Hindawi Publishing Corporation
Journal of Renewable Energy
Volume 2015, Article ID 170896, 7 pages
http://dx.doi.org/10.1155/2015/170896

*Research Article*

# Effect of Operating Conditions on Pollutants Concentration Emitted from a Spark Ignition Engine Fueled with Gasoline Bioethanol Blends

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Received 18 September 2014; Revised 5 April 2015; Accepted 13 April 2015

Academic Editor: Onder Ozgener



This study is an experimental investigation of the effect of bioethanol gasoline blending on exhaust emissions in terms of carbon dioxide $CO_2$, carbon monoxide CO, unburnt hydrocarbons UHC, and nitric oxide $NO_x$ of a spark ignition engine. Tests are conducted at controlled throttle and variable speed condition over the range of 1200 to 2000 rpm with intervals 400 rpm. Different compression ratios are tested for each speed, namely (7,8,10, and 11). Pure gasoline and bioethanol gasoline blends are used. The bioethanol used is produced from Iraqi date crop (Zehdi). Blending is done on energy replacement bases. Ethanol energy ratio (EER) used is 5%, 10%, and 15%. At each of the three designated engine speeds, the torque is set as 0, 3, 7, 10, and 14 N·m. It is found that ethanol blending reduces CO and UHC concentration in the exhaust gases by about 45% and 40.15%, respectively, and increases $NO_x$ and $CO_2$ concentrations in the exhaust gases by about 16.18% and 7.5%, respectively. It is found also that load and speed increase causes an increase in $CO_2$ and $NO_x$ concentrations and reduces CO and UHC concentrations. It is also found that increasing the compression ratio causes the emissions of $CO_2$ and $NO_x$ to decrease and those of CO and UHC to increase.

## 1. Introduction

In recent years, given the dramatically increasing demand of energy, public concern has steadily increased regarding a possible shortage of fossil fuel resources, energy safety policies, and environmental pollution regulations. The degradation of the global environment and the foreseeable future depletion of worldwide fossil fuel reserves have been the driving force to searching for alternative fuels that are sustainable and environmentally friendly. Ethanol fuel is one of the renewable fuels for addressing these issues. The potential of ethanol fuel in improving the performance of internal combustion engines has been recently the focus of many investigations [1, 2]. In 2005, the Australian Government's Biofuels Taskforce reported that the environmental and human health impact of using ethanol as a biofuel was a major issue requiring resolution in order to guide national policy measures aimed at reducing greenhouse gas emissions. Because of the excellent miscibility of bioethanol with common gasoline, it can be used as an additive to partially replace the gasoline as an automotive fuel [3]. Such mixtures are normally named after the amount or percentage of ethanol contained in the blended fuel [3].

Bioethanol is a renewable, biodegradable, and environmentally friendly alternative fuel, because it can be produced from agricultural products and scrapped resources. The road transport network using conventional fuels accounts for 23% of total greenhouse gas. These emissions can be reduced by using bioethanol fuel. Because of these benefits, bioethanol and ethanol-gasoline blends are widely investigated and used as alternative fuels in automotive vehicle [4–6]. The effects of ethanol addition to gasoline on engine performance and exhaust emissions were investigated experimentally and theoretically. It was found that the ethanol addition to gasoline has caused leaner operation and improved the combustion process. The potential of ethanol fuel in reducing the emission

pollution of internal combustion engines has been extensively investigated. Liao et al., 2005, [7] performed an experimental study in a closed combustion chamber to investigate combustion characteristics and pollutants emission of ethanol-gasoline blends at low temperature, which is related to the cold-start operation of engines fueled with ethanol-gasoline. The exhaust emissions were purposely measured in terms of unburned hydrocarbon UHC, CO, and $NO_x$. It was confirmed that the emissions of UHC during rich combustion at relatively low temperature increased with increasing the addition of ethanol.

Najafi et al. 2009 [8] analyzed experimentally the pollutant emissions of a four-stroke SI engine operated with ethanol-gasoline blends of 0%, 5%, 10%, 15%, and 20% with the aid of artificial neural network (ANN) theoretically. The concentrations of CO and UHC emissions in the exhaust pipe decreased when ethanol blends were increased. This was due to the high oxygen percentage in the ethanol. In contrast, the concentrations of $CO_2$ and $NO_x$ were found to be increased when ethanol is introduced. Yusaf et al. 2009 [9] evaluated the use of potato waste bioethanol as an alternative fuel for gasoline engines. The pollutant emissions of a four-stroke SI engine operating on ethanol-gasoline blends have been investigated experimentally and theoretically. Experiments were performed with the blends containing 5%, 10%, 15%, and 20% by volume of ethanol. Exhaust gas emissions were measured and analyzed for UHC, $CO_2$, CO, $O_2$, and $NO_x$ at engine speed ranging from 1000 to 5000 rpm. The concentrations of CO and UHC emissions in the exhaust pipe were decreased and the concentrations of $CO_2$ and $NO_x$ were increased when ethanol was introduced. Results obtained from both theoretical and experimental studies were compared. The simulation results have been validated against data from experiments and a good agreement was noticed between the trends in the predicted and measured results. Seshaiah, 2010, [10] performed tests on a variable compression ratio spark ignition designed to run on pure gasoline, LPG (Isobutene), and gasoline blended with ethanol 10%, 15%, 25%, and 35% by volume. In addition, the gasoline was mixed with kerosene at 15%, 25%, and 35% by volume without any engine modifications. The CO and $CO_2$ emissions had been also compared for all tested fuels. It was observed that the LPG is a promising fuel at all loads, which produced lesser carbon monoxide emission compared with other fuels tested. Ethanol was used as a fuel additive to the mineral gasoline; (up to 30% by volume) without any engine modification and with no efficiency loss. Ozsezen and Canakci, 2011, [11] studied the exhaust emissions of a vehicle fueled with low content alcohol (ethanol and methanol) blends and pure gasoline. The vehicle tests were performed at wide-open throttle using an eddy current chassis dynamometer with vehicle speeds of 40, 60, 80, and 100 km/hr. The test results obtained with the use of alcohol gasoline blends, 5% and 10% alcohol by volume, were compared with the pure gasoline results.

In general, alcohol gasoline blends provided higher combustion efficiency compared to pure gasoline. In exhaust emission results, a stable trend was not seen, especially for CO emission, but, on average, alcohol gasoline blends exhibited decreasing UHC emissions. In the 100 km/hr vehicle speed test, the alcohol gasoline blends provided lower $NO_x$ emission values compared to pure gasoline. At all vehicle speeds, minimum $CO_2$ emission was obtained when 5% methanol was added in gasoline. Sales and Sodré, 2012, [12] presented the exhaust emission levels from a flexible fuel engine with heated intake air and fuel during cold start operation. Electric resistances provided heating of intake air and fuel. The exhaust emissions from the engine equipped with heated intake air and ethanol injector were compared with the levels obtained from the conventional cold start system that uses gasoline as auxiliary fuel. The use of heated air and ethanol in substitution to the conventional system, that introduces gasoline in the intake pipe, to help cold start of a flexible fuel engine fuelled with hydrous ethanol (ethanol with 6.8% water mass content) produced significant reductions on raw exhaust UHC and CO emissions, especially in the first 150 s. Raw exhaust $NO_x$ emissions were slightly reduced after 200 s from cold start. Yang et al. 2012 [13] studied the effects of ethanol-blended gasoline on emissions of regulated air pollutant and carbonyls from motorcycles. In addition, durability testing was performed on two brand-new motorcycles of the same model, using E3 in one and E0 in the other, to assess the effects of E3 usage on motorcycle emissions. The results show that average emission factors of CO and UHC decreased by 20% and 5.27%, respectively, using E3 fuel. However, $NO_x$ and $CO_2$ emissions increased by 5.22% and 2.57%, respectively.

## 2. Experimental Apparatus and Procedure

The aim of work is to study the effect of bioethanol blending on the exhaust gas pollutants concentrations of a spark ignition engine. The bioethanol blending is done on energy replacement basis. Different blending ratios are to be tested. No engine modification is made. The test engine, the instrumentations, and the experimental program are described briefly in the following sections.

*2.1. Test Engine and Instrumentation.* The experiments are performed on a research engine, which is a variable compression ratio (varicomp), single cylinder, water cooled, dual fuel (gasoline/diesel) manufactured by prodit company, see Figure 1. The specifications of this engine are shown in Table 1. The exhaust gases are analyzed using MEG001 gas analysis and T156D gas analysis units while temperature measurement is done using thermocouple type K.

*2.2. Test Fuel.* The pollutants concentrations of bio-ethanol-blended gasoline (E5, E10, and E15) are to be evaluated and compared with that of neat gasoline fuel (E0). The purity ratio of bioethanol is 99.9% [14]. The fuel blends are prepared just before starting the experiment to provide homogenous fuel mixture. The ethanol-supplementation ratio by energy replacement is defined by the following equation:

$$\mathrm{EER} = \frac{\mathrm{EE}}{\mathrm{GE} + \mathrm{EE}} \times 100\%, \tag{1}$$

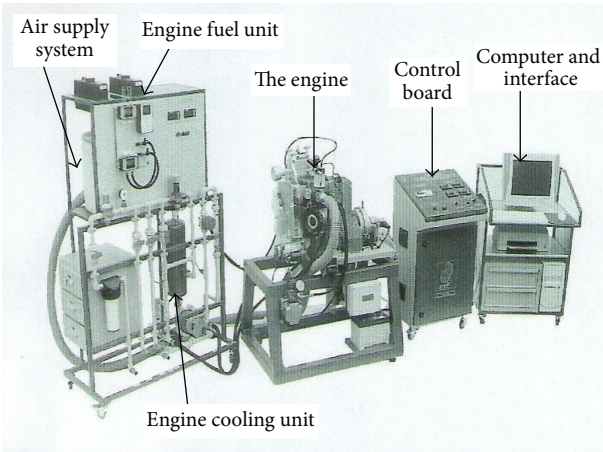


Figure 1: Test rig [14].

Table 1: Engine specifications.

| | |
|---|---|
| Manufacture | Prodites.a.s. |
| Cycle | Otto or Diesel four stroke |
| Diameter | 90 mm |
| Stroke | 85 mm |
| Swept volume | 541 $mm^3$ |
| Compression ratio | 4–17.5 |
| Max. power output | 4 kW at 2800 rpm |
| Max. torque | 28 N·m at 1600 rpm |
| Cooling type | Water cooled |
| No load speed range | 500–3600 rpm |
| Load speed range | 1200–3600 rpm |

where EER is ethanol energy ratio, EE is ethanol energy content, and GE is gasoline energy content:

$$\mathrm{EE} = (\mathrm{mxLCV})_{\mathrm{eth}}\,,$$
$$\mathrm{GE} = (\mathrm{mxLCV})_{\mathrm{Gas}}\,. \tag{2}$$

The properties of the two blended fuels are shown in Table 2.

*2.3. Experimental Procedures.* Tests are carried out at three different engine speeds ranging from 1200 rpm to 2000 rpm, by 400 rpm increments at various loads starting from no load to 14 N·m and at four different compression ratios (7 : 1, 8 : 1, 10 : 1, and 11 : 1). At each of these engine speeds, four different fuels are used which are neat unleaded gasoline (E0) and three bio-ethanol-blended gasoline, namely, E5, E10, and E15. The letter E refers to bioethanol while the followed number refers to the percentage of bioethanol in the blended fuel. For each experiment, the engine is allowed to reach a stable condition and then the measurements are recorded. The full experimental program is shown in Table 3.

Table 2: Test fuel properties.

| Properties | Gasoline | Ethanol |
|---|---|---|
| Chemical formula | $C_{8.23}H_{15.39}$ | $C_2H_5OH$ |
| Molecular weight (kg/kmol) | 114.15 | 46.07 |
| Density (kg/$m^3$ at 20°C) | 732 | 792 |
| Oxygen (% wt.) | 0 | 35 |
| Octane number (RON) | 86–94 | 105–108 |
| Boiling point (°C) | 25–230 | 78.5 |
| Latent heat of vaporization (kJ/kg) | 289 | 854 |
| Autoignition temperature (°C) | 257 | 423 |
| A/F ratio (by mass) | 14.7 | 9 |
| Lower heating value (MJ/kg) | 43.8 | 26.7 |
| Flash point | −43 | 9 |

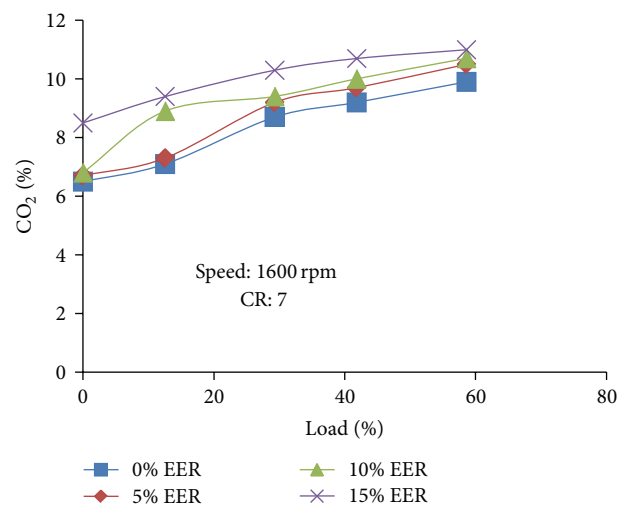


Figure 2: Effect of load on $CO_2$ concentration.

## 3. Results and Discussion

In this section, the experimental results of the effect of bioethanol addition to gasoline fuel on the pollutants emissions of a spark ignition engine have been presented and discussed. It must be mentioned here that the ethanol blending is based on energy replacement basis; see (1). The experimental program is limited to a bioethanol blending ratio ranging from 0% to 15% since at higher ratios the engine does not run smoothly.

*3.1. The Effect of Load.* Carbon dioxide is product of complete combustion of fuel. Normally, $CO_2$ emission increases with increase in load due to enhancement in combustion process as seen from Figure 2. Further, the presence of alcohol provides more oxygen for burning of fuel thus the emission of $CO_2$ increases with increasing the alcohol blending ratio. The stoichiometric air-fuel ratio of ethanol is about 2/3 that of gasoline; hence, the required amount of air for complete combustion of the blended fuel is reduced and the mixture becomes leaner. When the engine condition goes leaner, the

Table 3: The experimental program.

| Torque (N·m) | CR = 7, 8, 10, 11 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1200 rpm | | | | 1600 rpm | | | | 2000 rpm | | | |
| | EER | | | | EER | | | | EER | | | |
| | 0% | 5% | 10% | 15% | 0% | 5% | 10% | 15% | 0% | 5% | 10% | 15% |
| 0 | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | |
| 14 | | | | | | | | | | | | |

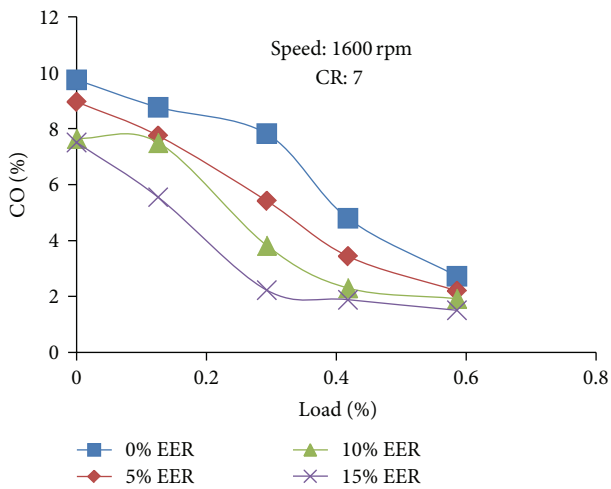


Figure 3: Effect of load on CO concentration.

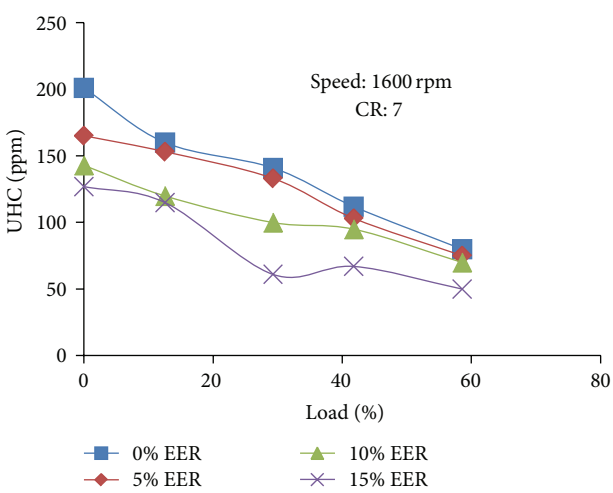


Figure 4: Effect of load on UHC concentration.

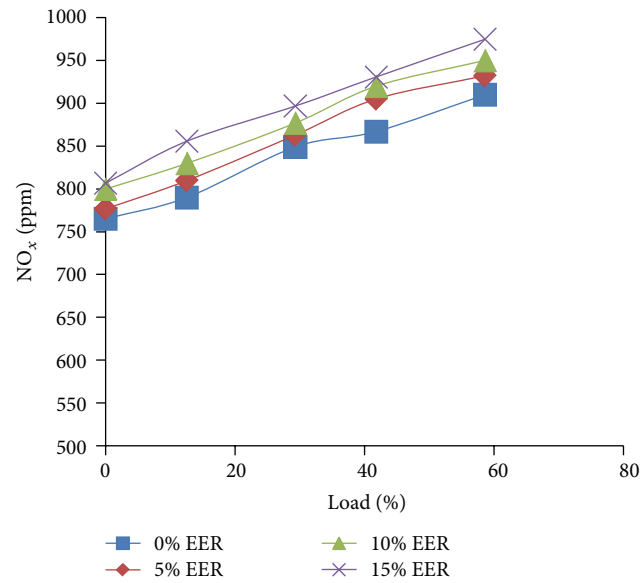


Figure 5: Effect of load on $NO_x$ concentration.

combustion process is more complete and the concentration of $CO_2$ emission gets higher.

The carbon monoxide concentration shows opposite behavior as compared with carbon dioxide as shown in Figure 3. The carbon monoxide concentration decreases as EER increases. This is because of the fact that addition of ethanol makes the mixture leaner, which gives better combustion and less CO production. The formation of carbon monoxide indicates loss of power because of oxygen deficiency in combustion chamber and hence incomplete combustion. The UHC emission decreases with increasing load and EER as shown in Figure 4, because increasing load results in stable combustion processes and faster flame speed. This is further improved by the addition of oxygenated alcohol. It provides more oxygen for the combustion process and leads to the so-called "leaning effect." Its final result is that better combustion is achieved therefore the concentration of UHC emission decreases as the ethanol content increases. The $NO_x$ concentration results are very complicated. It depends on combustion temperature, availability of oxygen, and time for combustion process. The $NO_x$ increases as the EER increases and as the load increases as shown in Figure 5. This is due to better combustion process, leading to higher combustion temperature, which favors $NO_x$ formation. As load on engine was increased, the $NO_x$ emissions for all blending ratios are also increased gradually. This is due to higher combustion temperature.

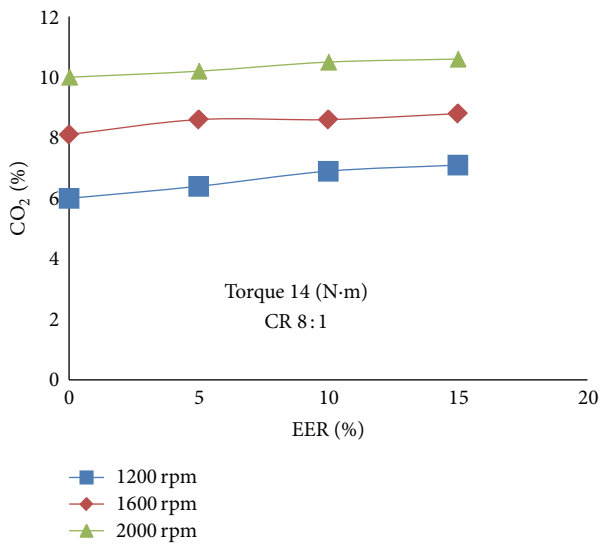


Figure 6: Effect of speed on $CO_2$ concentration.

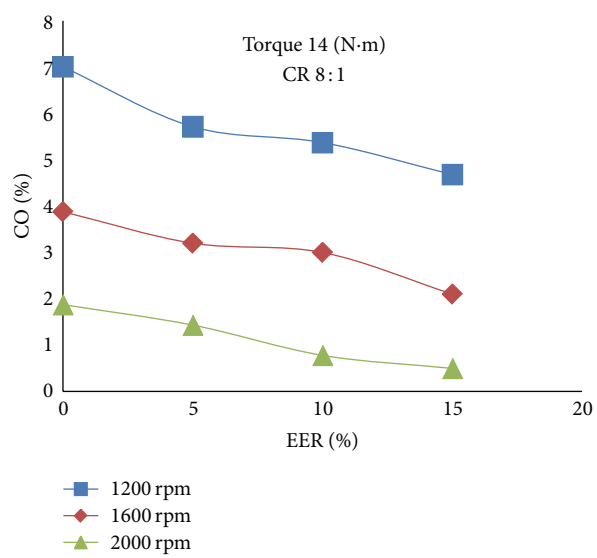


Figure 7: Effect of speed on CO concentration.

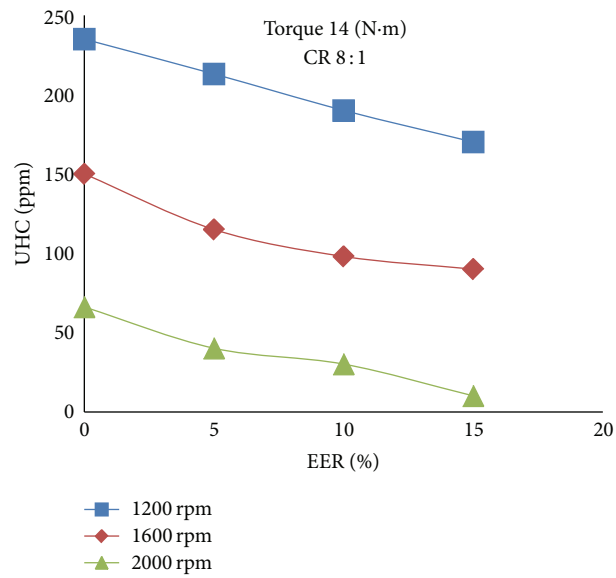


Figure 8: Effect of speed on UHC concentration.

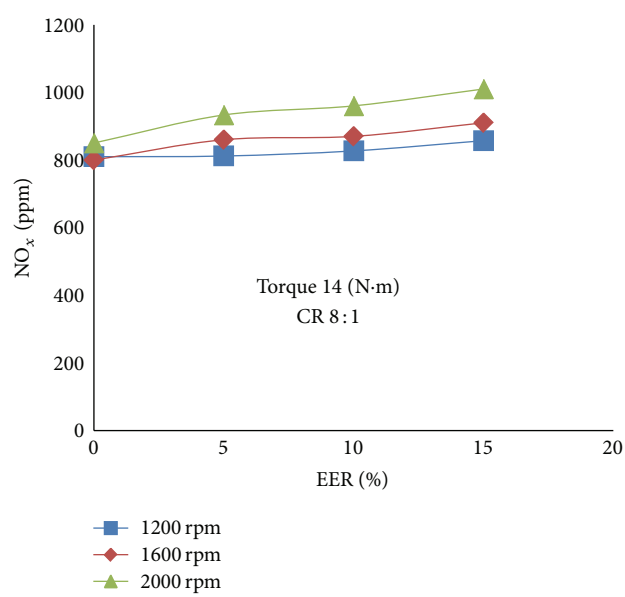


Figure 9: Effect of load on $NO_x$ concentration.

*3.2. The Effect of Engine Speed.* The carbon dioxide concentrations increase with increasing engine speed and EER while the CO decreases. This is due to larger oxidation rate of fuel carbon to $CO_2$ which is caused by presence of extra oxygen when using ethanol blending. The increase in engine speed improves engine volumetric efficiency and mixing process, leading to better combustion process. This leads to increasing $CO_2$ emissions and reducing CO emissions as shown in Figures 6 and 7. However, very high engine speed reduces volumetric efficiency which deteriorates combustion process. The unburnt hydrocarbon emission shows the same trend as CO since both are products of incomplete combustion of fuel; see Figure 8.

Figure 9 shows that the concentration of $NO_x$ increases with increasing engine speed and EER at constant load due to the increase in the cylinder temperature. This is due to higher temperature caused by better combustion process. The maximum level of $NO_x$ emission is obtained at maximum speed and maximum EER which is about 1010 ppm.

*3.3. Effect of Engine Compression Ratio.* The results show that the concentration of $CO_2$ decreases, Figure 10, while the concentrations of CO and UHC increase, Figures 11 and 12, respectively, with increasing compression ratio for all EER values. The decreasing in $CO_2$ concentration and the increasing in CO concentration may be due to the dissociation of $CO_2$ at high combustion temperature caused by increasing compression ratio and the presence of ethanol. The increasing in UHC concentration may be caused by

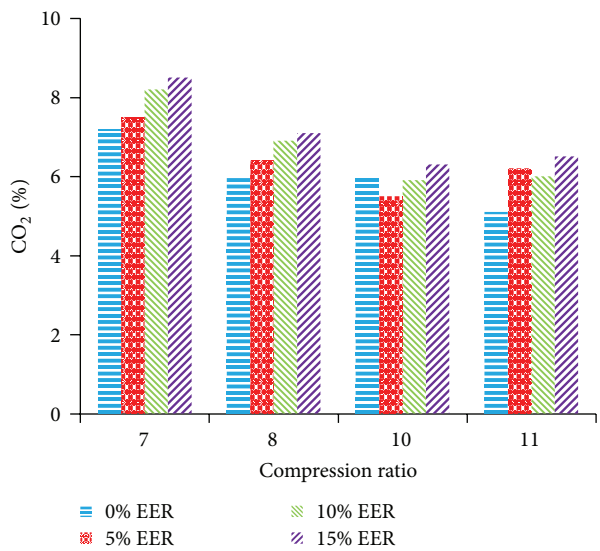


Figure 10: Effect of compression ratio on $CO_2$ concentration for different EER at 1200 rpm and load 14 N·m.

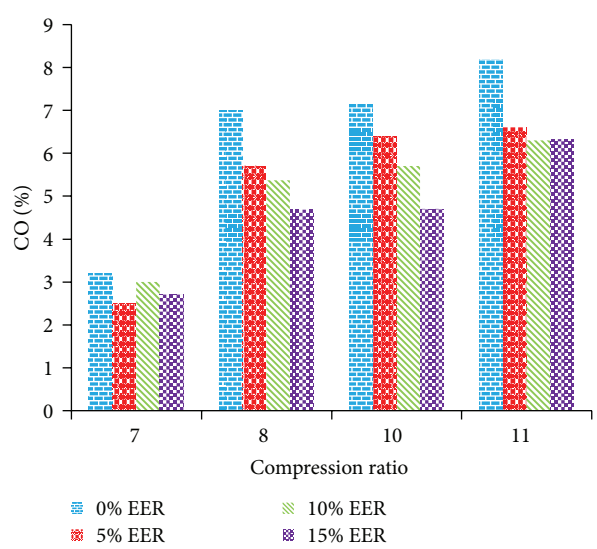


Figure 11: Effect of compression ratio on CO concentration for different EER at 1200 rpm and load 14 N·m.

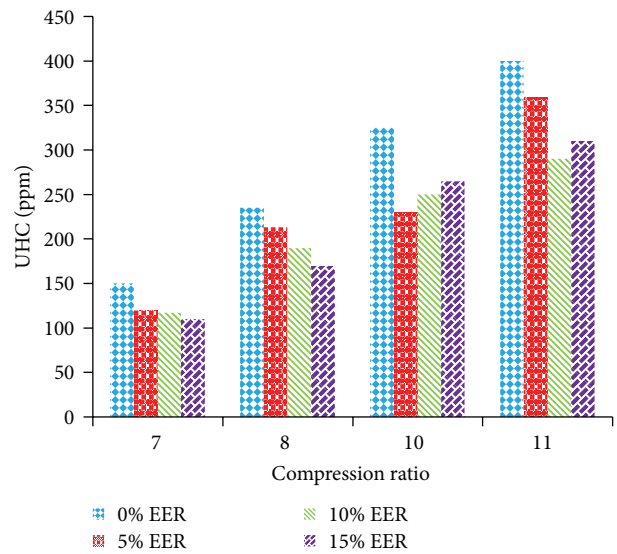


Figure 12: Effect of compression ratio on UHC concentration for different EER at 1200 rpm and load 14 N·m.

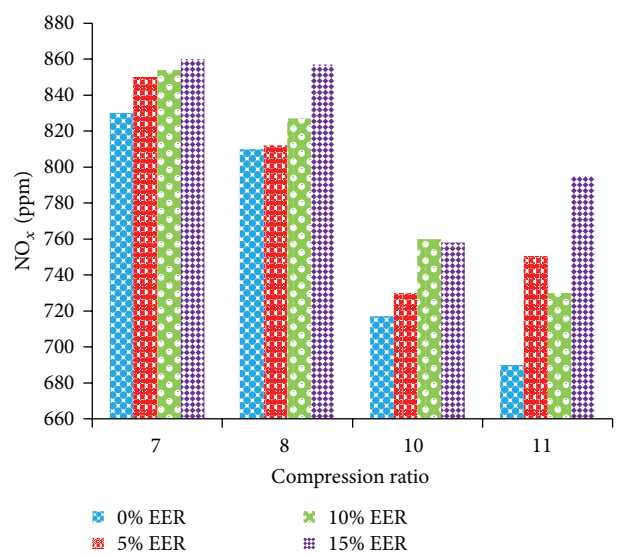


Figure 13: Effect of compression ratio on $NO_x$ concentration for different EER at 1200 rpm and load 14 N·m.

the increasing of crevice volume ratio caused by increasing compression ratio.

The variation of $NO_x$ concentration is shown in Figure 13. The figure shows that $NO_x$ concentration decreases slightly at low compression ratios (7 and 8) for all values of EER while the decrease is more noticeable at higher compression ratios as shown in Figure 13. This may be due to longer expansion stroke which gives lower temperature at later stages of expansion stroke.

Figures 14 and 15 show a comparison of results of present work with results of [15] for $CO_2$ and CO emissions. Comparison shows acceptable agreement in trends.

## 4. Conclusions

The main conclusions that can be drawn from the results and discussions in the previous section are as follows.

(1) The concentrations of $CO_2$ and $NO_x$ increase while the concentrations of CO and UHC decrease as EER increases.

(2) Increasing engine load causes an increase in the $CO_2$ and $NO_x$ emissions and a decrease in CO and UHC emissions.

(3) It was observed that the emission values of $CO_2$ and $NO_x$ increase while those of CO and UHC decrease with increased speed of engine.

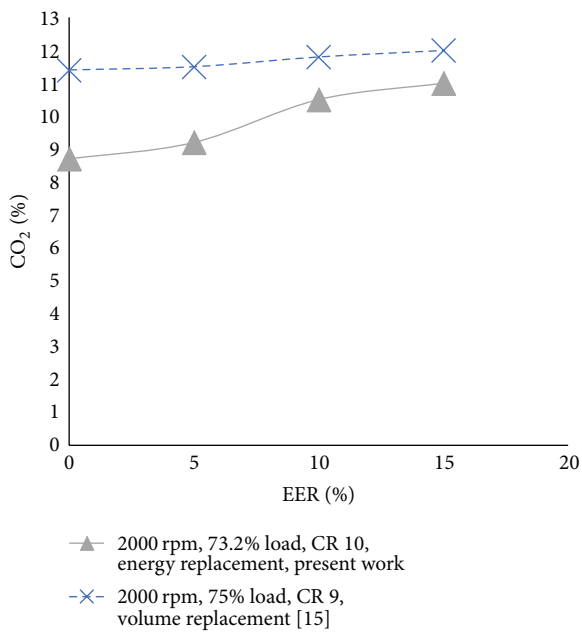


Figure 14: Comparison of present results with results of [15].

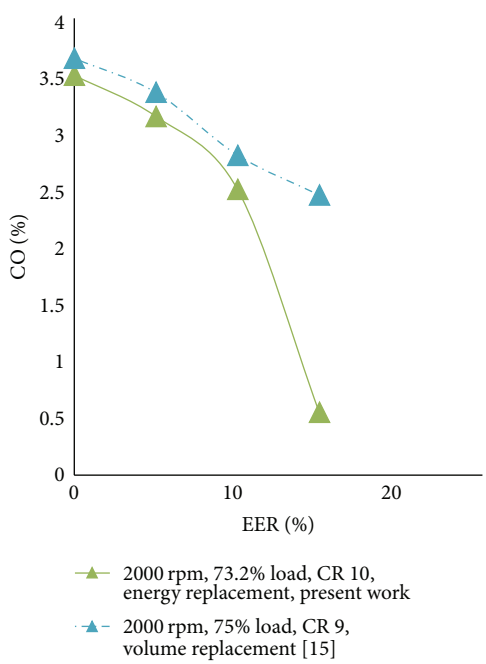


Figure 15: Comparison of present results with results of [15].

(4) With increasing the compression ratio the concentration values of the $CO_2$ and $NO_x$ decrease while the concentration values of the CO and UHC increase.

## Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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