Evaluating Exhaust Gas Emissions from Blended Ethanol-Gasoline Combustion in Two Iranian National Common Light-Vehicle Engines at Different Speeds

HOSSEIN YOUSEFI[1] **AND ALI FARHADI**[2,*]

[1] *Department of Renewable Energy and Environment, Faculty of New Sciences and Technologies, University of Tehran*
[2] *Shahid Rajaee Teacher Training University,Iran, Tehran*
[*] *Corresponding author email: a.farhadi@sru.ac.ir*

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This research evaluates the performance of the two most utilized light-vehicle engines in Tehran, Iran. This paper aims to assess exhaust gas emissions of blended ethanol-gasoline combustion in two of Iran's national engines, TU5 and EF7, at different engine speeds. For this, exhaust gases, including CO_2, CO, HC, and NO_x, are analyzed using ANOVA statistical analysis. Fuel samples with 0, 20, 40, 60, and 80 vol.% ethanol in gasoline are tested in the TU5 and EF7 engines at different engine speeds, i.e., 850, 1000, 2000, 3000, and 4000 rpm. Findings suggest that the amount of exhaust gases is majorly dependent on the engines' characteristics, particularly the air-to-fuel equivalence ratio. According to the experimental results, CO_2, HC, and NO_x emissions from the EF7 engine are higher than the TU5 engine at all speeds. CO is higher in the TU5 case, on the contrary. As per the variance analysis results, exhaust emissions are primarily contingent upon and influenced by the oxygen rate required for combustion, fuel richness, and cylinder temperature rather than the composition of ethanol-gasoline blends.

keywords: *Magnetic Field, Induced Pump, Boiling, Magnetic Nanofluid, Numerical Modeling.*

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1. INTRODUCTION

Fuel additives are important because they can be added to fuel for better engine performance [1]. As oxygenating, ethanol is one of the most important additives to improve fuel performance [2, 3]. Using this substance increases the heat of evaporation, decreases the combustion temperature, and increases the burning rate, ultimately leading to more CO and HC [4–6]. Evidence from previous studies [7, 8] shows that increasing the octane number decreases the engine performance and increases the emission level. Previous studies have shown a general reduction in CO and HC emissions; however, no clear trend exists regarding NO_x emissions [9]. Differences in exhaust emission trends and their relative amounts are due to differences in engine design and control strategies used in vehicle propulsion systems. Much research has been done on the relationship between oxygen additives in gasoline and pollutant concentration in the engine's exhaust gas [2]. However, there are still different and contradictory results regarding the combination of gasoline and ethanol. Adding ethanol and other oxygenates generally reduces hydrocarbon and carbon monoxide emissions [10, 11]. It also sometimes decreases nitrogen oxide emissions [5, 6, 12]. According to [6, 13] alcohol fuel with higher vaporization heat is more efficient than gasoline. Alcoholic fuels reduce the temperature of the air entering the engine and increase the brake's thermal efficiency with the engine's output power [14, 15]. Additionally, alcohol fuels vaporize more easily in the compression flow due to their high heat of vaporization. This is because the fuel absorbs heat from the cylinder during vaporization, the air-fuel mixture is easily compressed, and the thermal efficiency is improved by combining alcohol and gasoline [10, 16–18]. However, the higher heat of vaporization of alcohol fuel also has negative effects, especially on its ability to start the engine in cold conditions [13, 19–21]. Blended ethanol and gasoline have different physical and chemical properties compared to pure gasoline. These differences can lead to differences in flame development and propagation time in the engines' combustion chambers. With large differences between fuel characteristics and flame propagation timing, an SI engine originally designed to work with gasoline will produce poor performance.

This study aims to investigate polluting exhaust gases caused by the operation of different SI engines under the consumption of variable blends of ethanol and gasoline. The engines' functions should be adjusted to the fuel according to the momentary need. Therefore, this study evaluates engines' performance with variable fuel mixtures.

2. PROBLEM DESCRIPTION

In order to calculate all the operational aspects affecting the actual performance of cars, two Iranian cars have been considered and evaluated in this study. Assessments have been conducted on two national and most utilized spark-ignited four-cylinder engines, i.e., EF7 and TU5. Using laboratory tests, the effects of mixing ethanol with gasoline at various ratios, i.e., 100/0%, 80/20%, 60/40%, 40/60%, and 80/20% (gasoline/ethanol%), as well as at different engine speeds, i.e., 850, 1000, 2000, 3000 rpm, has been investigated, and exhaust gas emissions have been measured accordingly. Table 1 describes the technical characteristics of the TU5 and EF7 engines. A Super Flow SF902 engine test dynamometer (hydraulic, 0-1627 Nm range and 5 Nm resolution, USA) has been applied to assess engines' mechanical performance variables. The dynamometer is equipped with a PC-based control panel comprised of PC hardware and PCI data card, as well as a data acquisition system for monitoring and controlling torque (Nm), engine speed (rpm), mechanical power (kW HP-1), pressure (N m2), and temperature (°C). Characteristics of the dynamometer are presented in Table 2.

The dynamometer can be controlled automatically through the computer. A SUM-290122 fuel tank and a 6-kg Fenix Lexus electronic scale (0.5 g resolution) are used to measure fuel consumption. Moreover, a Galio Smart 2000X gas analyzer is used to determine the air-fuel ratio and exhaust gas composition. Engines' operating parameters are measured through ELM327 OBD scan and LabVIEW software interface. Additionally, fuel consumption is measured volumetrically using a 14-inch glass tube and a Legend Vision DVT camera.

FGA-4000XD gas analyzer (Infrared Industries, USA) determines exhaust gas composition and air-fuel ratio. The sampling rate and time of the gas analyzer are set at 3 and 120 seconds, respectively.

The analyzer has a non-dispersive infrared model for exhaust gas. The sample line pipe is installed on the exhaust pipe at 300 mm from the exhaust port to allow adequate mixing of the exhaust gases. Automatically, the analyzer requires a 15-minute warm-up period and then switches to automatic mode. Figure 1 illustrates the test system diagram adopted in this study. For all tests, it is considered that the corresponding engine operates at a steady state condition.

Unleaded gasoline and 99%-pure ethanol are used in this study to conduct the experiments. Unleaded gasoline is mixed with ethanol to obtain five experimental gasoline samples containing 0 to 80% ethanol. Moreover, a buret is used to control the appropriate proportions of ethanol and gasoline. The samples are prepared just before experimenting in order to ensure that fuel mixtures are homogeneous and, more importantly, to avoid ethanol reaction with water vapor. Samples' properties are described in Table 3.

Additionally, the effect of experimental factors has been analyzed using analysis of variance and GLM method in SAS 9.2 software. To perform multivariate analysis, the data are divided into training and validation. Means are compared using the Duncan approach at a significance level of 5% with SAS. Furthermore, the corresponding effects are analyzed according to their statistical significance.

3. RESULTS

The variance analysis has been performed to assess the effects of experimental factors on CO_2, CO, NO_x, and HC emissions from the case study engines. The experimental factors include engine kind (EK), ethanol percentage share in gasoline (EP), engine speed (ES), EK interaction with EP (EK*EP), EK interaction with ES (EK*ES), EP interaction with ES (EP*ES), and EK interaction with EP, as well as ES (EK*EP*ES). The corresponding results are presented in Table 4.

A. CO$_2$Emission Index

Assessments of the case study engines at different speeds show that the CO_2 emission index increases by adding 20, 40, and 60% ethanol to gasoline. This is mainly because the air-fuel equivalence ratio (ϕ) is improved when ethanol is added to the gasoline at such shares, resulting in lower CO and CO_2 emissions correspondingly.

As per Table 5, adding ethanol to gasoline reduces CO_2 emissions and increases engine speed. According to the results, the CO_2 mass fraction decreases with the increase of ϕ due to decreased oxygen available for complete combustion. Previous studies showed that adding up to 60% ethanol to gasoline culminates in higher CO_2 emissions [9, 22]. This study also complies with previous ones, showing that increasing the ethanol percentage to above 80% results in deviations from optimal combustion in both engines, thereby decreasing the CO_2 concentration. In fact, for a certain ethanol concentration from 20 to 60% in gasoline, CO_2 emissions from both engines increase because the oxygen content of ethanol allows complete combustion. However, since ethanol has a lower heat capacity than gasoline, adding up to 80% ethanol to gasoline reduces the flame temperature in both engines and, therefore, increases CO_2 emissions, on the other hand. A higher concentration of ethanol in gasoline (adding 80% ethanol to gasoline) lowers the flame temperature and increases CO_2 emissions because ethanol has a lower heat capacity than gasoline.

As per the results in Table 5, an increase in engine speed due to the betterment of fuel-air mixing and improvement in ignition increases CO_2 emissions. Using a more homogeneous fuel mixture at higher speeds causes better combustion, a combustion close to stoichiometry – reaction, which increases CO_2 emissions. The amount of CO_2 in the EF7 engine is higher than that of the TU5 engine. As per the results, the highest CO_2 emissions rate (17.11% vol.%) is obtained in the EF7 engine, while the lowest (7.39% vol.%) is in the TU5 engine. This is mainly due to providing more oxygen for combustion in the EF7 engine when compared with TU5.

In incomplete combustions, there is insufficient oxygen for fuel to react with oxygen, and lower CO_2, but higher CO, is produced accordingly. This behavior is attributed to ϕ, which is higher in the EF7 engine than in TU5. This is because the EF7 engine has been designed to allow lean burning.

B. CO Emission Index

AA comparison of CO emissions for different mixtures of ethanol and gasoline is presented in Table 5. Canakci et al. [9] compared the exhaust emissions from an SI engine with ethanol-gasoline mixed fuel compared to pure diesel. Their study showed no significant difference in the combustion efficiency through gasoline-ethanol mixing. As per their results, adding 85% ethanol to gasoline results in a 5% better combustion efficiency and lower CO emissions. The study of Costaliola et al. [23] also showed a

Table 1. The technical characteristics of the TU5 and EF7 engines.

Engine parameters	Unit	Detail	Detail
Model of car	-	Dena	Peugeot 206
Kind of engine	-	EF7	TU5
Fuel type	-	gasoline	gasoline
Number of cylinders	-	4	4
Number of valves / cylinder	-	4	4
Fuel system	-	MPFI	MPFI
Transmission	-	5-speed manual	5-speed manual
Date of manufacture	year	2020	2020
Registration date	year	2015	2003
Odometer reading	km	120	70
Cylinder displacement	CC	1761	1587
Bore and stroke	mm	78.7 × 85	78.5 × 82
Top speed	km / h	189	190
Compression ratio	-	9.1 : 1	10.9 : 1
Nozzle orifice diameter	mm	0.225	0.217
Tail pressure	bar	30	31
Swirl ratio	-	2.8	2.9
Connecting rod length	mm	133.5	139.0
Maximum power	-	113 PS / 6000 rpm	110 PS / 6000 rpm
Maximum torque	-	153 Nm at 3000 rpm	142 Nm at 4000 rpm
Cooling system	-	WP, OP and OPC	WP, OP and OPC
Engine oil capacity	L	5.5	3.75
Cooling capacity	kw	51	42
Weight of car	kg	1285	1054
Fuel consumption (urban)	L	8.9	8.6
Fuel consumption (extra urban)	L	4.9	4.7
Fuel consumption (combined)	L	6.9	6.4
Engine cylinder head material	-	AL SI9 CU3	AL SI7 CU1
Cylinder block material	-	Gray cast iron (gjlb1)	Gray cast iron (gjl250)
Thermal coefficient (head)	k^{-1}	24.12×10^{-6}	$23.38 \times 10 - 6$
Thermal coefficient (block)	C^{-1}	12.50×10^{-6}	12.50×10^{-6}

Table 2. The technical characteristics of the TU5 and EF7 engines.

Dynamometer	Measurement devices	TU5 and EF7 engines		
	Trademark	SuperFlow SF902		
	Range	0-1627 Nm		
	Power capacity	1119 kW		
	Maximum speed	15000 RPM		
Gas Analyser	Trademark	FGA 4000XD gas analyser		
	Variable	Method	Range	Accuracy
	CO	Infrared	0-10% V	± 5%
	CO_2	Infrared	0-20% V	± 5%
	HC	Infrared	0-10,000 ppm	± 5%
	NO_x	Infrared	0-2000 ppm	± 5%

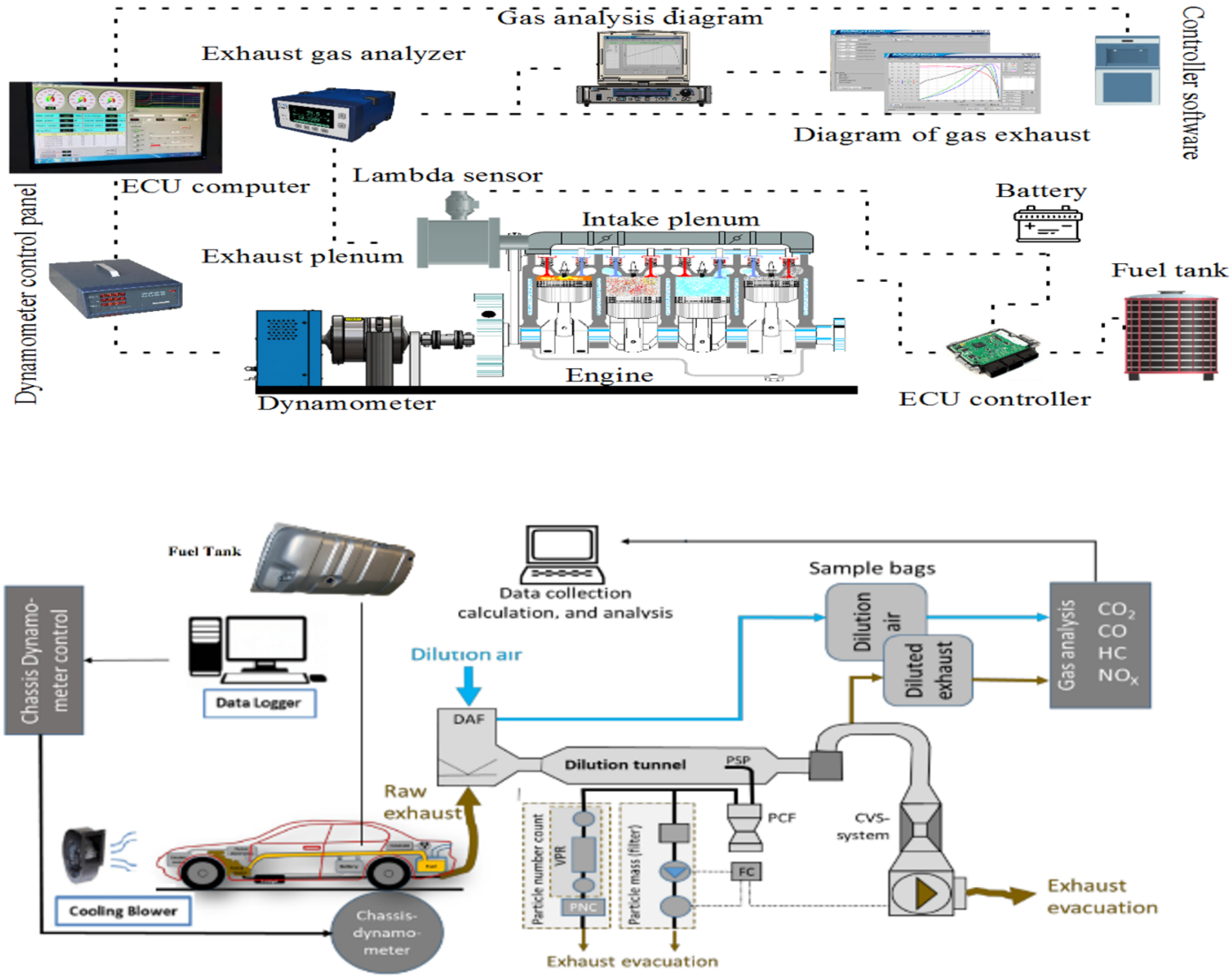

Fig. 1. Schematic diagram of the procedure adopted in this study to test the engines.

Table 3. Properties of gasoline, ethanol, and blended gasoline-ethanol.

Property	Gasoline	Ethanol	Ethanol 20%	Ethanol 40%	Ethanol 60%	Ethanol 80%
PPubChem CID	356	702	-	-	-	-
Chemical formula (liquid)	C_8H_{18}	C_2H_6O	-	-	-	-
Density [kg / m3]	748.93	789.46	742.74	708.28	769.64	782.43
Lower heating value [MJ / kg]	44.52	26.95	41.53	38.87	33.98	29.63
Boiling point [°C]	95.12	78.24 ± 0.09	-	-	-	-
Melting point [°C]	-57.12	-114.14	-	-	-	-
Molar mass [g / mol]	114.232	46.069	-	-	-	-
Research octane number	98.09	108.63	99.78	103.86	104.91	107.11
Motor octane number	86.64	89.04	87.05	87.64	88.23	88.67
Cetane number	13.76	6.17	12.76	10.06	8.54	7.23
Auto-ignition temperature [°C]	363	280	344	328	311	295
Flash point [°C]	-43.43	16.62	-31.56	-19.39	-10.01	13.47
Sulphur [mg/kg]	101	-	77	49	35	17
Oxygen content [max wt%]	0	34.8	8.4	15.1	17.76	29.6
Carbon to hydrogen ratio [C / H]	5.9	4.0	5.5	4.9	4.6	4.4
Acid value [mg KOH / g]	0.038	-	0.036	0.031	0.025	0.011
Heat of vaporization [kJ kg^{-1}]	305	840	-	-	-	-
Specific heat (vapor) [kJ $kg^{-1}K^{-1}$]	2.5	1.93	-	-	-	-
Specific heat (liquid) [kJ $kg^{-1}K^{-1}$]	2.4	1.7	-	-	-	-
Stoichiometric air-fuel ratio	15.13	9.00	-	-	-	-
Enthalpy (liquid) [MJ $kmol^{-1}$]	-259.28	224.10	-	-	-	-
Solubility in water	Not soluble	Very soluble	-	-	-	-
Reid vapour pressure at 38 °C [k Pa]	90	16	-	-	-	-
Enthalpy (gas) [MJ $kmol^{-1}$]	-277	-234.6	-	-	-	-
Water content [mg / kg]	-	~50,000	~7,000	~18,000	~31,000	~42,000
Conductivity	None	Yes	-	-	-	-
Smoke character	Black	Slight to none	-	-	-	-

Table 4. Analysis of variance for the main and interaction effects.

Source of variation	Mean squares				
	d.f.	CO_2	CO	NO_x	HC
EK	1	52.599**	0.481**	41160.001**	1522.649**
EP	4	255.416**	0.701**	95273.893**	1485.096**
ES	6	23.234**	1.924**	31499.286**	5662.159**
EK * EP	4	14.321**	0.004**	958.393**	8.997**
EK * ES	6	0.213**	0.001**	258.600**	5.215**
EP * ES	24	0.482**	0.004**	478.393**	11.935**
EK * EP * ES	24	1.061**	0.002**	171.743**	9.058**
Error	138	0.001	0.001	0.009	0.007
C.V. (%)	-	18.651	23.454	27.788	26.545

** Significance at the 0.01 probability level

significant reduction in CO emissions when a gasoline-ethanol mixture was tested in a prototype engine at 80 km/h speed. It was inferred that the reduction was made due to increased oxygen presence released from the ethanol compound.

In concurrence with previous studies, as per Table 5, this study's results show reductions in CO emissions from both tested engines by adding ethanol to gasoline. This is attributed to enhanced combustion efficiency, in other words, lower chemical energy lost due to incomplete combustion, which occurs due to increased oxygen provided by ethanol. Additionally, for the same reason, the level of CO emission decreases with increased engine speed. Moreover, the CO concentration in the cylinders of both engines follows a reverse trend compared to the CO_2 concentration. According to the results, the minimum CO emission rate is obtained with a 15/85% gasoline/ethanol% mixture in both cases. Furthermore, the results show that CO emissions decrease with a gradual increase in engine speed for ethanol-gasoline mixtures.

As per table 5, the average CO emission rate of the TU5 engine at different speeds is higher than the EF7 engine. The lowest CO emission rate obtained for the EF7 engine is around 3.01 vol.%. The figure for the TU5 engine is about 4.12 vol.% by comparison. In fact, anything that leads to incomplete combustion increases CO and HC emissions. The TU5 engine has been designed to utilize gasoline-rich fuels, which require excess air, compared to the EF7 engine, designed to burn lean fuels. Therefore, the utilization of a diluted fuel by ethanol in the TU5 engine leads to higher CO emissions in comparison to the EF7 engine.

C. HC Emissions Index

Previous studies [14, 18] showed that HC emissions follow a declining trend by adding 20-60% ethanol to pure gasoline. Nonetheless, the trend was reversed with 60-80% ethanol-containing fuel mixtures, inasmuch as the flame temperature, due to high ethanol's heat of vaporization, was reduced in such cases.

As per the results in Table 5 increasing the ethanol's share in the fuel composition reduces HC emissions at different engine speeds. According to the outcomes, adding 80% ethanol to pure gasoline reduces HC emissions from the EF7 engine by about 4%. Regarding the EF7 engine, the highest level of HC emissions is obtained with pure gasoline at the lowest engine speed. With respect to the TU6 engine, the lowest HC emission is achieved with 80/20 vol.% ethanol/gasoline composition at 4000 rpm.

As the engine speed increases, the level of HC emission decreases, and the average gas temperature in the cylinder increases. According to the results, the highest HC emission occurred at the lowest engine speed in both cases. This is mainly because fuel and air mix well at higher engine speeds. The more homogeneous fuel, the better combustion (stoichiometric combustion) at higher engine speed; therefore, the amount of HC decreases with increasing engine speed [4, 24–26]. However, as a matter of comparison, the HC values at all engine speeds are higher in the EF7 case compared to the TU5.

D. NO_x Emissions Index

Nitrogen oxide is considered one of the most important components of greenhouse gas emissions from car engines. According to Table 5, adding ethanol to gasoline leads to a significant reduction in NO_x levels. The fuel's higher heat of vaporization with adding ethanol to gasoline lowers the charge temperature during ignition. This reduces the inlet cylinder's temperature, resulting in lower NO_x emissions. NO_x emissions are affected by ignition timing and equivalence ratio. Increasing the ethanol content decreases the enthalpy of evaporation and the flame temperature, reducing NO_x emissions accordingly. This is why NO_x emissions decrease with the increase of ethanol percentage in the mixture.

Regarding the EF7 engine, the highest NO_x emission level is obtained at the highest engine speed (4000 rpm). As per Table 5, the lowest emission level, in this case, is achieved at the lowest engine speed (850 rpm). In fact, the inlet cylinder temperature increases at higher speeds, resulting in higher NO_x formation and NO_x emissions.

In the EF7 case, the highest NO_x (volume 321 ppm) emission is obtained with 80/20 vol.% ethanol/gasoline mixture at 4000 rpm engine speed. Nitrogen generally does not participate in combustion; however, some nitrogen is converted to nitrogen oxides at high temperatures, leading to higher NO_x formation and emission. This behavior is mainly attributed to ϕ, which is higher in the EF7 engine than in the TU5 engine. Rich mixtures

Table 5. Effect of EP interaction with ES on carbon dioxide (CO_2), monoxide carbon (CO), hydrocarbon (HC), and nitrogen oxides (NO_x) in EF7 and TU5 engines.

		CO_2		CO		HC		NO_x	
		% Vol.		% Vol.		ppm Vol.		ppm Vol.	
EP	ES (rpm)	EF7	TU5	EF7	TU5	EF7	TU5	EF7	TU5
0% E	850	11.09mn	8.58v	4.01a	4.12a	226.64a	220.56a	193g	189fg
	1000	11.18m	8.79rt	3.97b	4.01b	220.56c	218.36c	228ef	208ef
	2000	11.45l	9.82qr	3.81d	3.87c	212.86de	209.56f	268cd	234d
	3000	12.24j	9.93q	3.61h	3.65e	200.76f	198.56j	296b	259c
	4000	12.45i	10.21p	3.34m	3.41f	187.56gh	183.76p	321a	310a
	NEDC	12.31ij	9.89q	3.45k	3.53ef	194.16fg	186.46o	301b	291b
20% E	850	11.45l	11.09o	3.87c	4.01b	220.56c	212.86d	185gh	152h
	1000	11.72k	11.74n	3.87c	3.93bc	216.16cd	212.86d	209fg	188fg
	2000	12.71h	11.77n	3.64g	3.74de	205.72ef	200.29i	235e	197f
	3000	13.94e	12.27l	3.43kl	3.74de	193.06fg	188.66n	274cd	219ef
	4000	14.12de	12.38k	3.21op	3.51ef	183.75gh	176.56s	296b	239cd
	NEDC	14.01e	12.31kl	3.33mn	3.34fg	187.56gh	183.16pq	281c	221ef
40% E	850	12.35ij	12.09m	3.81d	3.92bc	215.62d	209.56f	163hi	138hi
	1000	13.78f	12.85i	3.73ef	3.81cd	209.56ef	205.16g	189gh	147hi
	2000	14.17d	14.41f	3.73ef	3.65e	200.76f	194.77k	209fg	186fg
	3000	15.24cd	14.96d	3.54i	3.42f	188.12gh	181.54q	234e	197f
	4000	15.55b	13.66h	3.31n	3.29fg	180.96h	174.98t	265d	222e
	NEDC	15.34c	14.11g	3.18p	3.34fg	183.79gh	177.66r	250de	201f
60% E	850	12.77j	13.23g	3.74e	3.85c	211.76de	205.72g	134ij	119ij
	1000	14.61e	14.17d	3.74e	3.75de	206.26ef	200.27i	154i	128ij
	2000	15.29cd	15.36c	3.64g	3.75de	198.56fg	192.53l	179h	154h
	3000	16.41c	14.17d	3.51j	3.61ef	183.8gh	177.12r	195g	168gh
	4000	17.11a	15.75a	3.22o	3.34fg	175.46i	169.45v	218f	191fg
	NEDC	16.78b	15.49bc	3.08q	3.19g	182.06gh	172.63u	205fg	181g
80% E	850	7.96qr	7.39y	3.71f	3.78d	221.62b	219.55b	105k	97j
	1000	8.87q	7.51x	3.61h	3.71de	215.56d	210.44e	123j	105j
	2000	9.86p	7.61w	3.42l	3.58ef	205.36ef	203.76h	139ij	119ij
	3000	10.77o	8.92r	3.21op	3.32fg	196.15fg	189.55m	154i	134i
	4000	11.34lm	8.65u	3.01r	3.09h	187.96gh	183.77p	169hi	152h
	NEDC	11.08mn	8.71t	3.21op	3.29fg	190.79g	186.65o	159i	141hi

Means in each column followed by a similar letter are not significantly different at a 5% probability level using the Duncan test.

The maximum, median, and lowest mean among characteristics were shown by dark green, yellow, and dark red color, respectively.

EP: ethanol percent (0% E: pure gasoline, 20% E: 20 percent of ethanol in gasoline, 40% E: 40 percent of ethanol in gasoline, 60% E: 60 percent of ethanol in gasoline, and 80% E: 80 percent of ethanol in gasoline), EK: kinds of engines (TU5 and EF7) and S: engine speeds (850 rpm, 1000 rpm, 2000 rpm, 3000 rpm, 4000 rpm, and NEDC: new European driving cycle) are less efficient but produce more power, on the other hand. Dilute blends are more efficient but increase the flame temperature, leading to more NO_x formation, on the other hand. Therefore, NO_x emissions from the EF7 engine, originally designed to work with dilute fuels, are comparatively higher than the TU5 engine, originally designed to burn rich fuels.

4. CONSLUSION

This paper experimentally evaluated CO_2, CO, HC, and NO_x emissions from two Iranian national engines, EF7 and TU5, when different percentages of ethanol were added to pure gasoline. The main results of this study are summarized as follows:

• Adding 20-60% ethanol to pure gasoline enhances the combustion efficiency in both engines but increases their CO_2 emissions, on the other hand. This is because the mass fraction of CO_2 increases with decreasing air-fuel equivalence ratio due to increased oxygen available for complete combustion. Nevertheless, when the ethanol's share in the mixture is increased to 80%, the CO_2 concentration decreases at different engine speeds because the higher the flame temperature decreases, and CO_2 emissions increase accordingly. As engine speed increases, CO_2 emissions from both engines increase because fuel and air mix better at higher engine speeds, thereby producing more CO_2. Moreover, increasing the fuel mixture's homogeneity causes better combustion and increases CO_2 emissions. The EF7 engine has been designed to work with dilute fuels and therefore has a higher air-to-fuel ratio in comparison to the TU5 engine to allow complete combustion. As a result, CO_2 emissions from the latter in all cases were higher than the former, designed originally to work with gasoline-rich fuels and, thus, has a lower air-to-fuel equivalence ratio by comparison.

• Regarding carbon monoxide, results suggest that adding ethanol to gasoline reduces CO emissions at different engine speeds in both cases. This is due to improving the combustion efficiency as a result of added oxygen released from the ethanol composition. Additionally, increasing engine speed improves combustion and reduces CO emissions.

• To any extent that fuel is richer, it requires more air for complete combustion. Thus, the CO and HC emissions from the TU5 engine, which has lower , are higher than the EF7 engine at all speeds. Increasing the ethanol share in the fuel composition from 60% to 80% decreases the flame temperature and increases the HC concentration in both engines accordingly. Furthermore, as the engine speed increases, the average gas temperature in the cylinder increases, and as a result, the level of HC emission decreases.

• Adding ethanol to gasoline reduces the vaporization heat of ethanol, decreasing the charge temperature at the cylinder inlet port and NO_x emissions accordingly. Moreover, increasing the engine speed increases the inlet cylinder temperature, leading to breaking down the chemical bond in the oxygen component, reacting with the nitrogen component, and finally forming more nitrogen oxides. Additionally, the EF7 engine's NO_x emission, due to having a higher air-to-fuel equivalence ratio, is higher than the TU5 engine at all speeds.

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