the (BSFC) will decrease. Also, when there are some differences in the compression ratio between the ethanol gasoline blended fuel and pure gasoline, the (BSFC) will decrease. Figure 7 devices the variations in (BSFC) for some ethanol-gasoline fuels under various compression ratios and engine. It can be seen from this figure that for both blends, the (BSFC) is first decreased with the increase of the engine speed up to almost 2500 rpm, then stayed constant till the speed 3500 rpm, and finally increased when the engine speed was raised up to about 4500 rpm. This means that both blends showed a similar behavior for the effect of engine speed on the (BSFC).

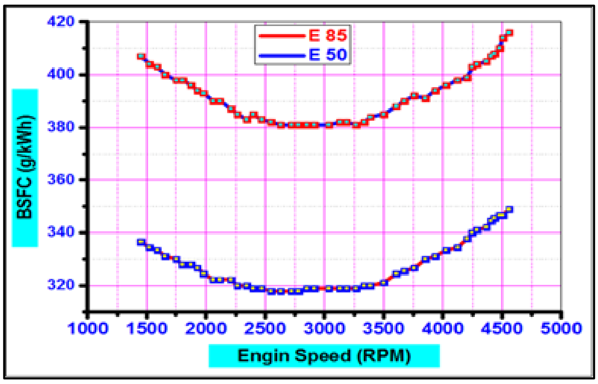


**Fig. 7. Variations in (BSFC) for some ethanol-gasoline fuel under different speeds.**

## 5. Results Comparison

In this research, there are a lot of results for comparison theoretically and experimentally, but one of the notable cases is about the air excess coefficient versus the unburned hydrocarbons emissions for theoretical and experimental results. Due to improvement in the combustion process (because the oxygen content is greater in bioethanol compared to gasoline, and the carbon content is smaller), this will result in a decrease in the (HC) emissions level for all air-fuel mixture dosages at the (E20) fuelling. Figure 8 exhibits a comparison between the level of the unburned hydrocarbons emission in both theoretical and experimental case.

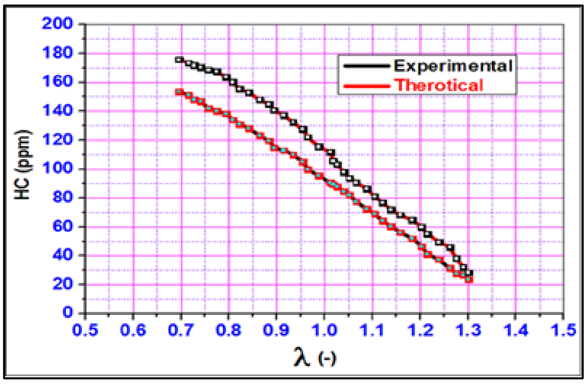


**Fig. 8. Comparison between the level of unburned hydrocarbons emission in both theoretical and experimental case.**

## 6. Conclusions

Some representative conclusions have been highlighted from this research work, and one can summarize them in the following points:

- Using the bioethanol will assure the engine operation and enhance the energetically of the performance of the engine. For the supercharged engines, bioethanol is considered the most efficient antiknock.
- By using bioethanol, the power engine will increase at the same dosage of the air-fuel mixture.
- The big advantage in using of (E20) fuelling for the engine reliability is that the difference between the maximum pressure rises and the maximum pressure rate is small.
- The smaller consumption of the brake specific energy and some improvement in the combustion of gasoline-(E20) blend at every dosage of the air-fuel mixture are achieved because of the better bioethanol combustion proprieties.
- At the air excess coefficient ($\lambda$ = 0.1), the level of Nitrogen oxides emissions ($NO_X$) for gasoline (80%)-bioethanol (20%) blend [E20] will be smaller, and the engine power will be greater. The level of ($NO_X$) emissions will decrease (50%) at the same engine power at [E20] with (l:1) compared to ($\lambda$ = 0.9).
- The reduction in the level of Nitrogen oxides emissions (NOx) when using bioethanol in the supercharged engine is highly important in the leaner dosages area.
- Depending on the obtained results in the present work, bioethanol can be considered as a good alternative fuel.

## Acknowledgement

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**Greek Symbols**

| | |
|---|---|
| $\lambda$ | Relative air/fuel ratio |

**Abbreviations**

| | |
|---|---|
| BSFC | Brake Specific Fuel Consumption |
| CI | Compression ignition |
| CO2 | Carbon dioxide |
| CR | Compression ratio |
| E20 | Ethanol 20% unleaded gasoline 80% blend |
| E50 | Ethanol 50% unleaded gasoline 50% blend |
| E85 | Ethanol 15% unleaded gasoline 85% blend |
| HC | Unburned hydrocarbons |
| NOx | Nitrogen oxides |
| P | Gases pressure |

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