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Investigations on the effects of ethanol–methanol–gasoline blends in a spark-ignition engine: Performance and emissions analysis

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ABSTRACT

This study discusses performance and exhaust emissions from spark-ignition engine fueled with ethanol–methanol–gasoline blends. The test results obtained with the use of low content rates of ethanol–methanol blends (3–10 vol.%) in gasoline were compared to ethanol–gasoline blends, methanol–gasoline blends and pure gasoline test results. Combustion and emission characteristics of ethanol, methanol and gasoline and their blends were evaluated. Results showed that when the vehicle was fueled with ethanol–methanol–gasoline blends, the concentrations of CO and UHC (unburnt hydrocarbons) emissions were significantly decreased, compared to the neat gasoline. Methanol–gasoline blends presented the lowest emissions of CO and UHC among all test fuels. Ethanol–gasoline blends showed a moderate emission level between the neat gasoline and ethanol–methanol–gasoline blends, e.g., ethanol–gasoline blends presented lower CO and UHC emissions than those of the neat gasoline but higher emissions than those of the ethanol–methanol–gasoline blends. In addition, the CO and UHC decreased and CO_2 increased when ethanol and/or methanol contents increased in the fuel blends. Furthermore, the effects of blended fuels on engine performance were investigated and results showed that methanol–gasoline blends presents the highest volumetric efficiency and torque; ethanol–gasoline blends provides the highest brake power, while ethanol–methanol–gasoline blends showed a moderate level of volumetric efficiency, torque and brake power between both methanol–gasoline and ethanol–gasoline blends; gasoline, on the other hand, showed the lowest volumetric efficiency, torque and brake power among all test fuels.

1. Introduction

Over the past decade, environmental concerns have increased significantly in the world. Excessive use of gasoline fuel in the ICE (internal combustion engine) shows that is not environmentally friendly. Gasoline leads to global environmental degradation effects such as climate change, greenhouse effect, acid rain, ozone depletion etc. [1]. One possible reason of environmentally unfriendly of gasoline fuel is that it contains octane boosting compounds. Such compounds are added separately to gasoline since gasoline itself has low octane rating. The octane boosting compounds in gasoline are needed since engines require certain minimum levels of octane to resist knocking and run smoothly. However, due to their environmental problems, different octane boosting compounds are examined. In the beginning, tetra ethyl lead (TEL) was added to gasoline as an octane enhancer where each gallon of gasoline requires 1 g of TEL to increase the octane rating by about 10 times [2]. However, TEL additives are toxic air pollutants and poison catalytic converter catalysts [3]. Accordingly, aromatics such as benzene and toluene have been used instead. However, aromatics produce much level of smoke and smog and they are classified among carcinogenic compounds [4]. Aromatics, in addition, can harm the ozone concentrations substantially [5]. Next, methyl tertiary butyl ether (MTBE) was presented as one of the most promising additives. MTBE was recommended because it is not as sensitive to water as other additives and tends not to increase fuel volatility [6]. However, MTBE showed a problem as it is contaminate groundwater and harm human health [7]. Currently, alcohols are the most popular additives where they have replaced all other additives as octane boosters in gasoline fuel [8]. Adding alcohols such as ethanol and methanol to gasoline allows the fuel to combust more

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completely due to the presence of oxygen, which increases the combustion efficiency and reduces air pollution. Besides, alcohols can be promoted as alternative fuels in ICE since they do not contain sulfur or complex organic compounds [9,10]; the organic emissions (ozone precursors) from alcohols combustion have lower reactivity, which can promote ozone formation substantially [11]. However, the presence of alcohols in fuel causes corrosion to metallic fuel system components [12]. In order to diminish such corrosion problems and make the best use of alcohols in the ICE, the engine systems should be redesigned or low blend rates could be used. The smaller the alcohol addition, the easier typical blending problems (phase separation, corrosion, changed vapor pressure, changed air requirement etc.) can be solved [13].

Many researchers studied the effects of alcohol–gasoline blends, e.g., ethanol–gasoline blends and methanol–gasoline blends, on the regulated exhaust emissions of SI (spark-ignition) engine [9,10,14–24]. It can be realized from the literature that ethanol or methanol–gasoline blends can effectively reduce the pollutant emissions, compared to the neat gasoline. However, the effects of ethanol–methanol–gasoline blends are rarely examined; it was found very few publications in literature concerning such dual fuel blends. Amongst, Turner et al. [25] studied the effect of ethanol–methanol–gasoline blends on NOx and CO_2 emissions. They applied different blend rates (G29.5 + E42.5 + M28, G37 + E21 + M42, G42 + E5 + M53, G40 + E10 + M50 and G39 + E15 + M46) and showed that dual fuel blends can reduce the CO_2 and NOx emissions than the neat gasoline. Sileghem et al. [26] investigated two different rates of ethanol–methanol–gasoline blends (G29.5 + E42.5 + M28 and G37 + E21 + M42) on CO and NOx emissions. Results showed that dual fuel blends can produce less NOx emission than the neat gasoline but higher than the neat methanol. In addition, dual fuel blends can generate less CO emissions than single fuel blends (ethanol–methanol or methanol–methanol) within certain engine speed conditions. Results also showed that dual fuel blends provide less NOx than ethanol–gasoline blends but higher than the methanol–gasoline blends. In the current study, we aim at investigating ethanol–methanol–gasoline blends at low rates (3–10 vol.% for both ethanol and methanol), which is not presented in early studies. The emissions of CO, CO_2 and UHC for the dual fuel blends are compared with those of single fuel blends, e.g., ethanol–gasoline and methanol–gasoline blends, at similar rates to recommend the best environmental additive to gasoline. Furthermore the influence of the dual fuel blends on engine performance (volumetric efficiency, torque and brake power) is examined and compared with the neat gasoline as well as single fuel blends, which is also not presented early.

2. Experimental methods

2.1. Test engine and fuel preparation

A spark-ignition engine with a bore of 65.1 mm and a stroke of 44.4 mm is used in this study. The engine is 1-cylinder, 4-stroke with a 7:1 compression ratio, air cooled, no catalytic converter unit and a carburetor fuel system. One may claim that carburetor is hardly current engine technology but carbureted engines are still widely used and developed, see e.g., [27–31]. In addition, the carburetor fuel system is very appropriate for use with fuel blends [31]. This is due to its high quality of mixture preparation and mixing of different fuels. The engine is connected with an air-cooled Dynostar Model ECB500 eddy current engine dynamometer with 7000 r/min maximum engine speed. An Electronic Ignition Control Unit (EICU) was used in the engine setup for defining the proper ignition at different loads. The engine was operated in speed range of 2600–3450 r/min and load of 1.3–1.6 KW using three different blended fuels: methanol–gasoline, ethanol–gasoline and ethanol–methanol–gasoline blends. The properties of such fuels are listed in Table 1 from refs. [3,32]. The ethanol–methanol–gasoline (EM) solutions were first prepared at three different rates in volume bases as 5:5:90, 3.5:3.5:93 and 1.5:1.5:97 for ethanol, methanol and gasoline, respectively. Then, the ethanol–gasoline (E) solutions were prepared in the rates of 10:90, 7:93 and 3:97 for ethanol and gasoline, respectively. The methanol–gasoline (M) solutions were also prepared in the same rates, e.g., 10:90, 7:93 and 3:97 for methanol and gasoline, respectively. The low rates of additives (ethanol and methanol) were applied in the current study to avoid modifying the engine systems and the corrosions caused by these additives, as mentioned early. Air/fuel mixture is controlled in the carburetor hardware according to engine load without rush out into consideration the fuel blends. The basic mechanism used to achieve the quality-controlled mixture delivery was to connect the pedal control to the valve which is normally used for presetting the mixture strength and to deactivate the butterfly valve in the range down to the decided equivalence ratio. The air flow into the engine was measured using a sharp-edged orifice plate and manometer. Fuel consumption was determined by measuring the fuel used for a period of time. The air properties were almost maintained at all experiments where the tests were conducted at the same ambient conditions, such as surrounding environmental temperature, humidity etc. Tests were performed when the engine reached its steady state operating temperature. This is very important because an air-cooled engine of the type used may have different heat transfer rates which can impact emissions of UHC and CO (to some extent). The experiments were conducted under wide-open throttle conditions, and at this throttle position, the engine speeds were varied in the interval of 100 r/min to evaluate the engine exhaust emissions and performance. The measurements were repeated about three times at each test condition where the repeatability was found to be acceptable and the averaged values were considered as final results.

2.2. Performance and exhaust emissions measurements

Gas analyzer of model Infralyt CL is used to measure the exhaust emissions and excess air ratio. The gas analyzer is connected via engine exhaust stainless steel tail pipe, which discharged emissions from engine without any dilution into the analyzer at temperature of about 40–50 °C. The gas analyzer measures CO, CO_2 and UHC in a range of 0–10 vol.% for CO, 0–20 vol.% for CO_2 and 0–2000 ppm for UHC, as shown in Table 2. The measurement technique of the gas analyzer works based on an infrared rays energy transmitted through the flow of exhaust gases to a detector. A rotating wheel interrupts the rays and produces a sequence of signals. The signals are analyzed automatically by a microprocessor and presented the

Table 1
Fuel properties [3,32].

	Methanol	Ethanol	Gasoline
Molecular formula	CH_3OH	C_2H_5OH	C_4–C_{12}
Molecular weight	32	46	95–120
Oxygen content (%)	50%	34.8%	0
Density (kg/m3)	792	785	740
LHV (MJ/kg)	20.0	26.9	44.3
Octane number	111	108	>90
Auto-ignition temp. (°C)	465	425	228–470
Stoichiometric A/F ratio	6.47	9.00	14.8
Latent heat of vapor. (kJ/kg)	1103	840	305
Boiling point (°C)	64	78	38–204

Table 2
Gas analyzer technical details.

Model	Infralyt CL
Measuring principle	NDIR
Measuring range	
CO	0–10 vol.%
CO_2	0–20 vol.%
UHC	0–2000 ppm vol.
O_2	0–25 % vol.
Lambda	0–9999
r/min	400–9999
Temp.	0–130 °C
Exhaust gas temp. range	0–600 °C
Environment operating temp.	5–45 °C
Humidity (rel.) not condensing	<90%
Warm-up time	<10 min
Accuracy	OIML class 1 and 0
Power supply	240 V/1 Ph/50 Hz alternative
Weight	ca. 9 kg
Dimensions (WxHxD)	294 mm × 203 mm × 430 mm
Connectable transducers	
	Trigger clamp
	Ignition pulse antenna
	Dwell angle probe
	Optical sensor
	Diagnostic connector
	Slack point sensor

measures. The sampling probe of the analyzer is connected to a water trap by a length of flexible hose to keep away from excessive amounts of condensate water. In addition, we avoid sudden raising the hose above the level of the analyzer to avoid condensate water entering into the filters. For accurate measurements, we keep cleaning of the gas ways. The measurements are carried out after a successful leak test and warm-up/calibration phase. The measurements of pollutant emissions are introduced on the analyzer panel as well as on a personal computer, which connected via data transmission cables with the analyzer. However, the engine performance measurements, which include volumetric efficiency, torque and brake power at varied engine speeds (2600–3450 r/min), are carried out via different sensors and dynamometer connected with the engine, as discussed above. Further details about experimental set up and procedure could be seen in our early publications, see e.g., [9,10,33,34].

3. Results and discussions

The engine performance including volumetric efficiency, torque and brake power and pollutant emissions of CO, CO_2 and UHC at using neat gasoline, ethanol–gasoline blends, methanol–gasoline blends and ethanol–methanol–gasoline blends at different rates (3–10 vol.% methanol and/or ethanol in gasoline) are summarized in Table 3. In the table, gasoline is referred as G; ethanol–gasoline blends with 10, 7 and 3 vol.% ethanol in gasoline are denoted as E10, E7 and E3, respectively; methanol–gasoline blends with 10, 7 and 3 vol.% methanol in gasoline are denoted as M10, M7 and M3, respectively; ethanol–methanol–gasoline blends with 10, 7 and 3 vol.% ethanol and methanol solutions in gasoline are denoted as EM10, EM7 and EM3, respectively. As shown in the table, the neat gasoline presents the highest emissions of CO and UHC and the lowest emissions of CO_2 at all engine speeds (2600–3450 r/min). However, the methanol–gasoline blends show the lowest emissions of CO and UHC and the highest of CO_2, e.g., the best emission results among all test fuels. The ethanol–gasoline blended fuels show higher emissions of CO and UHC and lower CO_2 than those of M at all rates (3, 7, and 10 vol.%). While the EM show a moderate level of emissions between E and M test fuels. In general, using blended fuels containing ethanol and/or methanol with gasoline results a significant reduction in CO and UHC emissions, compared to neat gasoline fuel. This is because the blended fuels contain oxygen, which can enhance the combustion process significantly, as it will discuss later in further details. Compared to neat gasoline, the relative decreases in the CO emissions of E3, E7 and E10 are about 15.5%, 31% and 42%, respectively; the CO emissions of M3, M7 and M10 are decreased by about 17.7%, 51.5% and 55.5%, respectively; however the CO emissions of EM3, EM7 and EM10 are decreased by about 17.5%, 35.5% and 46.6%, respectively, as shown in Fig. 1.

The comparison of UHC emissions for test fuels is shown also in Fig. 1. Compared to neat gasoline, the UHC emissions of M3, M7 and M10 are reduced by about 19.6%, 16% and 26%, respectively; while E3, E7 and E10 are reduced by about 3.5%, 14% and 21.5%, respectively; whilst EM3, EM7 and EM10 are reduced by about 10.7%, 15.3% and 23.2%, respectively. As seen, the UHC is very low for the M, followed by EM and then by E blends, compared to the neat gasoline. The UHC emissions are indication of combustion quality, e.g., it is lower when the combustion is enhanced.

The comparison of CO_2 emissions for test fuels is shown in Fig. 1. The changes in CO_2 emissions have an opposite manner when compared to the CO and UHC emissions; CO_2 emissions increase while the CO and UHC emissions decrease, as shown in Fig. 1. This is reasonable since CO_2 emissions depend on CO and UHC emissions concentration. CO_2 is maximized for M, followed by EM, E and finally the G fuel, as shown in Fig. 1. In particular, the CO_2 emissions of M3, M7 and M10 are higher than that for gasoline fuel by about 3%, 8% and 9.2%, respectively; the CO_2 of EM3, EM7 and EM10 are higher by about 3%, 5.1% and 7.1%, respectively; the CO_2 of E3, E7 and E10 are higher by about 1%, 1.7% and 4%, respectively, compared to the neat gasoline. As seen from these experimental values, the effect of M on CO_2 emissions is minute significant than those of EM and E. In general, the emission of CO_2 is a product of complete combustion due to sufficient amount of air in the air-fuel mixture and plenty time in the cycle for completion of combustion process. So that with sufficient oxygen/air and time, the process of CO–CO_2 as well as UHC–CO_2 will be enhanced and, in turn, maximizing CO_2 emissions, as it will be discussed in details subsequently.

The reasons of emissions trends could be explained in details as follows. Ethanol and methanol contain oxygen atoms in their basic forms, see Table 1. When ethanol and/or methanol are added to gasoline fuel, they can provide more oxygen for the combustion process and that leads to the so-called ethanol and/or methanol leaning effect. Blended fuels, therefore, can be treated as partially oxidized hydrocarbons. Owing to the partially oxidized and the leaning effects of blended fuels, CO and UHC emissions decrease tremendously and CO_2 emissions increase. Furthermore, the methanol–gasoline blends present the lowest CO and UHC than other test fuels, as mentioned early, due to its great leaning effect. This is because the oxygen ratio in methanol fuel is 50%, however, in ethanol fuel is about 34.8%, as shown in Table 1. This is also the reason for providing the EM fuels with fewer emissions (CO and UHC) than those of E fuels. It was also observed that by using 10 vol.% blended fuels, the emissions were lower than those of 7 vol.% and 3 vol.% of same fuel type since adding more ethanol and methanol to gasoline leads to a leaner better combustion.

The emissions are also significantly related to A/F (air to fuel) ratio. The stoichiometric A/F ratio for pure gasoline is about 14.8 and those for the blended fuels are lower (A/F for methanol and ethanol is 6.4 and 9, respectively, as shown in Table 1). When blended fuels are applied, the engine fuel system will supply similar fuel quantity as in gasoline condition (the gasoline engine is not tuned for the fuel blends, as mentioned early). This ultimately makes the A/F mixture of the ethanol and/or methanol–gasoline blended fuel being leaner, in addition to the leaning effect due to

Table 3
Performance and pollutants emitted from gasoline (G) and blended fuels [ethanol–gasoline (E), methanol–gasoline (M) and ethanol–methanol–gasoline blends (EM)].

	G	E3	E7	E10	M3	M7	M10	EM3	EM7	EM10	N r/min
CO	3.9	3.2	2.9	2	3.6	1.5	1.4	3.6	2.5	1.9	
CO_2	12.2	12.5	12.6	13.2	12.4	13.6	13.2	12.4	13	13.2	
UHC	242	218	200	190	210	215	205	210	205	197	3450
BP	2.12	2.32	2.35	2.38	2.34	2.24	2.29	2.33	2.34	2.34	
Tq	4.45	4.43	4.48	4.57	4.47	4.44	4.51	4.28	4.3	4.36	
VE	0.27	0.28	0.28	0.45	0.28	0.405	0.4	0.403	0.406	0.407	
CO	4.5	3.8	3.1	2.6	3.7	2.2	2	3.7	2.9	2.4	
CO_2	11.8	12.3	12.8	13	12.3	13.3	13	12.3	12.9	13	
UHC	280	270	240	220	225	235	207	250	237	215	3400
BP	2.23	2.37	2.44	2.45	2.39	-	2.35	-	2.34	2.37	
Tq	4.56	4.54	4.63	4.68	4.57	4.5	4.62	-	4.5	4.6	
VE	0.275	0.277	0.276	0.411	0.277	-	0.405	-	0.4	0.405	
CO	4.9	4.4	4.2	3.8	4.3	3.3	3.7	4.6	3.9	3.7	
CO_2	11.3	11.8	11.9	12.1	11.7	12.4	11.7	11.7	11.9	11.9	
UHC	319	310	291	268	226	250	217	280	270	230	3300
BP	2.345	2.427	2.473	2.501	2.42	2.38	2.44	2.37	2.40	2.42	
Tq	4.63	4.65	4.72	4.78	4.63	4.6	-	4.55	4.54	4.64	
VE	0.268	0.282	0.275	0.408	0.278	0.404	-	0.408	0.405	0.407	
CO	5.5	5.4	5	4.3	4.6	4.3	4.5	5.4	4.7	4.4	
CO_2	11.1	11.2	11.4	11.8	10.8	11.7	11.3	10.8	11.5	11.6	
UHC	322	315	300	280	230	270	235	290	280	250	3200
BP	2.44	2.455	2.511	2.537	2.47	2.453	2.46	2.45	2.49	2.5	
Tq	4.66	4.71	4.8	4.84	4.72	4.68	4.7	4.47	4.54	4.76	
VE	0.27	0.281	0.27	0.414	0.276	0.414	0.425	0.409	0.407	0.407	
CO	5.9	5.8	5.7	5.2	5	4.7	4.7	5.8	5.3	5	
CO_2	10.8	10.9	10.9	11	10.5	11.5	10.9	10.5	11	11.2	
UHC	325	321	315	295	224	265	232	300	285	260	3100
BP	2.455	2.499	2.513	2.529	2.51	2.473	2.51	2.46	2.46	2.47	
Tq	4.69	4.77	4.82	4.85	4.8	4.69	4.74	4.62	4.59	4.75	
VE	0.272	0.279	0.269	0.418	0.274	0.428	0.446	0.408	0.405	0.404	
CO	6.6	6.9	6.5	5.7	5.6	5.1	5.5	6.7	6	5.6	
CO_2	10.2	10.4	10.5	10.6	10.3	11.2	10.6	10.3	10.6	10.6	
UHC	341	339	325	310	240	301	268	325	315	285	3000
BP	2.453	2.506	2.522	2.545	2.5	2.491	2.53	2.42	2.44	2.43	
Tq	4.68	4.79	4.81	4.86	4.77	4.64	-	4.63	4.69	4.73	
VE	0.27	0.267	0.268	0.438	0.27	0.445	0.467	0.412	0.425	0.415	
CO	7.5	7.2	6.8	6.2	6.4	6.3	6.2	7.3	6.5	6.2	
CO_2	9.8	9.9	9.9	10.2	10.1	10.6	10.7	10.1	10.3	10.5	
UHC	343	341	334	331	293	314	290	330	325	320	2900
BP	2.422	2.478	2.481	2.517	2.46	2.494	2.49	2.39	2.4	2.43	
Tq	4.62	4.76	4.78	4.81	4.7	4.62	4.69	4.57	4.67	4.71	
VE	0.265	0.262	0.265	-	0.266	0.456	0.46	0.421	0.417	0.418	
CO	8.2	8.1	7.3	7	7.2	6.8	6.7	8.1	7	6.8	
CO_2	9.3	9.3	9.5	9.7	10	10.3	10.3	10	9.8	10	
UHC	357	350	344	340	300	320	310	340	335	330	2800
BP	2.399	2.432	2.465	2.503	2.42	2.458	2.49	2.35	2.4	2.45	
Tq	4.58	4.71	4.71	4.74	4.62	4.56	4.68	4.58	4.61	4.76	
VE	0.262	0.257	0.26	0.458	0.263	0.464	0.471	0.427	0.422	0.424	
CO	8.7	8.6	8.2	7.3	8.3	7.4	7	8.6	7.7	7.2	
CO_2	8.9	8.9	9.2	9.5	9.4	9.9	10	9.4	9.5	9.6	
UHC	365	361	355	350	313	327	350	357	353	351	2700
BP	2.389	2.417	2.447	2.495	2.44	2.45	2.45	2.43	2.453	2.49	
Tq	4.56	4.66	4.63	4.67	4.67	4.62	4.62	4.59	4.6	4.56	
VE	0.255	0.252	0.277	0.467	0.252	0.473	0.47	0.43	0.43	0.43	
CO	9.2	9	8.5	7.5	8.8	7.6	7.5	9.1	8	7.8	
CO_2	8.6	8.7	8.8	9.3	9	9.3	9.8	9	9	9.5	
UHC	379	375	372	369	328	338	356	370	365	358	2600
BP	2.42	2.45	2.471	2.519	2.46	-	2.47	2.24	2.26	2.45	
Tq	4.52	4.61	4.61	4.6	4.7	4.72	4.61	4.54	4.62	4.67	
VE	0.25	0.245	0.278	0.478	0.244	0.478	0.46	0.44	0.44	0.449	

G: gasoline; E3, E7 and E10: 3,7 and 10 vol.% ethanol in gasoline; M3, M7 and M10: 3,7 and 10 vol.% methanol in gasoline; EM3, EM7 and EM10: 3,7 and 10 vol.% ethanol and methanol in gasoline; CO and CO_2 in vol.%; UHC in ppm. BP is brake power in KW, Tq is torque in Nm and VE is volumetric efficiency.

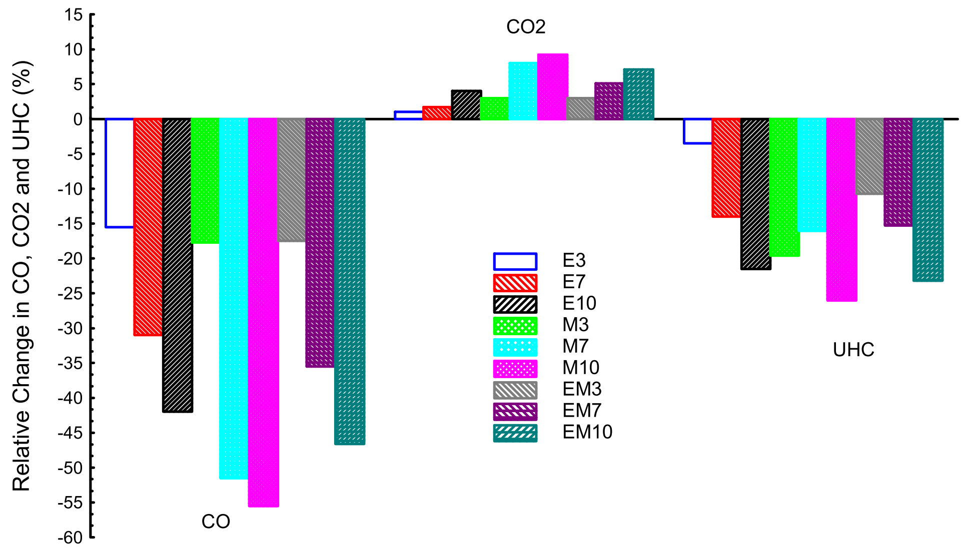

Fig. 1. Comparison of CO, CO_2 and UHC emissions from different blended fuels, captions are similar to those in Table 3.

their nature oxygen contents. When the combustion is leaner, more complete combustion and, in turn, lower emissions are achieved. In particular, the leaning effect of fuel causes the fuel burning in a shorter duration time, e.g., closer to TDC (top dead center). However, as gasoline content increases in the blends, the fuel needs larger time to be burnt and, in turn, more emissions are introduced.

The higher boiling point of gasoline fuel may also be given a precious reason for its higher CO and UHC emissions, compared to ethanol and/or methanol–gasoline blends; the boiling points of methanol, ethanol and gasoline are respectively 64, 78 and 38–204 °C, as shown in Table 1. Because a high boiling point causes that the fuel may comprise fractions or components that may not be completely vaporized and burnt, thereby increasing CO and UHC emissions. This may refer to that ethanol and methanol have single boiling point, due to having one type of hydrocarbon, however, unlike for the gasoline fuel. On the other hand, the lowest boiling point of methanol, compared to ethanol and gasoline, is another reason for providing M with the lowest emissions (CO and UHC), followed by EM and E, respectively.

One of the additional important reasons for the reductions in CO and UHC emissions and, in turn, increasing of CO_2 emissions of blended fuels are that ethanol and methanol have higher latent heat of vaporization than that of gasoline. As shown in Table 1, the latent heats of vaporization for ethanol and methanol are respectively about 2.7 and 3.6 times higher than that of gasoline; this provides a lower intake manifold temperature for the blended fuels, which had a positive effect on volumetric efficiency, as shown in Fig. 2. The higher volumetric efficiency leads to more access air in the combustion chamber and, in turn, lowers CO and UHC emissions. It can be also noticed that the volumetric efficiency of M is higher than E (the latent heat of vaporization of methanol is 1.3 times higher than that of ethanol), as shown in Fig. 2; this is another reason for cleaner combustion of M (due to its more access air) than the E fuels. The higher volumetric efficiency also leads to a higher output torque from engine at using M than that E, as shown in Fig. 2. On the other hand, EM provided moderate volumetric efficiency and torque between M and E. Furthermore, the improved antiknock behavior (due to the addition of ethanol and methanol, which raises the octane number) allowed a more advanced timing that results in higher combustion pressure and thus much higher torque and power than those of the gasoline fuel [3,35].

Based on performance and emission results as well as fuel characteristics analysis demonstrated above, one may conclude that in case of aiming at very low emissions of CO and UHC, it is recommended to use M; however, if one is interested in getting the highest output power from engine, one should use E instead

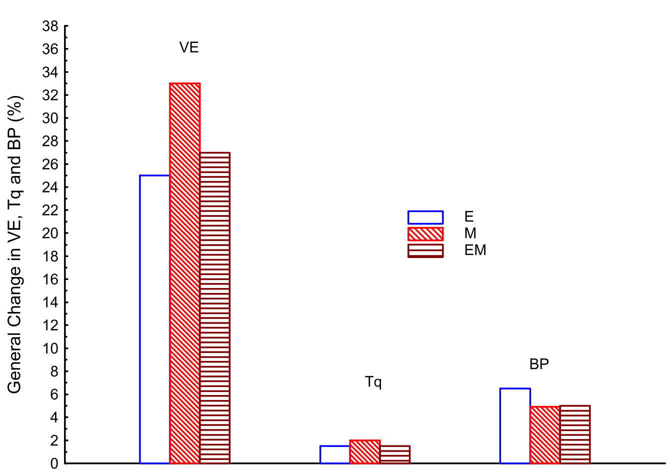

Fig. 2. General change in volumetric efficiency (VE), torque (Tq) and brake power (BP) for ethanol–gasoline blends (E), methanol–gasoline blends (M), ethanol–methanol–gasoline blends (EM) and neat gasoline (base line) in average basis.

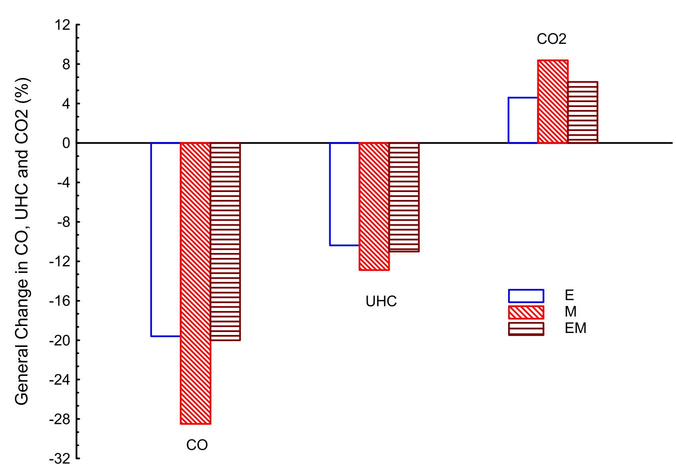

Fig. 3. General change in CO, CO_2 and UHC emissions for ethanol–gasoline blends (E), methanol–gasoline blends (M), ethanol–methanol–gasoline blends (EM) and neat gasoline (base line) in average basis.

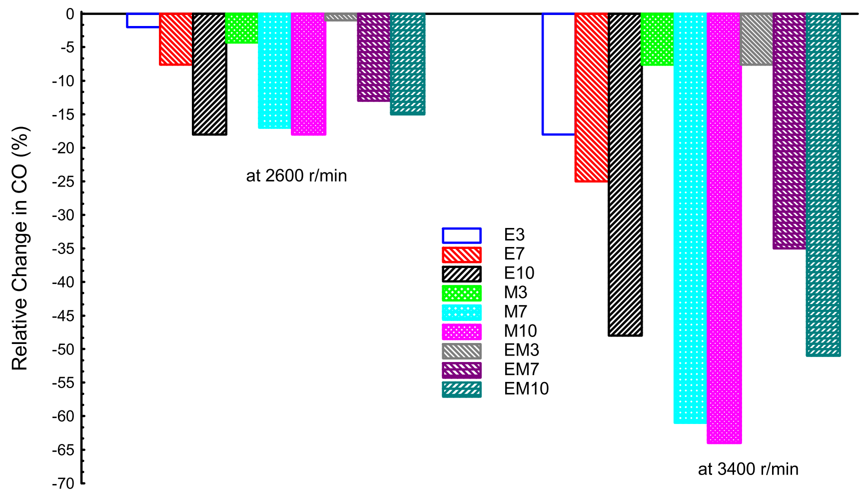

Fig. 4. Comparison of CO emissions from different blended fuels at two different speeds (2600 and 3400 r/min); captions are similar to those in Table 3.

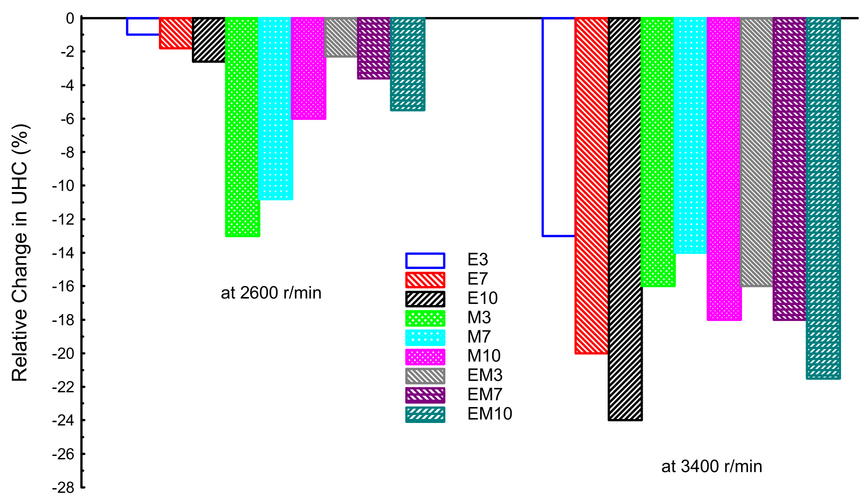

Fig. 5. Comparison of UHC emissions from different blended fuels at two different speeds (2600 and 3400 r/min); captions are similar to those in Table 3.

(heating value for ethanol is 1.3 times higher than that of methanol, as shown in Table 1, and that leads to higher Bp from E than that from M and EM). However, to get a moderate emissions of CO and UHC as well as volumetric efficiency, torque and brake power, one should use EM fuel in SI engine. The general performance and emissions trends of all test fuels are summerized in Figs. 2 and 3.

The effect of various engine speeds (2600–3450 r/min) on CO, CO_2 and UHC emissions using different blended fuels is also

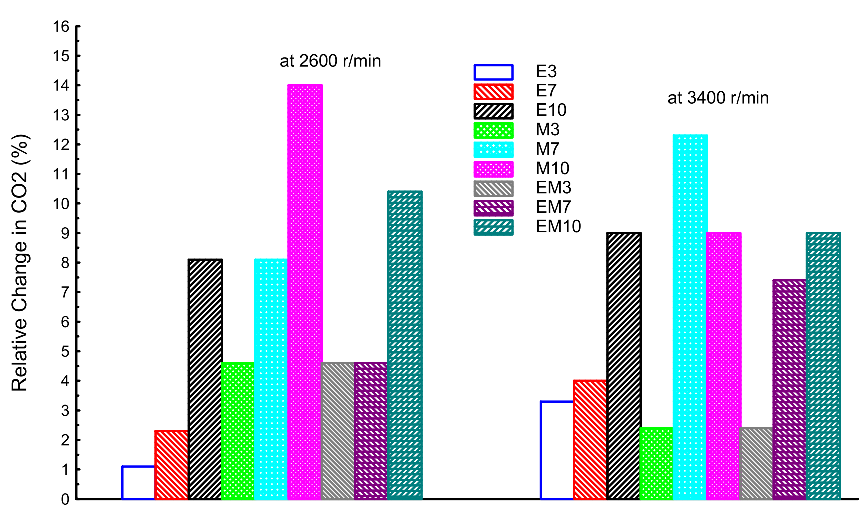

Fig. 6. Comparison of CO_2 emissions from different blended fuels at two different speeds (2600 and 3400 r/min); captions are similar to those in Table 3.

investigated, as shown in Figs. 4–6 and Table 3. As seen, for all test fuels, a decreasing in UHC and CO emissions and an increasing in CO_2 emission took place with the increasing vehicle speed. The case in point for EM blends for example at 2600 r/min, the CO and UHC emissions are respectively about 13% and 3.7%, in average, compared to neat gasoline. However, at 3450 r/min, the CO and UHC emissions for the same fuel become about 35% and 15%, respectively. Accordingly, it can be concluded that the addition of ethanol and methanol into gasoline is more efficient for getting lower emissions at high engine speeds (>3000 r/min). This refers to that the volumetric efficiency, torque and brake power are enhanced at high engine speeds, as shown in Table 3.

4. Conclusions

In this study, engine performance and pollutant emissions from different blended fuels in types (ethanol, methanol and gasoline) and rates (3–10 vol.% methanol and/or ethanol in gasoline) have been investigated experimentally. The test results indicated that ethanol–methanol–gasoline blends (EM) burn cleaner than both ethanol–gasoline blends (E) and the neat gasoline fuel (G); however, the methanol–gasoline blends (M) confirm the lowest emissions of CO and UHC among all test fuels. In numbers, the M fuels show lower CO and UHC emissions than the EM by about 5.5% and 6%, respectively; while the EM provide lower CO and UHC emissions by about 5% and 2%, respectively, compared to E; whilst, the E give a relative decrease in CO and UHC emissions by about 31% and 14%, respectively, compared to the G fuel. It was also noticed that by adding more ethanol and/or methanol to gasoline the engine produces less emissions; precisely, the CO and UHC emissions at using EM3 (3 vol.% ethanol and methanol in gasoline) are decreased by about 17% and 10%, however, they became lower by about 35% and 15% at using EM7 and they became lower by about 46% and 23%, respectively, at using EM10, compared to neat gasoline. It can be also noticed that the addition of ethanol and/or methanol to gasoline at low engine speeds is not as efficient on decreasing emissions as at high engine speeds and, in turn, blended fuels are recommended to be used at all engine speeds but especially at high vehicle speeds (>3000 r/min). Finally, this study demonstrate that if we aim to get less emissions of CO and UHC and higher both volumetric efficiency and output torque from SI engines we should use M fuels; however, if we intersetd in getting a higher output power with a bit low CO and UHC emissions, but higher than M, we should use E blends; to get a low moderate emissions of CO and UHC as well as a high moderate volumetric efficiency, torque and power, we should use EM fuels.

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