Shahid Bahonar University of Kerman

Biomechanism and Bioenergy Research

Online ISSN: 2821-1855
Homepage: https://bbr.uk.ac.ir

Iranian Society of Agricultural Machinery Engineering and Mechanization

Comparative Analysis of Exhaust Emission Pollutants from Two Gasoline Engines

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ARTICLE INFO

Article type:

Research Article

Article history:

Received 01 October 2023

Received in revised form 08 November 2023

Accepted 26 December 2023

Available Online 28 December 2023

Keywords:

Compression Ratio, Engine, Environment, Fuel, Pollutant.

ABSTRACT

In order to investigate the impact of four types of consumed fuels on the emission of exhaust gases from two common car engines (TYPE I and TYPE II) under identical conditions, an experimental study was conducted in Islam Abad Gharb, the central location for automotive technical. The study followed factorial completely randomized design with six replicates. After preparing the engines according to relevant standards, sampling was carried out while the engines were idling at a low RPM with the gear lever in neutral. The fuels examined in this research comprised export gasoline, super gasoline, regular gasoline, and CNG gas. The measured exhaust gases exhausted from the engines included oxygen (O_2), carbon monoxide (CO), carbon dioxide (CO_2), unburned hydrocarbons (HC), and nitrogen oxides (NO_X). These gases were compared with international standards and those set by automotive technical inspection centers. The results indicated that the volumetric percentages of oxygen produced during the combustion of export gasoline are 0.14% and 0.04% for TYPE II and TYPE I engines, respectively. Additionally, carbon monoxide percentages are 0.016% and 0.023% for TYPE II and TYPE I engines. Furthermore, carbon dioxide emissions are 8.56% and 10.20% for TYPE II and TYPE I engines, respectively. The TYPE I engine exhibits a lower impact on hydrocarbon emissions across all fuels. In terms of nitrogen oxide (NOx) concentrations, the TYPE I engine consistently plays a lesser role compared to the TYPE II engine for all tested fuels.

Cite this article: Yeganeh, R., Ghamari, B., Rezaei, G., & Ghavami Jolandan, S. (2023). Comparative Analysis of Exhaust Emission Pollutants from Two Gasoline Engines. *Biomechanism and Bioenergy Research*, *2*(2), 143-153. https://doi.org/10.22103/BBR.2023.22592.1072

Publisher: Shahid Bahonar University of Kerman
DOI: https://doi.org/10.22103/BBR.2023.22592.1072

INTRODUCTION

To examine the impact of the type of fuel on the emission of pollutants from internal combustion engines, the issue related to fuel consumption and the emission of exhaust gases from internal combustion engines has become a significant global challenge (Rabe et al., 2022; Radlińska et al., 2020). The detrimental environmental and end-point effects of pollutants on human health are more apparent than ever before, prompting all scientific efforts and research, particularly in the realm of reducing pollutant emissions and improving the efficiency of internal combustion engines (Agreement, 2015). Recent studies indicate that the type of consumed fuel can have a substantial effect on the emissions from internal combustion engines (Chambliss et al., 2013; Magara-Gomez et al., 2012; Micallef & Sammut, 2010). For instance, a recent study by Rabe et al, (2022) demonstrated that the type of fuel directly influences the composition and quantity of pollutants produced by internal combustion engines, posing significant implications for the environment and human health.

On a global scale, the current framework regarding climate change in the United Nations Framework Convention on Climate Change (UNFCCC) underscores the importance of international cooperation in addressing climate change-related issues and reducing emissions from transportation, many of which rely on internal combustion engines (Micallef & Sammut, 2010). Additionally, the International Council on Clean Transportation (ICCT) has played a crucial role in conducting research and providing policy recommendations for reducing vehicle emissions, contributing to the development of clean fuel technologies and cleaner vehicles (Chambliss et al., 2013). Furthermore, the Environmental Protection Agency (EPA) has played a fundamental role in monitoring air quality and pollutant data in the United States, offering valuable recommendations for the impact of fuel consumption on air quality and public health (Magara-Gomez et al., 2012).

Internal combustion engines play a crucial role in modern transportation, contributing to various environmental concerns, including air quality degradation. Vehicle emissions encompass a spectrum of pollutants, such as Volatile Organic Compounds (VOCs), Carbon Monoxide (CO), Nitrogen Oxides (NOx), and Particulate Matter (PM). The complexity of these emissions arises from the dynamic interplay between engine operating parameters and the characteristics of the fuel utilized. The combustion efficiency of internal combustion engines is significantly influenced by fuel properties, which have undergone continuous refinement to enhance combustion characteristics and reduce environmental impact. This paper explores the intricate relationship between fuel types and emission profiles, considering factors like Octane and Cetane numbers, lower heat values, densities, and evaporation properties. Efforts to optimize fuel formulations and engine technologies aim to achieve complete combustion, minimizing emissions of harmful substances. However, challenges persist, particularly in diesel engines, where the combustion process often leads to incomplete combustion, releasing unburned hydrocarbons and other pollutants into the environment (Arslan & Özdalyan, 2020; Vander Wal & Mueller, 2006; Wallington et al., 2006; Winebrake et al., 2000).

According to a study conducted by Khoshkname et al. (2022), the use of biofuels, including ethanol, propanol, butanol, and pentanol, in a four-cylinder gasoline engine exhibited promising results. The research demonstrated increased engine power and torque with the addition of alcoholic fuels to gasoline. Although brake-specific fuel consumption showed an initial increase compared to pure gasoline, this trend reversed as the engine speed increased. The study also highlighted the environmental benefits of biofuels, as evidenced by lower NOX pollutant levels compared to pure gasoline, a decrease in HC emissions with higher percentages of pentanol, and a significant reduction in CO emissions at certain engine speeds.

The study conducted by Yao et al. (2011), investigated the viability of ethanol-gasoline blends for vehicular use, emphasizing their potential role in air quality management. Testing low-mileage and high-mileage passenger cars, the research found that ethanol-gasoline blends, even with a 3% ethanol volume, led to lower emissions of criteria pollutants and BTEX compared to unleaded gasoline. However, an increase in formaldehyde and acetaldehyde emissions was noted with higher ethanol content. The study concluded that implementing ethanol-gasoline blends in existing vehicles without engine adjustments could effectively reduce criteria pollutants and VOC-related ozone formation, although a rise in certain carcinogenic toxins was observed.

These studies not only contribute to advancing scientific knowledge about engine pollutants but also play a vital role in formulating future policies and strategies to optimize fuel choices with a positive impact on the environment and local air quality (Aslam et al., 2006; Huang et al., 2016; Jahirul et al., 2007; Jahirul et al., 2010; Jayaratne et al., 2009; Liu et al., 2009; Neeft et al., 1996; Rakopoulos et al., 2004; T. Zannis & D. Hountalas, 2004; Zannis et al., 2009; T. C. Zannis & D. T. Hountalas, 2004). In this paper we examine the levels of different exhaust emission pollutants for two common type of automobile engines.

MATERIALS AND METHODS

In this study, two types of engines with the characteristics described in Table 1 were used to conduct the experiments.

Table 1. Technical Specifications of the Tested Engines

Parameters	Engine Type	
	TYPE I	TYPE II
Year of Manufacture	2015	2015
Fuel Injection System	Injector	Injector
Number of Cylinders	4	4
Number of Valves	8	16
Engine Displacement (CC)	1761	1587
Compression Ratio	11.5	10.5
Maximum Torque (Nm)	155	142
Maximum Speed (Km/h)	192	190
Engine Power (hp)	110	110
Fuel Type	Gas and Petrol	Gas and Petrol

A QROTECH QRO-401 five-gas analyzer, manufactured in China, was used to measure the exhaust gases produced by the engines under test. This device is capable of measuring (O_2, CO, CO_2, HC, NOX) gases. The technical specifications of the device are provided in Table 2, and a visual representation is shown in Figure 1.

Table 2. Technical Specifications of the Five-Gas Analyzer Device

Gas Type and Measurement Unit	Measurement Range	Measurement Accuracy
HC (ppm)	0-9999	1
CO (% vol)	0-99.9	0.1
CO2 (% vol)	0-20	0.1
O2 (%)	0-25	0.1
NOx (ppm)	0-5000	1

The QRO-401 five-gas analyzer, manufactured by QROTECH in China, was used for measuring the exhaust gases produced by the engines under test (Figure 1).

Figure 1. Five-Gas Analyzer Device

This device is capable of measuring the gases oxygen (O_2), carbon monoxide (CO), carbon dioxide (CO2), hydrocarbons (HC), and nitrogen oxides (NOX). The technical specifications of the device are provided in Table 2.

Conducting experiments

Before conducting the experiments, the engines were started and kept running for half an hour to reach the optimal engine temperature. This step was taken to ensure the consistency of pollutant behavior under both cold and warm engine conditions, as the performance of pollutants can vary between a cold and warm engine (Shaeri & Rahmati, 2012). After temperature stabilization, the measurement of output parameters resulting from engine combustion (including O_2, CO, CO_2, HC, NO_X) was initiated. For this purpose, the sensor (probe) of the five-gas test device was placed near the exhaust output of the engines.

Upon completion of each test for each of the engines, the tested fuel was emptied from the vehicle, and the engine remained running for 15 minutes to completely consume any remaining fuel in the fuel supply pipes. Then, fresh fuel was poured into the fuel tank, and the next test was conducted. This method was employed to achieve greater accuracy in measurements.

Various levels of variables for measuring the exhaust gases resulting from the combustion of the engines under test are provided in the table below. In this study, the total number of conducted tests reached 48 cases, with 6 repetitions.

Table 3. Various levels of measured variables

Variables	Variable Levels			
Engine Type	TYPE I	TYPE II	-	-
Fuel Type	Regular Gasoline	Super Gasoline	Export Gasoline	CNG

Data Analysis Method: In this study, each test was performed with 6 repetitions for each engine. Then, the data were analyzed based on a completely randomized design using SAS 9.1 software, and the graphs were plotted using Excel 2013 software. The results in this study were compared with the available standards in Table 4 within the specified range.

Table 4. Permissible Limits of Exhaust Gases from Fuel-Injected Vehicles (Shaeri & Rahmati, 2012)

Parameter	NOx (ppm)	HC (ppm)	CO_2 (%)	CO (%)	O2 (%)
Limit	< 50	< 250	> 14	< 2.5	< 3

RESULTS AND DISCUSSION

The results of the analysis of variance for the effect of fuel type on the volumetric percentage of oxygen gas emissions from engine exhausts are presented in Table 5.

Table 5. Results of Analysis of Variance for the Effect of Fuel Type on the Emission of Oxygen Gas from Engine Combustion

Sources of Variation	Degrees of Freedom		Sum of Squares		Mean Squares	
	TYPE I	TYPE II	TYPE I	TYPE II	TYPE I	TYPE II
Fuel Type	3	3	0.164	0.509	0.054^{*}	0.169^{**}
Error	8	8	0.069	0.054	0.008	0.006
Total	11	11	0.234	0.564	-	-

** and * indicate significance at the 1% and 5% probability levels, respectively

Given that the effect of fuel type on the oxygen output is significant at a 5% probability level, a mean comparison test was conducted (Figure 2). The results indicate that the oxygen production in both engines (TYPE I and TYPE II) is below the permissible standard limit (less than 3 by Volume percentage). It is also worth mentioning that the emission of this gas (O_2) poses no risk to living organisms.

In the statistical analysis for the TYPE I engine, considering the common letters on the averages of regular gasoline and super gasoline treatments, the results were significant at a 5% probability level. Additionally, in the statistical analysis for the TYPE II engine, the results were significant at a 1% probability level (Figure 2).

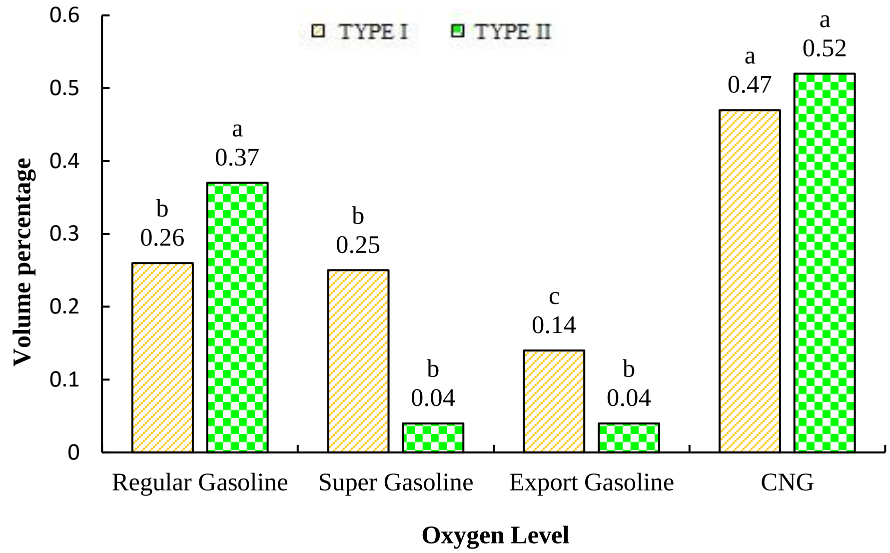

Figure 2. Average concentration of oxygen gas output from engine exhaust

The results reported in Figure 2 indicate that in both engines TYPE I and TYPE II, the volumetric percentage of produced oxygen during the use of export gasoline is 0.14% and 0.04%, respectively. This value is significantly lower compared to other fuels, suggesting the superiority of export gasoline in terms of fuel-to-air ratio and proper combustion proportion.

The results of the analysis of variance and comparison of the average volumetric percentage of CO pollutant concentration output from the engines, considering the tested fuels, are presented in Table 6 and Figure 3, respectively.

Table 6. Results of the analysis of variance on the effect of fuel type on the emission of carbon monoxide (CO) from engine combustion

Sources of Variation	Degrees of Freedom		Sum of Squares		Mean Squares	
	TYPE I	TYPE II	TYPE I	TYPE II	TYPE I	TYPE II
Fuel Type	3	3	0.003	0.001	0.001*	0.0006*
Error	8	8	0.001	0.001	0.0002	0.0001
Total	11	11	0.004	0.002	-	-

* Indicate significance at the 5% probability levels

As observed, in both engines TYPE I and TYPE II, the average volumetric percentage of the pollutant CO is lower than the standard limit (less than 2.5% volumetric). It is also worth noting that carbon monoxide is produced in the engine when the combustion mixture of fuel and air is rich, and there is not enough oxygen for the combustion cycle. This gas is flammable and burns with a blue flame. Carbon monoxide is lethal at high concentrations and, at low concentrations, can cause fatigue, headaches, dizziness, seizures, and nausea.

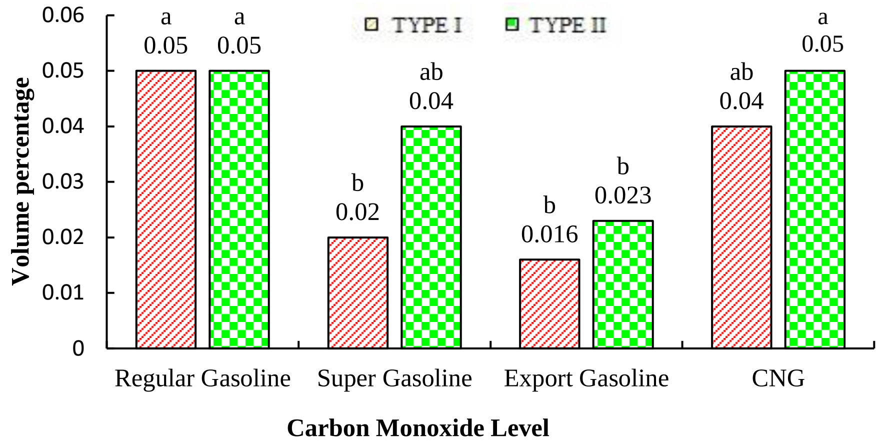

Figure 3. Average Carbon Monoxide Gas Concentration Emitted from Engine Exhausts

In the statistical analysis for both TYPE I and TYPE II engines, the results showed a significant difference at a 5% probability level, despite common letters on the average treatments. Furthermore, Figure 3 indicates that for both TYPE I and TYPE II engines, the volumetric percentage of carbon monoxide produced from the combustion of export gasoline is 0.016% and 0.023%, respectively. This percentage is significantly lower compared to other fuels and environmental standards, indicating the superiority of export gasoline in terms of complete combustion and an appropriate fuel-to-air ratio.

The results of the variance analysis in Table 7 and the comparison of the average volumetric percentage of CO_2 emitted from the engine exhausts due to combustion with the tested fuels are presented in Figure 4.

Table 7. Results of variance analysis on the effect of fuel type on carbon dioxide emissions from engine combustion

Sources of Variation	Degrees of Freedom		Sum of Squares		Mean Squares	
	TYPE I	TYPE II	TYPE I	TYPE II	TYPE I	TYPE II
Fuel Type	3	3	15.59	26.96	5.19**	8.98**
Error	8	8	0.06	0.35	0.008	0.04
Total	11	11	15.65	27.32	-	-

** Indicates significance at the 1% probability level.

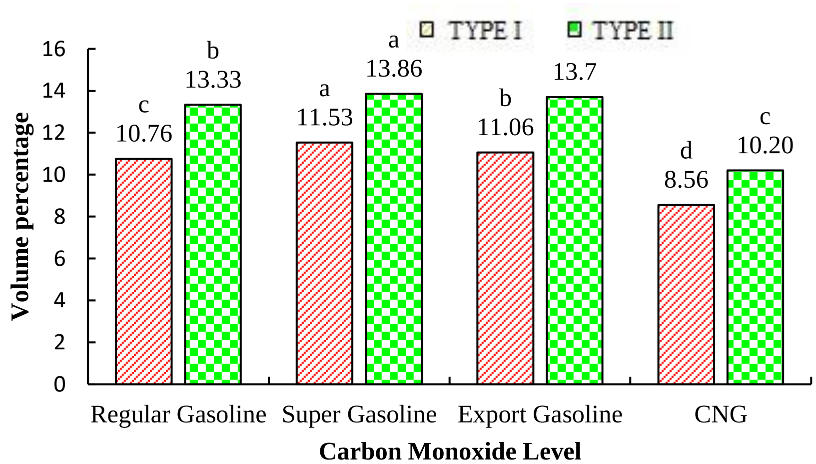

Figure 4. Average Concentration of Carbon Dioxide Gas Emitted from Engine Exhausts

The results indicate that the level of carbon dioxide (CO_2) produced in both engines, TYPE I and TYPE II, is below the permissible standard (less than 14% volume). Furthermore, the results show that the average concentration of CO_2 emitted from the TYPE II engine is close to the standard limit for all tested fuels. Considering that environmental standards report an acceptable limit exceeding 14%, it can be inferred that the TYPE II engine's performance in emitting CO_2 is more favorable than that of the TYPE I engine, possibly due to the lower compression ratio of the TYPE II engine compared to the TYPE I engine. Researchers have reported that an increase in compression ratio leads to increased air pollution and the likelihood of engine knocking (Davidson, 2003).

Carbon dioxide is colorless and odorless, and it has detrimental effects on the environment. It also contributes to calcium deposition in body tissues and reduces contractile force in the heart. These findings align with the results reported by (Baumgarten, 2006). Excessive carbon monoxide levels contribute to greenhouse gas issues and global warming crises. The increase in greenhouse gas concentrations (water vapor, CO_2, methane, nitrogen oxides, CFC) disrupts Earth's heat exchange, acting as a barrier to the return of reflected heat radiation by the Earth's crust. Consequently, atmospheric temperature rises, leading to global warming. Similar findings were reported by (Baumgarten, 2006; Davidson, 2003; Lancet, 2006).

Statistical analysis for both engines (TYPE I and TYPE II) indicates a significant difference at a 1% probability level. Moreover, in Figure 4, the results demonstrate that the volume percentage of carbon dioxide emitted during gas usage for both engines (TYPE I and TYPE II) is 8.56% and 10.20%, respectively, which is lower than other fuels and environmental standards. Therefore, considering the environmental standards, the gas delivery system of the engines under test should undergo technical inspection or, alternatively, less gas-intensive fuels should be used.

The results of the analysis of variance in Table 8 and the comparison of the average concentrations of unburned hydrocarbons (HC) emitted from the engine exhausts, considering the tested fuels, are reported in Figure 5. The results indicate that, in both engines TYPE I and TYPE II, the average concentration of HC pollutants is below the standard limit (less than 250 ppm). The reason for this may be the absence of various factors involved in the production of hydrocarbons, with the most important of these factors being: the non-stoichiometric air-to-fuel ratio, incomplete combustion, volumes related to leaks and gaps, leakage through the exhaust valve, simultaneous valve opening, deposits, and the presence of oil on the combustion chamber walls.

Table 8. Results of the analysis of variance on the effect of fuel type on the emission of unburned hydrocarbons from engine combustion

Sources of Variation	Degrees of Freedom		Sum of Squares		Mean Squares	
	TYPE I	TYPE II	TYPE I	TYPE II	TYPE I	TYPE II
Fuel Type	3	3	50768.25	44100	16922.75**	14700n.s
Error	8	8	2700.66	2474	337.58	309.25
Total	11	11	53468.91	46574	-	-

**Indicates significance at the 1% probability level, and n.s indicates non-significance

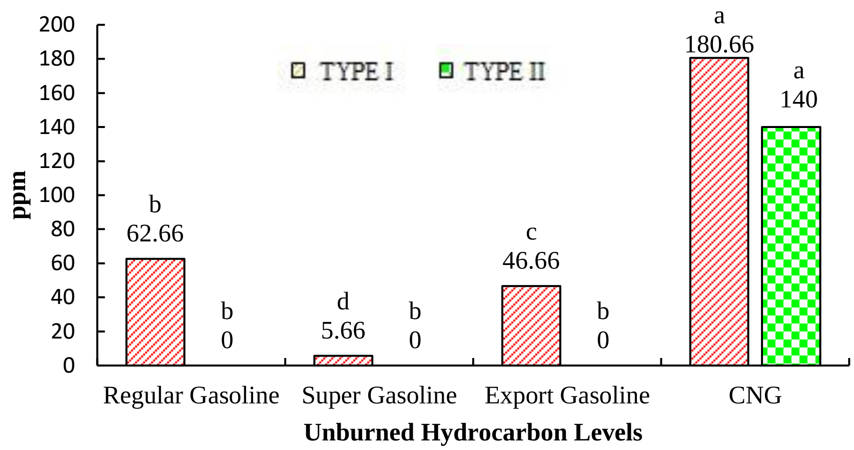

Figure 5. Average concentration of exhaust hydrocarbons from engine exhaust

In the statistical analysis for the TYPE I engine, the results indicate a significant difference at a 1% level of probability due to the absence of common letters on the average of treatment results. This suggests that with 99% confidence, there is a significant difference between the average treatments (different fuels). Furthermore, in the analysis of the TYPE II engine, the presence of common letters on the average treatments results indicates a lack of statistical difference between these factors.

In Figure 5, by comparing the level of emitted hydrocarbons between the TYPE I and TYPE II engines, it can be observed that the TYPE II engine plays the least role in the emission of exhaust hydrocarbons for all consumed fuels. This result highlights the superiority of the TYPE II engine over the TYPE I engine. Similar studies by researchers have reported that engine deposits contribute to an increase in both hydrocarbons (HC) and carbon monoxide (CO) emissions (Caceres et al., 2003; Zand et al., 2007; Zerda et al., 2001).

Table 9 presents the results of the analysis of variance, and Figure 6 compares the average concentrations of nitrogen oxides (NO_x) emitted from the exhaust of engines based on the tested fuels. By comparing the level of nitrogen oxide emissions between the two engines, TYPE I and TYPE II, it is observed that the TYPE II engine plays the least role in nitrogen oxide emissions for all consumed fuels. One possible reason for this is the higher air intake due to having 16 air valves, demonstrating the superiority of the TYPE II engine over the TYPE I engine. Additionally, the statistical analysis results for the average treatments in both TYPE I and TYPE II engines showed a significant difference at a 1% probability level.

Table 9. Results of the analysis of variance for the effect of fuel type on the emission of nitrogen oxides from engine combustion.

Sources of Variation	Degrees of Freedom		Sum of Squares		Mean Squares	
	TYPE I	TYPE II	TYPE I	TYPE II	TYPE I	TYPE II
Fuel Type	3	3	566.33	204	188.77**	68**
Error	8	8	75.33	2	9.41	0.25
Total	11	11	641.66	206	-	-

** Indicates significance at the 1% probability level

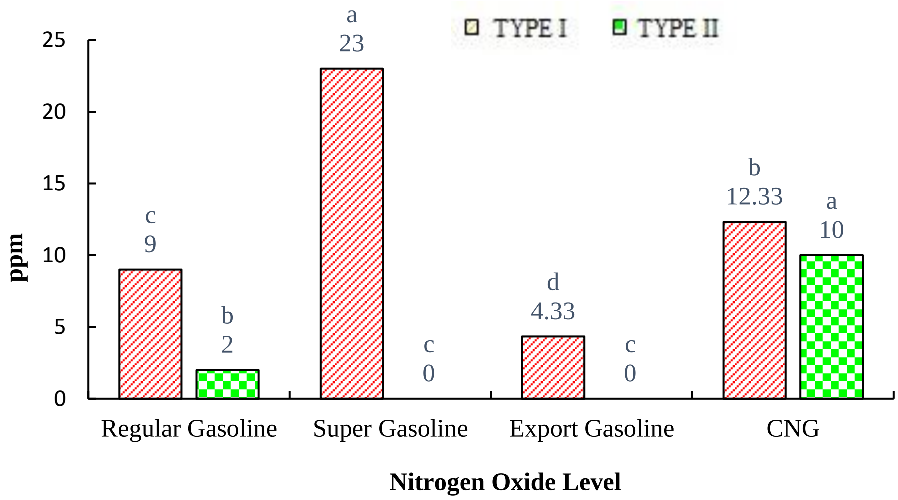

Figure 6. Average Concentration of Nitrogen Oxide Emissions from Engine Exhausts

Some researchers have compared the emission of pollutants resulted from the use of gasoline with bioethanol. In general, the results indicate that ethanol-gasoline blends demonstrate a reduction in standard pollutants, although the levels of aldehydes increase (Yao, et al, 2011). Gasoline and biofuels exhibit significant differences in engine exhaust gases. The use of biofuels, especially when compared to gasoline, can lead to a reduction in pollutants such as nitrogen oxides (NO_X), carbon monoxide (CO), hydrocarbons (HC), and carbon dioxide (CO_2) emissions (Khoshkname, et. Al, 2022). Therefore, biofuels can contribute to improving air quality and reducing negative environmental impacts. These differences depend on factors such as the chemical composition of the fuel, engine performance, and testing conditions. On the other hand, some studies have indicated that the use of biofuels may be associated with an increase in specific pollutants, such as aldehydes. These variations highlight the complexity of the subject and the need for precise management in the selection and use of fuels.

CONCLUSION

In this study, the impact of using different fuels on the exhaust gas emissions from the engines of two TYPE I and TYPE II vehicles was investigated, and the following results were obtained:

- In all treatments, the level of exhaust gas emissions from engine combustion was found to be low and acceptable compared to the standards.
- The results indicated that the TYPE II engine had the least contribution to greenhouse gas emissions in all consumed fuels, highlighting the superiority of the TYPE II engine over the TYPE I engine.
- To prevent air pollution, various plans are proposed, but the most crucial step in this regard is taken by the people. Vehicles are one of the most significant contributors to air pollution, and implementing changes in the usual methods of using personal vehicles can significantly reduce air pollution.

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