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Article

Use of Span 80 and Tween 80 for blending gasoline and alcohol in spark ignition engines

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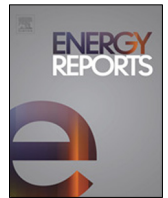
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Research paper

Use of Span 80 and Tween 80 for blending gasoline and alcohol in spark ignition engines

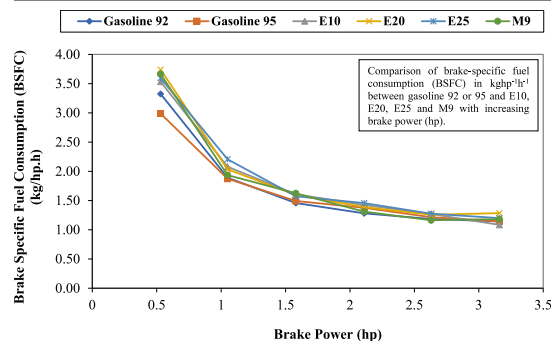
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HIGHLIGHTS

- Span 80/tween 80 mixture can be used to blend alcohol with gasoline.
- Span80/tween 80 mixture improves water tolerance of alcohol/gasoline blends.
- Span80/tween 80 mixture prevents metal corrosion in alcohol/gasoline blends.
- The resulted alcohol/gasoline blends can be used in spark ignition vehicles.
- The blends are compatible with gasoline international quality standards.

GRAPHICAL ABSTRACT



Using Span 80 and Tween 80 when blending methanol or ethanol with gasoline solves phase separation and corrosion problems. Blends containing up to 25% ethanol and 9% methanol with gasoline were created in this study. The resulting blends showed combustion efficiency in Spark Ignition (SI) engines comparable with the commercial gasolines 95 and 92.

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ABSTRACT

Span 80 and Tween 80 are biodegradable surfactants that can be added to blended fuels such as hydrated bioethanol–gasoline and methanol–gasoline. They increase the fuels' water tolerance and reduce their corrosive properties, without altering their fuel characteristics. For this study, a mixture of surfactants Span 80 and Tween 80 was added to create an emulsion and the optimum hydrophilic:lipophilic balance (HLB) was determined. The effect of this additive mixture on spark ignition (SI) engines and the resulting gas emissions were also investigated.

Four kinds of fuel mixtures were tested in this study. They were: 10% denatured (DN) ethanol mixed with 90% commercial unleaded gasoline 92 (E10); a blend of 63% commercial unleaded gasoline 92, 17% straight-run naphtha and 20% DN ethanol (E20); 75% commercial unleaded gasoline 80 and 25% DN ethanol (E25); and 9% methanol with 91% commercial unleaded gasoline 92 (M9).

The four product blends were compliant with the international standards EN-228 and ASTM-D4814. They also produced good engine performance and reduced amounts of carbon monoxide (CO) and nitrogen oxide (NO_x) emissions compared with standard fuels.

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1. Introduction

Increasing temperatures and changing weather patterns around the world are alarming climate change scientists. Great strides

were made in 2015 in the worldwide bid to address climate change. During the 21st Conference of the Parties (COP 21) to the United Nations Framework Convention on Climate Change (UNFCCC), global leaders agreed that there was a need to stop world mean temperatures increasing by more than two degrees C. This collaborative drive to stop climate change was unique; the final accord, known subsequently as the Paris agreement after the city

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in which the meeting was held, strongly encouraged every nation to assist in the attempt to accomplish this objective. The terms of the Paris agreement came into effect one year after adoption of the document, on 5th October 2016 (World Bank et al., 2016).

Burning fossil fuels emit greenhouse gases, so the Paris agreement put in place new environmental recommendations for any new fuel source. Biofuels such as bioethanol and methanol produce smaller amounts of polluting gases when burnt compared with standard fossil fuels. Consequently, these are increasingly being used in different industries.

Transport vehicles currently produce copious amounts of exhaust greenhouse gases. Bioalcohol is seen as a viable alternative fuel source to combat this problem. Mixing bioalcohol with gasoline also helps to reduce the use of fossil fuels. Nikolaus August was a German scientist who used ethanol as a fuel for internal combustion engines in 1876 (Groysman, 2014). This is a potential way to reduce pollution from old vehicles that are still being used in developing countries, such as those in Africa.

Most cars used in the developing world are fitted with SI engines that employ gasoline as a fuel. They are not compatible with methanol/ethanol–gasoline mixtures. However, if compatibility can be achieved, use of blended alcohol and gasoline would be helpful to combat increasing fuel prices and it could decrease global warming.

This study was performed in Egypt, where many of the cars are old and conversion to use of blended alcohol and gasoline would benefit the environment and the economy. However, currently there are many barriers that prevent use of blends in SI engines. Ethanol and methanol are soluble in water but demonstrate low miscibility with gasoline in the presence of trace water. Consequently, blending gasoline with ethanol or methanol in the presence of water can cause phase separation. Additives can be efficient regulators to circumvent this problem. Examples of these additives include longer chain alcohols such as iso-propanol, 1-butanol and n-decanol, and several commercial non-ionic, and anionic fatty acid, surfactants. Prevention of phase separation improves drivability and minimizes corrosion of water-sensitive engine parts composed of metals such as aluminum (Surisetty et al., 2011).

In this study, a mixture of Tween 80, which is a hydrophilic surfactant, and Span 80, a hydrophobic surfactant, was employed. First, this reduces corrosion because surfactants adhere strongly to metal surfaces, forming a barrier to ingress of water. The Span 80 and Tween 80 surfactants have hetero oxygen atoms, so they have good anti-corrosive activity in a hydrocarbon medium (Tiu and Advincula, 2015). Second, the mixture acts as an emulsifier and improves the water tolerance of the methanol/ethanol–gasoline blend. Span 80 has an HLB value of 4.3, which falls within the usual range of HLB 4–6 for water-in-oil (W/O) emulsifiers. Tween 80 has an HLB value of 15, within the range of HLB 8–18 for oil-in-water (O/W) emulsifiers.

Blends of methanol and ethanol with gasoline show reduced engine emissions compared with those produced when burning pure fossil fuels, particularly gasoline. This is because engine emissions are correlated with the oxygen content of the alcohols. Emissions are reduced despite the lower heating value of the alcohols, which decreases the engine efficiency so that more blend is required to provide equivalent engine power relative to gasoline (Awad et al., 2018).

The aim of this study is to devise an easy method to use biodegradable surfactants as additives, in order to facilitate blending of low-octane gasoline with high concentrations of DN ethanol or methanol. The goal is to solve the problems of corrosion of the engine parts and phase separation of the fuel, to produce a fuel with a more environmentally friendly, high-octane number which can be useful commercially.

2. Material and methods

2.1. Materials

Hydrous ethanol (95.0% v/v), synthesized from molasses, was bought from the International Company for Medical Industries SAE. It had the following specifications: boiling point 78.3 °C; density of 0.8098 g cm⁻³ at 20 °C; refractive index 1.3636. DN ethanol was bought from Sokar El Hawamdia (Egyptian Sugar and Integrated Industries Company SAE). It consisted of 92% v/v ethanol with 3% v/v methanol, 4.9% v/v water and 0.1% v/v bone oil. It had the following specifications: boiling point 77.8 °C; density of 0.8110 g cm⁻³ at 15 °C; refractive index 1.3636. Methanol was bought from Emethanex with density 0.7920 g cm⁻³. Commercial gasolines 95, 92 and 80 were bought from gas stations in Egypt. Straight-run naphtha, light naphtha and heavy naphtha were brought from the Alexandria National Company for Refinery and Petrochemicals (ANRPC). Tween 80 and Span 80 were bought from Loba Chemie with physical properties shown in Table 1.

2.2. Methods

2.2.1. Optimum HLB test

The first step was to find the best HLB number for the surfactant. HLB numbers 5.4, 5.9 and 6.4 were tested. Blends were prepared comprising 50 ml of gasoline 95, 50 ml of hydrated bioethanol, 3 ml of methanol and 10 ml of surfactant. Then, the blend was titrated against distilled water until the phase separation point (that is, water no longer dissolved in the blend).

The HLB numbers for Span 80 and Tween 80 surfactant mix were calculated using Eq. (1) which is given in Box 1.

The optimum HLB number was used later in tests of the DN ethanol/methanol–gasoline blends. The optimal mix between Span 80 and Tween 80 is referred to as ST80.

2.2.2. Preparation of alcohol–gasoline blend emulsion

Four different blends were prepared and tested in this study:

- E10: DN ethanol (10% vol.) and commercial unleaded gasoline 92 (90% vol.);
- E20: DN ethanol (20% vol.), straight-run naphtha (17% vol.) and gasoline 92 (63% vol.);
- E25: commercial unleaded gasoline 80 (75% vol.) and DN ethanol (25% vol.);
- M9: methanol (9% vol.) and gasoline 92 (91% vol.).

ST80 was added to each of these blends, which were then stirred at 1500 rpm for 15 min using a magnetic stirrer.

All samples used in the test car were prepared two months before usage.

2.2.3. Phase separation

The phase separation of the fuel was observed with different quantities of ST80 present to determine the best ratio of ST80:blend. Each of the four blends E10, E20, E25 and M9 was mixed with ST80 at ratios of 0.25, 0.5, 0.75 and 1.0% vol. These were kept for six months, one month at –2 °C and five months at room temperature.

2.2.4. Alcohol/gasoline blend fuel characteristics tests

A series of tests were performed.

- The research octane number (RON) was analyzed using a CFR machine (ASTM D-2699) employing a compression ratio method;
- density was measured at 15 °C according to ASTM D1298;

Table 1
Physical properties of Span 80 and Tween 80.

Surfactant appearance	Appearance	HLB (unitless)	Molecular weight (g.mol ⁻¹)
Span 80	Brown liquid	4.3	428.59
Tween 80	Amber sticky liquid	15	1309.63

$$\text{HLB (Surfactant Mixture)} = \frac{\text{Mass (Span 80)} \times \text{HLB (Span 80)} + \text{Mass (Tween 80)} \times \text{HLB(Tween 80)}}{\text{Mass (Tween 80)} + \text{Mass(Span 80)}} \quad (1)$$

Box I.

- Reid vapor pressure (RVP) was measured at 100 °F according to ASTM D323;
- copper ST corrosion (3 hrs. at 50 °C) was analyzed according to ASTM D130;
- lead content (impurities) at 15 °C gm/l was calculated according to ASTM D3237;
- the induction period was calculated according to ASTM D525;
- total paraffins, total iso-paraffins, total olefins, total naphthenes, total aromatics, C14+, and total oxygenates were all measured according to ASTM D5134;
- total sulfur was measured according to ASTM D4045;
- distillation was performed according to ASTM D86;
- vapor lock was found according to EN 228.

Scanning electron microscopy (SEM) was used to investigate the metal surfaces with a Jeol-JSM-5300 apparatus. Tests were done at ANRPC company laboratories.

2.2.5. Corrosion tests

Carbon steel alloy AISI 1020 with chemical composition given in Table 2, and aluminum alloys AA1050A with chemical composition given in Table 3, were prepared in rectangular shapes. For carbon steel AISI 1020, the area was 27.87 cm² and density was 7.87 g cm⁻³. For aluminum AA1050A, area was 6.40 cm², and density was 2.71 g cm⁻³.

The corrosion rate was determined using weight loss according to ASTM G1. The metal specimens for both alloys were immersed separately in each fuel blend E10, E20, E25 and M9 for 90 days. Then, the specimens were dried and weighed. The corrosion rate was measured using Eq. (2).

$$\text{Corrosion rate} = \frac{KW}{ATD} \quad (2)$$

where K const. = 8.76 × 10⁴, W = mass loss in grams, A = area in cm², T = time of exposure of the metal sample in hours, D = density in g cm⁻³.

2.2.6. Engine and emission tests

Both gasolines 92 and 95, used as references, and each of the four blends E10, E20, E25 and M9 were investigated for SI engine performance. Gasolines 92 was a reference for E25, and gasoline 95 was a reference for M9, E10 and E20. The technical specifications of the system are given in Table 4. The engine was connected with a water brake dynamometer and with a gas analyzer FGA4000XDS at the exhaust pipe before the catalytic converter to measure the emission gases. The quantities of hydrocarbons (HC), carbon monoxide (CO) and carbon dioxide (CO₂) were measured by non-dispersive infrared (NDIR), and nitrogen oxides (NO_x) were measured using an electrochemical cell. Emission gas measurements were made after running the car engine and slowing it down. The test room is shown in Fig. 1.

First, the lead-free gasoline 92 and 95 were tested alone as references. Then M9, E10, E20 and E25 were tested with the same

Table 2

Chemical composition of carbon steel AISI 1020.

Element	Content (%)
Manganese, Mn	0.50
Carbon, C	0.20
Sulfur, S	0.05
Phosphorous, P	0.04
Iron, Fe	Balance

Table 3

Chemical composition of aluminum AA1050A.

Element	Content (%)
Cu	0.05
Mg	0.05%
Si	0.25%
Fe	0.4%
Mn	0.05%
Zn	0.07%
Ti	0.05%
Al	Balance

Table 4

Engine technical specification.

Manufacture	Fiat
Model	126
Capacity	652 cc
No. of cylinders	2
Compression ratio	8
Idle speed	850 ± 50
Output	5.2 (kW) at 1500 rpm

procedures on the same day. Each experiment began with engine warm-up for 30 min at no-load conditions. After that the engine was accelerated to the given test speed. Then the engine was loaded with the water brake dynamometer. Data were recorded once the engine operating parameters had stabilized. Each test was repeated twice. The lubricating oil was cooled to maintain the ambient temperature and humidity throughout the test. Fuel consumption (FC) was recorded through mass measurement by electronic balance of the fuel supplied to the engine at stable operating conditions. The balance had resolution of 0.001 g. FC was measured in grams per minute, three times on average. Then the value was corrected to kilograms per hour, as seen in Eq. (3). All equipment used in the engine test had been calibrated according to ISO 9001 in Misr Petroleum's central laboratories in Cairo.

Rate of mass fuel consumption (m_f)

$$= \frac{\text{mass of fuel consumed (kg)}}{\text{time (hr)}} \quad (3)$$

2.2.7. Brake specific fuel consumption (BSFC)

Specific fuel consumption is defined as the amount of fuel consumed for each unit of brake power developed per hour. It is



Fig. 1. The test room (engine and dynamometer) connected to the gas analyzer.

Table 5

Water tolerance results for different HLB numbers of ST80.

HLB	Water tolerance in ml	Water tolerance in % volume
5.4	2.9	2.57
5.9	3.3	2.92
6.4	3.0	2.66

a clear indication of the efficiency with which an engine develops power from fuel, and it is calculated using the following equation:

$$\text{BSFC} = \frac{\text{rate of mass of fuel consumed (kg/hr)}}{\text{brake power (hp)}} \quad (4)$$

3. Results and discussion

3.1. Phase separation test

As shown in [Table 5](#), HLB 5.9 was the optimum for the blend. Therefore, HLB 5.9 was used later in tests with the blends.

The minimum optimum ratio of ST80:blend to be used was found to be: 0.5% for E10; 0.75% for M9; 1.0% for E20; and 1.0% for E25 as seen in [Table 6](#).

After six months using these ratios of ST80:blend, there was no phase separation. The four blends were observed to be clear and transparent after six months as shown in [Figs. 2–5](#).

The presence of emulsion may be due to the formation of a nano-emulsion. This is a fine oil-in-water dispersion forming droplets with a size range of 50 nm to 600 nm. In contrast with micro-emulsions which are thermodynamically stable, nano-emulsions are only kinetically stable ([Fu et al., 2010](#); [Bouchemal et al., 2004](#)). However, nano-emulsions have long-term physical stability approaching thermodynamic stability. Also, nano-emulsions can be prepared using lower surfactant concentrations ([Tadros et al., 2004](#)). Since the Span 80 and Tween 80 blends share a similar hydrophobic (monooleate) tail with different sizes of head groups, the efficiency of the mixtures used in the study were increased, and the results produced were synergistic. Better results were obtained when Tween 80 was mixed with DN ethanol and Span 80 was mixed with gasoline before they were intermixed with each other, according to the laboratory results. But industry



Fig. 2. E10 after 6 months.



Fig. 3. E20 after 6 months.



Fig. 4. E25 after 6 months.

Table 6

Water tolerance results of E10, E20, E25 and M9 for different % vol. of ST80 with HLB 5.9, (a) after one month at -2°C , and (b) after six months at room temperature.

ST80	After one month at -2°C				After six months at room temperatures			
	E10	E20	E25	M9	E10	E20	E25	M9
	Phase Separation (Yes/No)							
0.25%	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0.5%	No	Yes	Yes	Yes	No	Yes	Yes	Yes
0.75%	No	Yes	Yes	No	No	Yes	Yes	No
1.0%	No	No	No	No	No	No	No	No



Fig. 5. M9 after 6 months.

practices will dictate whether this step will be taken in a manufacturing situation and whether the extra energy consumption due to use of more than one mixer tank can be tolerated (Fu et al., 2010).

3.2. Fuel specifications according to international standards

As depicted in Table 7, E10, E20, E25 and M9 were tested in accordance with ASTM D 4814 and the European Committee for Standardization EN228. The results showed that the four blends fulfilled all the pre-requisites of the international guidelines. However, they failed in terms of C14+ and oxygenate emissions. This result was expected, since ST80 and DN ethanol/methanol had been added to the mixture. This study aims to show that the drawbacks of using DN ethanol/methanol can be managed by using ST80.

Vapor lock is related to using light oxygenates in fuel blending, and it is important that this be taken into account. The calculations related to gasolines of these units are presented in Eq. (5).

$$\text{VLI} = 10 \cdot \text{VP} + 7 \cdot \text{E70} \quad (5)$$

In this equation, VLI is the vapor lock index. According to the EN228 standard, VLI for summer time has a maximum figure of 1000 and for winter time, 1250. VP is the vapor pressure measured in kilopascals (kPa) and is determined using ASTM D323. E70 is the percentage of fuel evaporation at 70°C and is determined using ASTM D86.

$$\text{VLI of E10} = 10 \times 57.8592 + 7 \times 48 = 914.592$$

$$\text{VLI of E20} = 10 \times 61.781895 + 7 \times 47 = 946.819$$

$$\text{VLI of E25} = 10 \times 63.743 + 7 \times 50 = 987.432$$

$$\text{VLI of M9} = 10 \times 71.588545 + 7 \times 37 = 974.900$$

The volatility properties of the blend will be compared according to EN 228 international standard. It was found that VLI of E10, E20, E25 and M9 are 914.59, 946.819, 987.432 and 974.9 consecutively and that is in the safe region according to EN 228.

The volatility properties of the blends were compared according to the EN228 international standard. It was found that the VLIs of E10, E20, E25 and M9 were 914.59, 946.82, 987.43 and 974.90 consecutively. These are in the safe region according to EN228.

3.3. Corrosion studies

Since oxygen is present in methanol, ethanol and water, the blends have higher conductance rates than gasoline. These increase the rates of corrosion and therefore cause more damage to the metal components in the automobile's fuel injection system. Hence, if these blends are to be adopted for use, it will be essential to employ an organic substance that can decrease corrosion in both vapor and liquid phases, to reduce the probability of corrosion to a minimum.

3.3.1. Weight loss experiment

It was concluded that the test did not deliver precise results since immersion did not bring about any change in the weight. It can be concluded that the combination of ST80 and E10, E20, E25 or M9 does not cause any significant damage to the fuel delivery system.

3.3.2. Scanning electron microscope (SEM) analysis

SEM micrographs showing the surface morphology of the corroded carbon steel and aluminum specimens after immersion are presented in Figs. 6–7. The specimens were immersed for 90 days in a solution of gasoline with different amounts of ethanol. The micrographs demonstrate that nonionic surfactants Tween 80 and Span 80 made uniform surface films on the specimen surfaces. They show that these surfactants greatly inhibited corrosion of carbon steel and aluminum. The surfactants acted as mixed-type inhibitors because their hetero oxygen atoms exhibited anticorrosive activity in a hydrocarbon medium. At the lowest surfactant concentration required to prevent phase separation, corrosion was not observed (Jafari et al., 2010).

3.4. Engine performance test

It was found that mass fuel consumption of the E10, E20, E25 and M9 blends was greater than that of the gasoline 92 or 95 (See Fig. 8). This is because the addition of methanol/ethanol leads to a decrease in the net heating value of the blend as the heating value of methanol/ethanol is lower than that of pure gasoline (Schifter et al., 2011). However, the presence of methanol/DN ethanol in the four blends led to an increase in the engine performance octane number because ethanol and water or methanol have higher latent heats of vaporization than gasoline. So, E10, E20, E25 and M9 decreased the engine knocking (Schifter et al., 2013). Therefore, the engine consumed more E10, E20, E25 and M9 than pure gasoline to give the same equivalent engine power (Costa and Sodr , 2010).

Also, the BSFC was higher when using E10, E20, E25 or M9 compared with gasoline 92 or 95 (See Fig. 9). This is similarly because methanol/ethanol has a lower heat value than the unleaded gasoline, while water does not react at all (Topg l et al., 2006). Water

Table 7
Results of Fuel Analysis of the four blends.

Test	Method	Specification	Results			
			E10	E20	E25	M9
Appearance	Visual	Clear, Bright & free from suspended matter				
Density at 15 °C (g cm ⁻³)	ASTM D1298	0.7200–.7750	0.7548	0.7555	0.7494	0.7527
R.V.P at 100° F (kg cm ⁻²)	ASTM D323	Max. 1.02 Winter Max.0.71 Summer	0.59	0.63	0.65	0.73
Color	Visual	Reported	Yellow	Yellow	Red	Yellow
Existent gum content (mg/100ml)	ASTM D381	Max. 5.0	1.0	1.0	1.0	1.0
Research octane number (RON)	ASTM D2699	Reported	95.3	95.1	92.3	95.2
Copper ST. corrosion (3hrs at 50 °C)	ASTM D130	Max. DIV.1	1.0	1.0	1.0	1.0
Lead content at 15 °C (g.l ⁻¹)	ASTM D3237	Max. 0.005	Nil	Nil	Nil	Nil
Induction period (min)	ASTM D-525	Min. 360	> 360	> 360	> 360	> 360
Paraffins content % vol.		Reported	8.44	11.44	14.60	8.26
Iso-Paraffins content % vol.		Reported	40.27	34.60	31.32	40.72
Naphthenes content % vol.		Reported	6.67	8.46	3.04	6.75
Olefins content % vol.		Max. 2.0	1.34	0.98	1.88	1.36
Aromatics content % vol.	ASTM D5134	Max.42	32.83	23.73	23.41	33.19
Oxygenates content % vol.		Reported for the research purpose	9.94	19.80	24.76	8.96
C14+ content % vol.		Reported for the research purpose	0.51	0.99	0.99	0.76
Benzene content % vol.		Max.1.0	0.39	0.47	0.87	0.39
Total Sulfur (ppm)	ASTM D4045	Max.10	2.1	1.9	3.8	2.1
Distillation						
I.B.P °C			46	49	43	46
10% recovery °C		Max. 70	50	58	54	55
50% recovery °C	ASTM D86	Max. 120	73	100	70	83
90% recovery °C		Max. 190	152	158	136	153
F.B.P °C		Max. 210	198	201	188	200
Residue & Loss %vol		Max. 2.0	0.5	0.5	0.5	0.5

also does not add energy content to the fuel; rather, water absorbs heat to evaporate, and its presence led to an observed decrease in the compression work and in the engine power output (Schifter et al., 2013). Ethanol increases the anti-knocking characteristics of the fuel, and it makes the use of the higher compression ratio feasible as it increases the cylinder pressure and the work done on the pistons. Consequently, this leads to an increase in the engine output power. On the other hand, the low energy content of ethanol in comparison with gasoline, measured by volume or mass, leads to a higher volumetric consumption. Therefore, in these experiments, more ethanol was required to obtain the same wheel power produced by the engine, compared with gasoline (Costa and Sodr , 2011). The greater the water content, the higher the BSFC, and inversely, the lower the gasoline content, the higher the BSFC because fuel consumption increased. Therefore, the BSFC for E25 was greater than that for E20, which was greater than that for E10. It was noted that the BSFC began to decrease with increasing engine loading. This was due to increasing combustion and volumetric efficiency, which was in turn due to changes in the action of the intake valve. This remained open for a longer time and led to an increase in the amount of air entering the system (Eyidogan et al., 2010). There is a general consensus among researchers that engines operate with higher BSFC when driven by ethanol fuel relative to gasoline, as a consequence of ethanol's reduced heating value (Thangaveluac et al., 2016).

3.5. Emission gases test

Table 8 shows that CO emissions were decreased by blending gasoline with DN ethanol or methanol. This was due to the improved complete combustion. For the same reason, CO₂ emissions increased a little (Manzetti and Andersen, 2015; Hsieh et al., 2002). However, the low proportion of carbon within methanol relative to gasoline resulted in a reduced total concentration of CO and CO₂. Consequently, the table shows decreases in production of both CO and CO₂ (Dai et al., 2013). More than 80% of the research conducted into the use of blended ethanol fuel in SI engines reported decreased CO emissions (Thangaveluac et al., 2016). Around 60% of

the reports noted that CO₂ emissions increased following addition of ethanol fuel to SI engines (Thangaveluac et al., 2016).

Water and ethanol in DN ethanol, or methanol alone, all have higher latent heats of vaporization than gasoline. Therefore, they decrease the temperature at the end of the intake stroke. However, the latent heat of water is higher than that of ethanol. Hence, when water evaporates, it absorbs heat and decreases the peak temperature.

The emissions of NO_x were decreased when burning E10, E20, E25 or M9 compared with gasoline, because of inhibition of the activation of thermal NO_x mechanisms (Tunest l et al., 2002; Ivani c et al., 2005; Balki et al., 2014; Costagliola et al., 2013). Similarly, the use of methanol/DN ethanol led to lean combustion and inhibited the activation of thermal NO_x mechanisms (Dai et al., 2013; Tunest l et al., 2002). Indeed, previous work shows that the NO_x concentration depends mainly on the excess air ratio (Park et al., 2010; Niven, 2005). It has been extensively reported that reductions in NO_x emissions are associated with the addition of ethanol to SI engines (Thangaveluac et al., 2016). Hydrocarbon (HC) emissions also decrease because the high oxygen content of ethanol increases the efficiency of the combustion reactions. This is despite the presence of heavy HC from ST80 and the effect of decreased temperature on the oxidation reactions of HC (Kadota et al., 2007; Kadota and Yamasaki, 2002). More than 90 per cent of reports agree that the amount of non-combusted HC emissions is reduced through utilization of ethanol fuel blends in an SI engine, relative to gasoline (Thangaveluac et al., 2016).

On the other hand, this was not the case in this study when employing M9 or E10. This was because of their high ST80 content in comparison with the 9.0% methanol and 10% DN ethanol content respectively (Park et al., 2010; Niven, 2005). That is also why more HC emissions were observed using M9 rather than E10. The ST80 content of M9 was 0.75% vol. compared with methanol content of 9% vol. The ST80 content of E10 was 0.5% vol. compared with DN ethanol content of 10% vol.

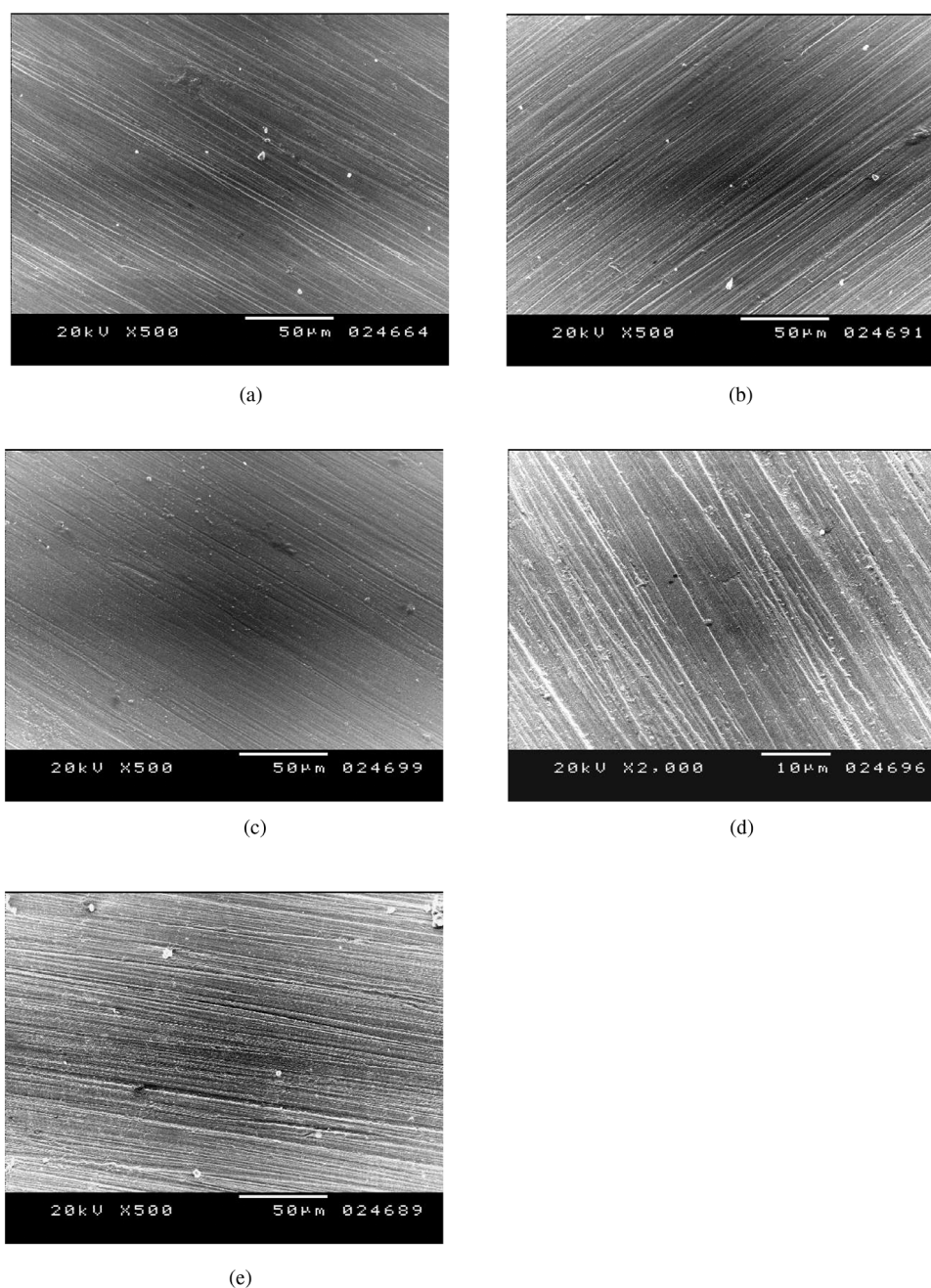


Fig. 6. Carbon steel sheet shown (a) blank, and after 90 days immersion in (b) E10, (c) E25, (d) E20 and (e) M9.

Table 8

Comparison between emission gases in gasoline 95 and E10.

Emission Gases (ppm)	HC	CO	CO ₂	NO _x
E10 (RON = 95)	138	3.16	4.36	22
E20 (RON = 95)	123	2.48	4.52	19
M9 (RON = 95)	152	3.29	4.13	23
Gasoline 95 (RON = 95)	126	3.43	4.34	25
E25 (RON = 92)	98	2.34	4.64	19
Gasoline 92 (RON = 92)	158	3.54	4.13	20

3.6. Road test

The four blends E10, E20, E25 and M9 were tested in a car (Model Shahin) with an SI engine at Misr Petroleum central laboratories in Cairo. The car was operated for about one hour using each

of the four blends separately. No knocking or high engine voice problems were noticed.

4. Conclusion

In the future, commercial gasoline in its current form will not be available because it depends on fossil fuel, use of which is planned to be phased out. Also, fuel used in transportation systems is a major cause of global warming. So it is necessary to develop alternative fuels. Bioethanol is one of these alternatives. The four blends E10, E20, E25 and M9 used in this study showed good results according to international standards for fuel used in SI engines. Addition of ST80 improved their water tolerance properties and reduced the corrosion rate. Among these, E25 with ST80 showed good performance in SI engines, with lower CO and NO_x emissions than those from commercial gasoline. The use of these four blends

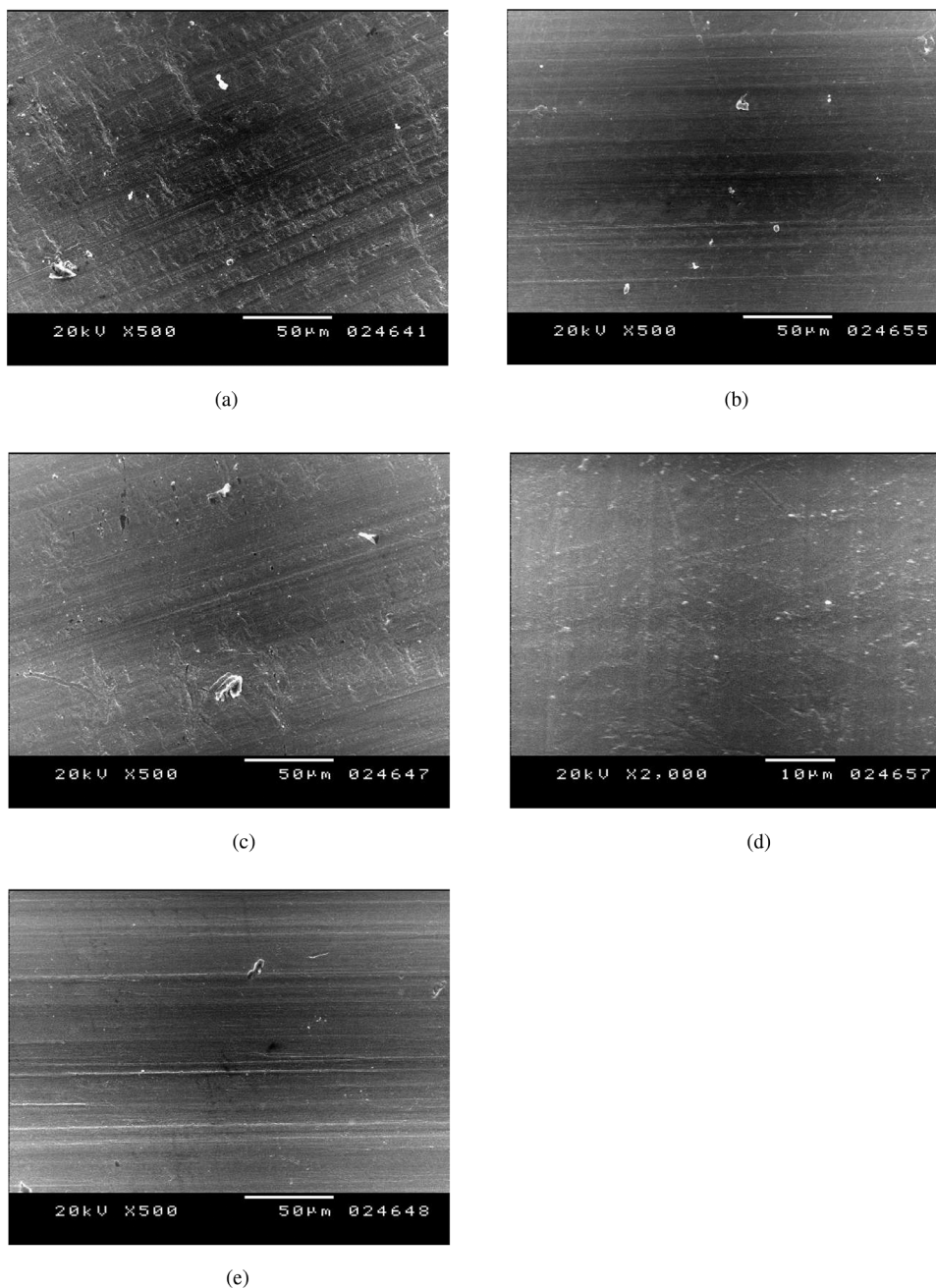


Fig. 7. Aluminum sheet pictured (a) blank, and after 90 days immersion in (b) E10, (c) E25, (d) E20 and (e) M9.

as an alternative for gasoline could help to decrease production of greenhouse gases and provide a sustainable option for the future.

These blends showed good results in a commercial old vehicle commonly used in Egypt. Therefore, using ST80 as an additive may solve problems associated with the use of bioethanol blended with gasoline, and satisfy the needs of the Egyptian market. ST80 is suitable for many kinds of vehicle in the international market.

However, government support will be required to avoid market fluctuations if such a blend is to be introduced. For example, when gasoline is cheaper than ethanol, drivers will use gasoline, but this will leave the world unprepared for future risks such as environmental impacts, fossil fuel depletion or sudden increases in gasoline prices. Furthermore, it is better to use the remaining limited fossil fuel resources in manufacturing industries such as polymer synthesis rather than burning it in the air and polluting the environment.

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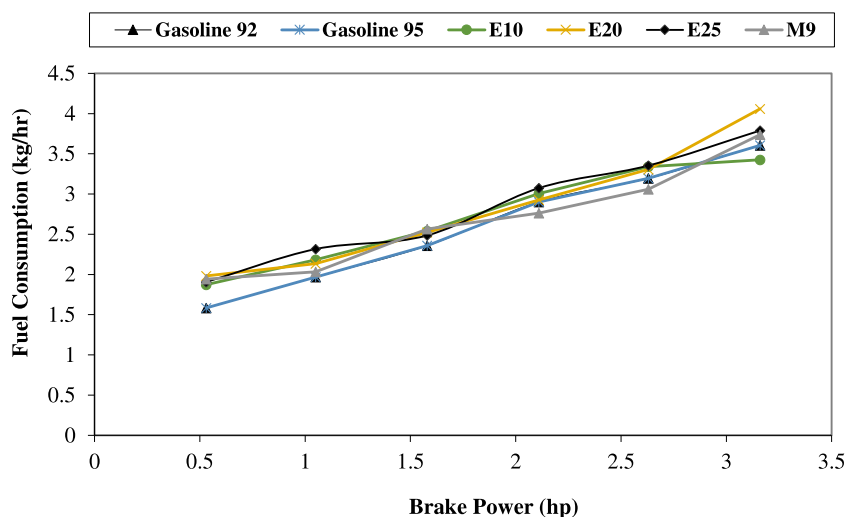


Fig. 8. The effect of increasing brake power (hp) on fuel consumption (kg hr^{-1}) for gasoline 92, gasoline 95, E10, E20, E25 and M9.

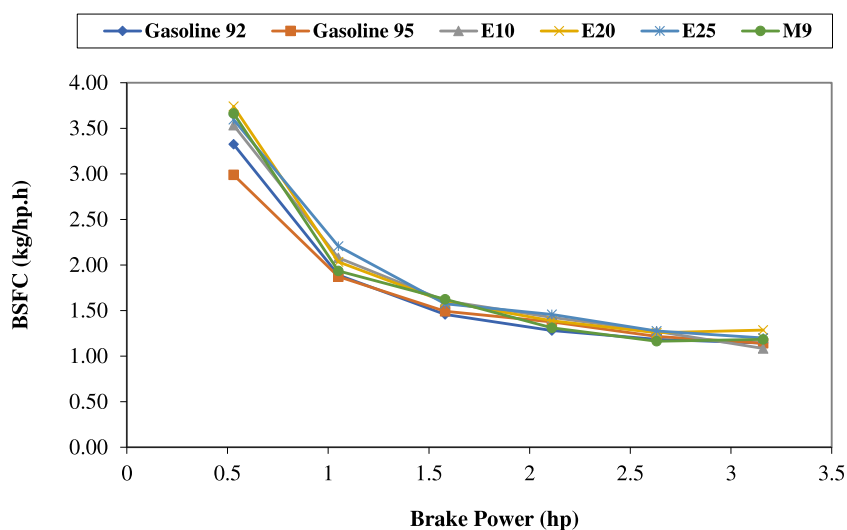


Fig. 9. The effect of increasing brake power (hp) on BSFC ($\text{kg hp}^{-1}\text{h}^{-1}$) for gasoline 92, gasoline 95, E10, E20, E25 and M9.

Declarations of interest

None.

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