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COMPARATIVE INVESTIGATION THE USE OF METHANOL AND METHYL TERTIARY BUTYL ETHER IN GASOLINE ON ENGINE PERFORMANCE, CO EMISSIONS AND FUEL COST

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Abstract: This study is concerned with investigating experimentally the effects of methanol and Methyl tert-Butyl Ether (MTBE) blending to base gasoline on the performance CO emissions and fuel cost of a spark ignition (SI) engine. The fuel blends were prepared by addition 5, 10, 15, and 20 vol % of methanol and MTBE with a specified amount of base gasoline. The methanol- and MTBE-gasoline blends were designated as M5, M10, M15, M20, and MTBE5, MTBE10, MTBE15, MTBE20, respectively. Experiments were conducted under various engine speeds, spark timings (STs), and compression ratios (CRs). The engine was operated under wide-open throttle conditions. The results of the study showed that the M5 and MTBE10 blends yield the best engine performance in terms of the brake mean effective pressure (bmep), while the M20 and MTBE15 blends are the best performers in terms of brake thermal efficiency (bte). Moreover, M20 and MTBE10 blends give the minimum CO emission values. The economical analysis performed in the study is based on both the current blending fuel prices in Turkey and brake specific fuel consumption (bsfc) of the engine while using gasoline, methanol-gasoline, and MTBE-gasoline blends. It was obtained that, in contrast to the improvement of engine performance, efficiency and CO emissions, methanol and MTBE blends caused increases in fuel costs because of the expensive methanol and MTBE prices in Turkey. Uncertainty analysis was also performed in this study, and it was found that; the uncertainties in the measurement devices do not have noticeable influences on the variations of engine characteristics.

Keywords: Oxygenates, Fuel additives, Methanol blends, MTBE blends, SI engine performance, CO emissions.

BENZİNE METANOL VE MTBE KATILMASININ MOTOR PERFORMANSINA, CO EMİSYONUNA VE YAKIT FİYATINA ETKİLERİNİN KARŞILAŞTIRMALI OLARAK İNCELENMESİ

Özet: Bu çalışmada, metanolün ve metil tersiyer bütil eterin (MTBE) benzine katılmasının buji ateşlemeli motorun performansına, karbon monoksit (CO) emisyonuna ve yakıt fiyatına etkileri deneysel olarak incelenmiştir. Yakıt karışımları metanol ve MTBE'nin farklı hacimsel oranlarda (%5, 10, 15, 20) belirli bir hacimdeki benzine katılmasıyla hazırlanmıştır. Böylece metanol-benzin karışımları M5, M10, M15, M20 ve MTBE-benzin karışımları MTBE5, MTBE10, MTBE15, MTBE20 şeklinde adlandırılmıştır. Deneyler, tam gaz durumunda, değişken devir sayılarında, farklı sıkıştırma oranı ve farklı ateşleme avansı değerlerinde gerçekleştirilmiştir. M5 ve MTBE10 karışımları en iyi ortalama efektif basınç değerlerini (dolayısıyla en yüksek güç ve moment değerlerini) verirken M20 ve MTBE15 karışımları en iyi efektif verim değerlerini (dolayısıyla en düşük özgül yakıt tüketimi değerlerini) vermiştir. Aynı zamanda M20 ve MTBE10 karışımları ile en düşük CO emisyonu değerleri elde edilmiştir. Sunulan çalışmada Türkiye'deki güncel fiyatlara ve yakıt karışımlarının özgül yakıt tüketimi değerlerine dayalı bir maliyet analizi yapılmış olup metanol ve MTBE karışımlarının fiyatları Türkiye'de metanol ve MTBE fiyatlarının yüksek olması sebebiyle benzine göre yüksek çıkmıştır. Ayrıca, deneysel sonuçların güvenirliğini göstermek için çalışmada belirsizlik analizi uygulanmış ve ölçüm cihazlarından kaynaklanan belirsizliklerin motor karakteristiklerini öenmli ölçüde etkilemediği görülmüştür.

Anahtar kelimeler: Oksijenatlar, Yakıt katkıları, Metanol karışımları, MTBE karışımları, Buji ateşlemeli motor performansı, CO emisyonu.

NOMENCLATURE

AEC	ir excess coefficient [-]
AFR	air-fuel ratio [kg air/kg fuel]
bmep	brake mean effective pressure [kPa]
bsfc	brake specific fuel consumption [kg fuel/kWh]
bte	brake thermal efficiency [%]
CAD	crank angle degree [°]
CR	compression ratio [-]
f	price of unit volume of fuels [$/L]
F	cost of fuel or fuel blends per kWh [$/kWh]
LHV	lower heating value [kJ/kg]
M_d	moment or torque [Nm]
n	engine speed [rpm]
N_e	brake power [kW]
P_0	ambient pressure [MPa]
ST	spark timing [°]
T_0	ambient temperature [K]
U	uncertainty [%]
Greek letters	
ρ	density [kg/m^3]
ω	angular speed [1/s]
Subscripts	
s	stoichiometric
g	gasoline

INTRODUCTION

Fossil fuels continue to be the main source of energy for domestic heating, power generation and transportation. The combustion of such fuels in various combustion systems, however, emits many harmful pollutants, which endanger the survival of life in our planet (Al-Baghdadi, 2000). These pollutant emissions have direct and indirect effects on people, buildings, agriculture and ecosystems etc. (Kolke and Walsh 2002; Mierlo et al., 2003). Transportation vehicles have a significant portion in global energy consumption and environmental pollution. Additionally, fossil fuel reserves are becoming exhausted at an alarming rate, and prices of fossil fuels used for transportation are increasing gradually (Kowalewicz and Wojtyniak, 2005; Piel, 2001; Das et al., 2000). Global concern on the oil crises in the 1970s, the rise in awareness of environmental issues, future energy security, vehicle pollutant emissions, and fuel conservation goals have increased interest in moving away from petroleum fuels for transportation and toward alternative fuels and advanced technologies (Lofgren and Hammar, 2000; Johansson, 1999; Ogden et al., 2004). The favorable alternative fuels should be abundant, cheap to compete by conventional fuels and they can be replaced with or be added to conventional fuels to decrease the dependency on petroleum based fuels. Oxygenated fuels, which have certain high-octane oxygen-containing organic compounds, are a good choice among the various alternative fuels. Oxygenates include a wide range of alcohols and ethers but, methanol, ethanol, and methyl tert-butyl ether (MTBE) are the most commonly used oxygenates (Huang et al., 2000; Nadim et al., 2001; Sezer and Bilgin, 2008). Methanol, for example, can be produced from coal, natural gas, biomass, and even combustible trash and municipal wastes. Producing of methanol from coal is hopeful, because the coal is the most abundant energy resource in the world that could supply our future fuel needs in the long term (Harrington and Pilot, 1975). Excellent combustion properties, to be the cheapest alcohol fuel per calorific unit, and having mostly eliminative problems make the methanol a strong alternative fuel for SI engine applications (Harrington and Pilot, 1975; Ingamells and Lindquist, 1975; Abu-Zaid et al., 2004). Methanol can be used as pure or fuel additive in gasoline to improve its properties. On the other hand, methyl tert-butyl ether ($C_5H_{12}O$) is manufactured via chemical reaction of isobutylene (C_4H_8) and methanol (CH_4O), it is more suitable as a gasoline additive to improve its octane quality and ensure the cleaner combustion (Sezer and Bilgin, 2008; Aboul-Fotouh, 2004). It is clearly evident that the addition of methanol or MTBE to gasoline is one of the most effective methods to improve octane quality of gasoline and reduction of pollutant emissions.

For these reasons, there are numerous studies on the use of pure methanol in SI engines and methanol or MTBE as a blending agent in gasoline (Harrington and Pilot, 1975; Ingamells and Lindquist, 1975; Abu-Zaid et al., 2004; Song et al., 2007; Al-Farayedhi et al., 2000; Hamdan and Al-Subaih, 2002; Poulopoulos and Philippopoulos, 2000). But, there has been a scarcity in literature on the economic analysis based on both “fuel prices” in the market and “fuel consumption” of the engine. In some countries, like China, methanol can be the cheapest alternative liquid fuel per calorific unit (Liao et al., 2006). Therefore, blending methanol to gasoline could not make any negative effect on the consumed fuel price. But, in some other countries, like Turkey, the price of the methanol is almost 5 times expensive than gasoline per liter. Thus, even though the fuel consumption of the engine decreases, the cost of the fuel blend can increase because of the high methanol price. Therefore, an economic analysis, based on blending fuel prices and engine fuel consumption, should be carried out in the studies about using of various fuel blends in engines. The aim of this study is to perform an economical analysis in addition to the performance and CO emissions analysis of an SI engine using gasoline-methanol and gasoline-MTBE blends. The uncertainty analysis was also performed in the study that has mostly not considered in the experimental studies on internal combustion engines.

EXPERIMENTAL SECTION

Properties of the Fuels

In this study, methanol and MTBE having a purity of 99.9% were used as fuel additives. The properties of methanol, MTBE, and gasoline are given in Table 1.

Table1. Properties of the fuels.

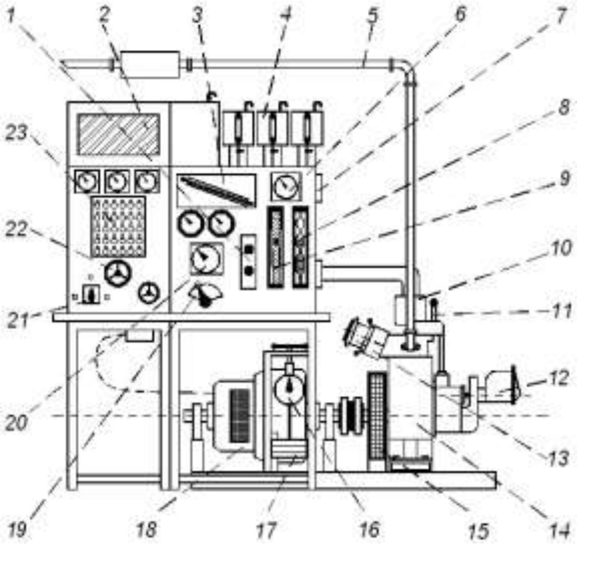
Property	Base	Methanol	MTBE
Chemical formula	$C_{6-8.3}H_{13.1-18}$[a]	CH_3OH	$C_5H_{12}O$
Molecular mass (kg/kmol)	86–115[a]	32.04	88.15
Oxygen percent (mass %)		50	18.2
Density (kg/m^3)	710–740[a]	793	758
Boiling temperature (°C)	26.7–225[a]	64.9	55
RVP (kPa)	41–103[b]	34[b]	7.8
Latent heat of vap. (kJ/kg)	300–350[a]	1160	340
Low heating value (kJ/kg)	43075[c]	20000	35200
AFR$_s$ (kg/kg)	14.5[d]	6.47[d]	11.76
RON	91[a]	111	117
MON	80[a]	92	101

[a]From catalogue of Turkish Petroleum Office Company, [b]from (Piel, 2001), [c]from tests performed in Department of Chemistry at KTU.

The fuel blends were prepared by adding 5, 10, 15, and 20 vol % of methanol and MTBE separately to a certain amount of base gasoline. The blends were prepared just before starting the experiments to obtain a homogenous mixture and prevent phase separation.

Experimental Setup and Test Procedure

The test bed consists of a test engine, the measurement instruments, and a control panel. The engine used in the experiments is a single cylinder, variable compression, four-stroke engine, which can operate as an SI engine or compression ignition engine by replacing the engine head. The schematic layout of experimental setup is given in Fig. 1 and the major specifications of the test engine are given in Table 2.



1. Start/stop
2. Electric resistances
3. Inclined manometer
4. Fuel tanks
5. Exhaust pipe
6. Tachometer
7. Orifice meter & surge tank
8. Fuel flow meter
9. Rotameter
10. Carburetor
11. Decompression lever
12. Ignition module
13. Compression ratio changing unit
14. Test engine
15. Flywheel
16. Weighing device
17. Balancing weights
18. Electrical motor/dynamometer
19. Throttle controller
20. Exhaust gas thermometer
21. Motor/generator selector
22. Loading rheostat
23. Loading keys

Figure 1. The schematic layout of experimental setup.

Table 2. Engine specifications.

Cycle	four stroke
Cooling system	water cooled
Number of cylinders	1
Bore × stroke	90 mm × 120 mm
Displacement volume	763.4 cm^3
Compression ratio	Variable (7.5 to 24.5)

The test engine is coupled to an electrical dynamometer, which is used to load the engine and measure the engine output torque. A calibrated burette and stopwatch were used to measure the engine fuel consumption. The mass flow rate of air was measured by means of an orifice and an inclined manometer. The ambient pressure and temperature of the test room were measured by using a barometer and thermometer, respectively. The experiments have been performed for the CRs of 7.5, 8, 8.5, and STs of 7.5, 10, 12.5o before top dead center (BTDC). The engine was operated at wide open throttle (WOT), and engine speed was varied from 900 to 1600 rpm. The carburetor setting, which was initially adjusted for base gasoline, was not varied throughout the experiments. The experimental data was recorded after the engine had reached the steady operation conditions. The brake torque, volume flow rate of fuel, mass flow rate of air and CO emissions were measured during the experiments. Experimental calculations are presented in the next section, and further details can be found in Sezer (2002), Bilgin et al. (2002).

CALCULATIONS

Performance Parameters

The brake power of the engine was calculated using following formula:

$$N_{\mathrm{e,1}} = M_{\mathrm{d}}\omega \tag{1}$$

where, $\omega = \pi n/30$ is angular speed of the crankshaft.

The calculated brake power was converted to the standard atmospheric conditions by taking into account the humidity of air as

$$N_{\mathrm{e}} = N_{\mathrm{e,1}} \frac{0.1013}{P_0} \sqrt{\frac{T_0}{293}}\, X_{\mathrm{hum}} \tag{2}$$

The humidity correction factor, X_{hum}, in Eq. 2 was determined from psychometric chart by considering the dry and wet thermometer bulb temperatures.

The stoichiometric air-fuel ratio and lower heating value of the blends are determined as

$$\mathrm{AFR}_{\mathrm{s,blend}} = \frac{\sum x_i \rho_i \mathrm{AFR}_{\mathrm{s},i}}{\sum x_i \rho_i} \tag{3}$$

$$\mathrm{LHV}_{\mathrm{blend}} = \frac{\sum x_i \rho_i \mathrm{LHV}_i}{\sum x_i \rho_i} \qquad (4)$$

where the subscript i refers to the blending components, i.e., gasoline, methanol or MTBE, and x_i refers to the volume ratio of the blending components in the fuel blend.

Economical Analysis

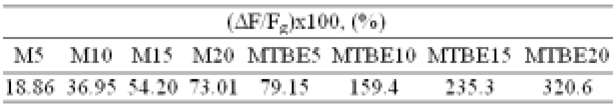
As mentioned in the introduction, there are many studies in the literature about the effects of blends on engine performance, but there is a scarcity about economic analysis based on both fuel price and fuel consumption of the engine. Since the fuel prices differ widely in the market, even though the blends give lower fuel consumption than base fuel, the total cost can be increase according to the price of the blending agent. For this reason, it should be carried out an economic analysis based on both fuels' price and fuel consumptions of the engine. The relationship originally developed by Durgun (2002) and given by Şahin and Durgun (2007) is very suitable in this respect, and it was used in this study:

$$\frac{\Delta F}{F_g} \times 100 = \left\{ \frac{bsfc_{\mathrm{blend}}}{bsfc_{\mathrm{g}}} \left(\frac{\sum x_i r_i}{\sum x_i s_i} \right) - 1 \right\} \times 100 \qquad (5)$$

In Eq.5 r_i and s_i are the ratios of prices per liter and densities of the blending agents to the base fuel, respectively.

Considering the current prices of base gasoline, Merck pure grade methanol, and MTBE in Turkey as \$2.3/L, \$11.5/L and 40 \$/L, respectively, the determined increment ratios in the costs for fuel blends compared to gasoline have been given in Table 3.

Table 3. Increment ratios in the costs for fuel blends.



$(\Delta F/F_g)$x100, (%)							
M5	M10	M15	M20	MTBE5	MTBE10	MTBE15	MTBE20
18.86	36.95	54.20	73.01	79.15	159.4	235.3	320.6

These results show that blending either methanol or MTBE to gasoline seems uneconomic because of too high prices for these blending agents currently in Turkey.

Uncertainty Analysis

The results of the experiments calculated from several measured physical quantities generally have certain uncertainties. Therefore, the results have uncertainties because of the uncertainties in the primary measurements. The method used for estimating the uncertainties in this study was developed by Kline and McClintock, and given in (Holman, 2001; Kostic, 2003). According to this method, if the result R is a function of the independent variables x_1, x_2…, x_n, it can be expressed as

$$R = R(x_1,\ x_2, \cdots, x_n) \qquad (6)$$

Then, the uncertainty in the result U_R can be calculated using the following root-sum-of-the-squares rule

$$U_R = \sqrt{U_{R,1}^2 + U_{R,2}^2 + \cdots + U_{R,n}^2} = \sqrt{\sum_{i=1}^{n} U_{R,i}^2} \qquad (7)$$

The $U_{R,i}$ values in the above equation, corresponding to the uncertainties of each measured quantity x_i, are determined as follows:

$$U_{R,i} = \left| \frac{\partial R}{\partial x_i} \right| U_i \qquad (1 \le i \le \mathrm{n}) \qquad (8)$$

The above approximation is also called as partial uncertainty in the result because of the dependence on a measured quantity x_i and its uncertainty U_i.

The uncertainty in the torque, for example, comes from the measured force and the length of the moment arm, which have uncertainties of ± 0.5 N and ± 1 mm, respectively. The calculated uncertainty in the brake torque becomes 0.005% from these uncertainties for the test engine. Variations of the whole uncertainties with respect to engine speed were given in Table. 4. It should be noted that the computed uncertainties do not have noticeable influences on the variation of the engine characteristics.

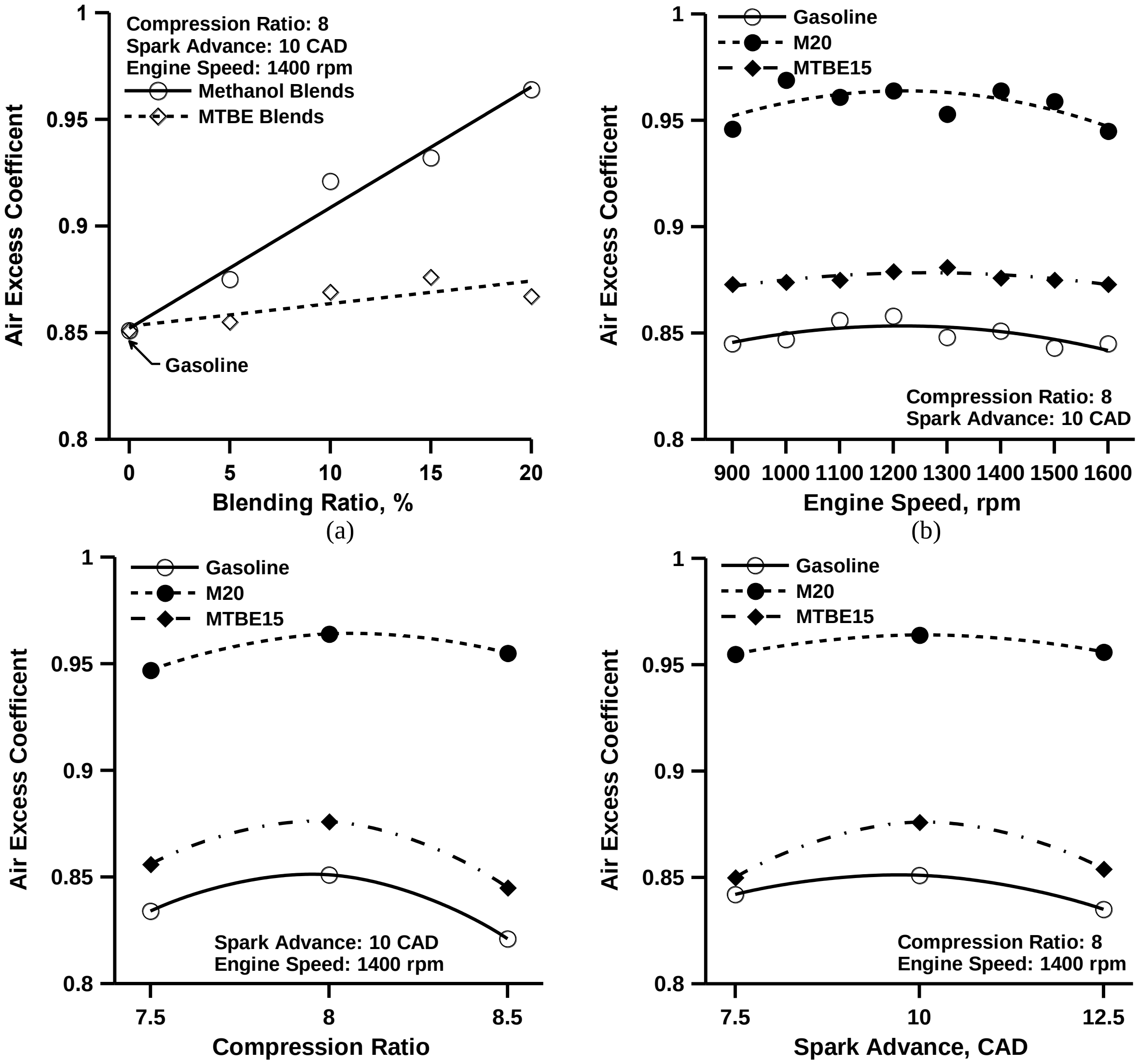
Table 4. Variation of uncertainty values to engine speed.

n	Uncertainty values				
(rpm)	M_d (%)	N_e (%)	*bmep* (%)	*bsfc* (%)	*bte* (%)
900	0.005	0.456	0.618	0.885	0.913
1000	0.005	0.454	0.616	0.959	0.994
1100	0.005	0.450	0.613	1.036	1.079
1200	0.005	0.447	0.611	1.114	1.167
1300	0.005	0.443	0.608	1.206	1.270
1400	0.005	0.442	0.607	1.287	1.361
1500	0.005	0.444	0.609	1.355	1.440
1600	0.005	0.447	0.611	1.422	1.517

RESULTS AND DISCUSSION

Air Excess Coefficient (AEC)

Variations of the AEC with blending ratio, engine speed, CR, and ST were given in parts a-d of Fig. 2, respectively. As shown in Fig. 2a, AECs increase with increasing ratio of blending agents. The increase in AEC with increasing methanol percentage can be attributed to both "cooling" and "leaning" effects of methanol. As seen in Table 1, the latent heat of vaporization of methanol is considerably higher than that of gasoline and MTBE. The addition of methanol to base gasoline results in an increase in the latent heat for the methanol blends, which results in a cooler, and hence, denser charge induced. Additionally, methanol has a lower stoichiometric AFR than gasoline because of the oxygen content in its basic form. On the other hand, increase in AEC with addition of MTBE can be attributed to only its “leaning” effect because of the MTBE has almost the same latent heat of vaporization with gasoline. Since oxygen content of MTBE in molecular form is lower than methanol, increase in AEC with increasing blending ratio becomes lesser than methanol. The dependency of AECs on engine speed is shown in Fig. 2b for M20 and MTBE15 blends, as the best performers in terms of bte, for a CR of 8 and ST of 10° BTDC. The M20 blend has quite higher AEC values than those of MTBE15 and gasoline for all engine speeds. The higher ACEs were obtained generally at the middle engine speeds. For the same blends, variations of AECs as a function of CR and ST are given in Fig. 2c and d, respectively. Similar variations can be also observed from these figures.



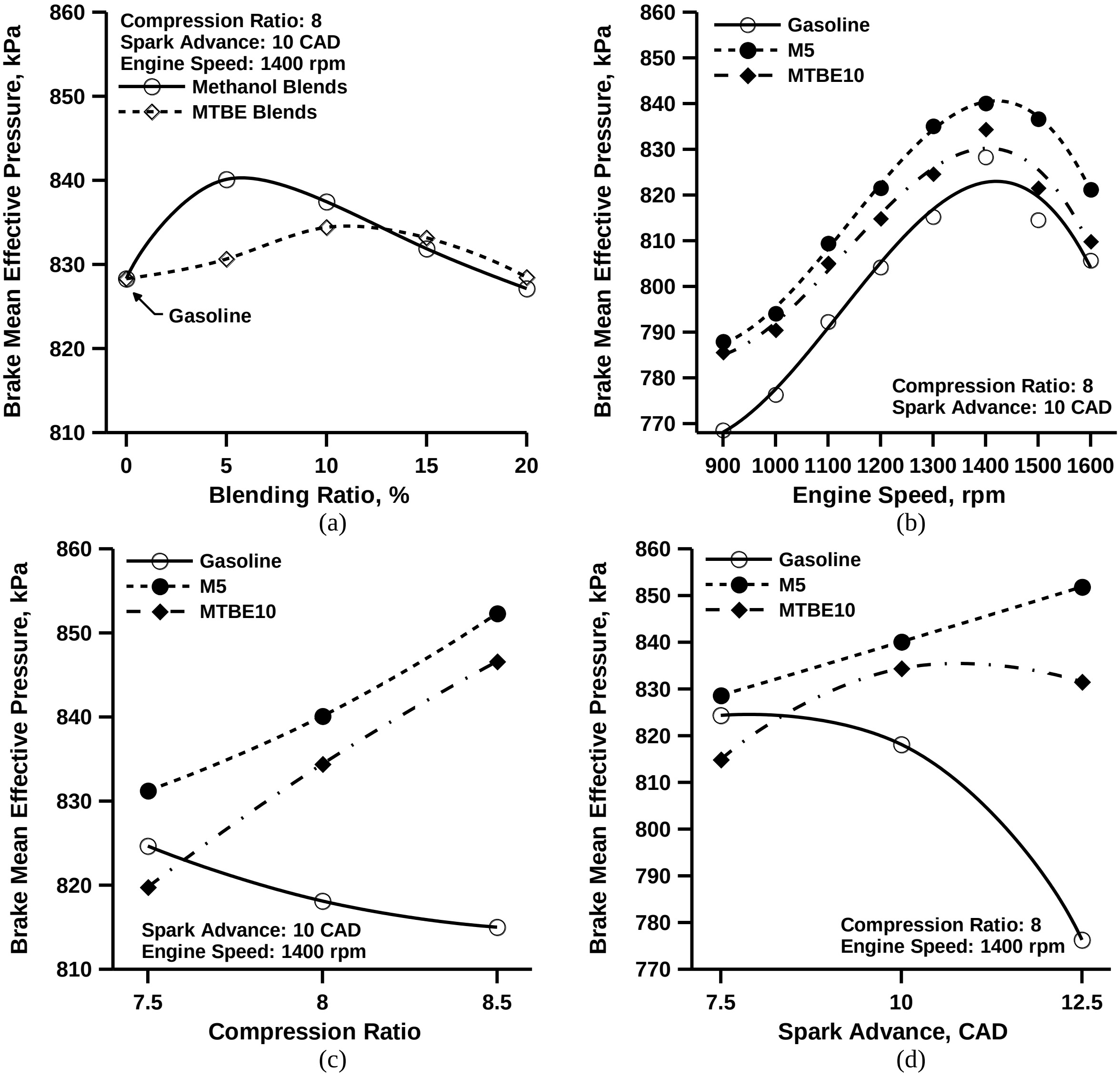
(a) (b)

(c) (d)

Figure 2. Variations of AEC for various operating conditions.

Brake Mean Effective Pressure (bmep)

Variations of the bmep with blending ratio, engine speed, CR, and ST were given in parts a-d of Fig. 3, respectively. Here, bmep is preferred as an engine output parameter because it enables to compare the results without considering the engine dimensions. For the methanol blends, bmep increases with increasing methanol ratio up to 5%, and then it starts to decrease. For the MTBE blends, however, bmep increases until 10% MTBE ratio and after the peak value at MTBE10 blend it starts to decrease, similar to methanol. Thus, the best performance was acquired with the M5 and MTBE10 blends in terms of bmep among the all tested blends. Fig. 3b shows the variations of bmep values with engine speed for a CR of 8 and ST of 10° BTDC. The M5 blend gave the highest bmep values for all engine speeds, while gasoline gives the lowest ones. The increases in bmep for methanol and MTBE blends can be attributed to improving of combustion efficiency. The leaning of cylinder charge by using blended fuels makes the combustion to be more complete. The presence of oxygen in methanol and MTBE also assists to homogenize the fuel-air mixture in the cylinder and, therefore, combustion efficiency improves. However, further methanol and MTBE addition cause to decrease in energy content of the blend and this results in decrease in bmep because of the domination of the lower calorific value of methanol and MTBE over the gain of improved combustion efficiency. The effects of the CR on bmep were given in Fig. 3c. As expected, increases in CR result in increases in bmep for M5 and MTBE10 blends, while bmep decreases with increasing CR for gasoline. The lower octane rating of gasoline causes to knocking combustion as CR increases. It is well known that knocking combustion in an SI engine causes a very high rate of energy release, and excessive temperatures and pressures in the cylinder. Therefore, it adversely affects performance and efficiency of the engine. The variations in bmep with respect to ST were given in Fig. 3d. As seen in this figure, gasoline gives almost equal performance to M5 and MTBE10 blends at lower spark advance. On the other hand, the blends gave the best performances for the higher values of STs. These variations in bmep depending on ST can be based on octane number of fuels like above explanations on CR. The noticeable result that can be concluded from Fig. 3 is that the M5 and MTBE10 blends give the best bmep values for the operating conditions specified in the figure. The increments in bmep values obtained with M5 and MTBE10 blends are about 1.4 and 0.7%, respectively, in comparison with that of gasoline.



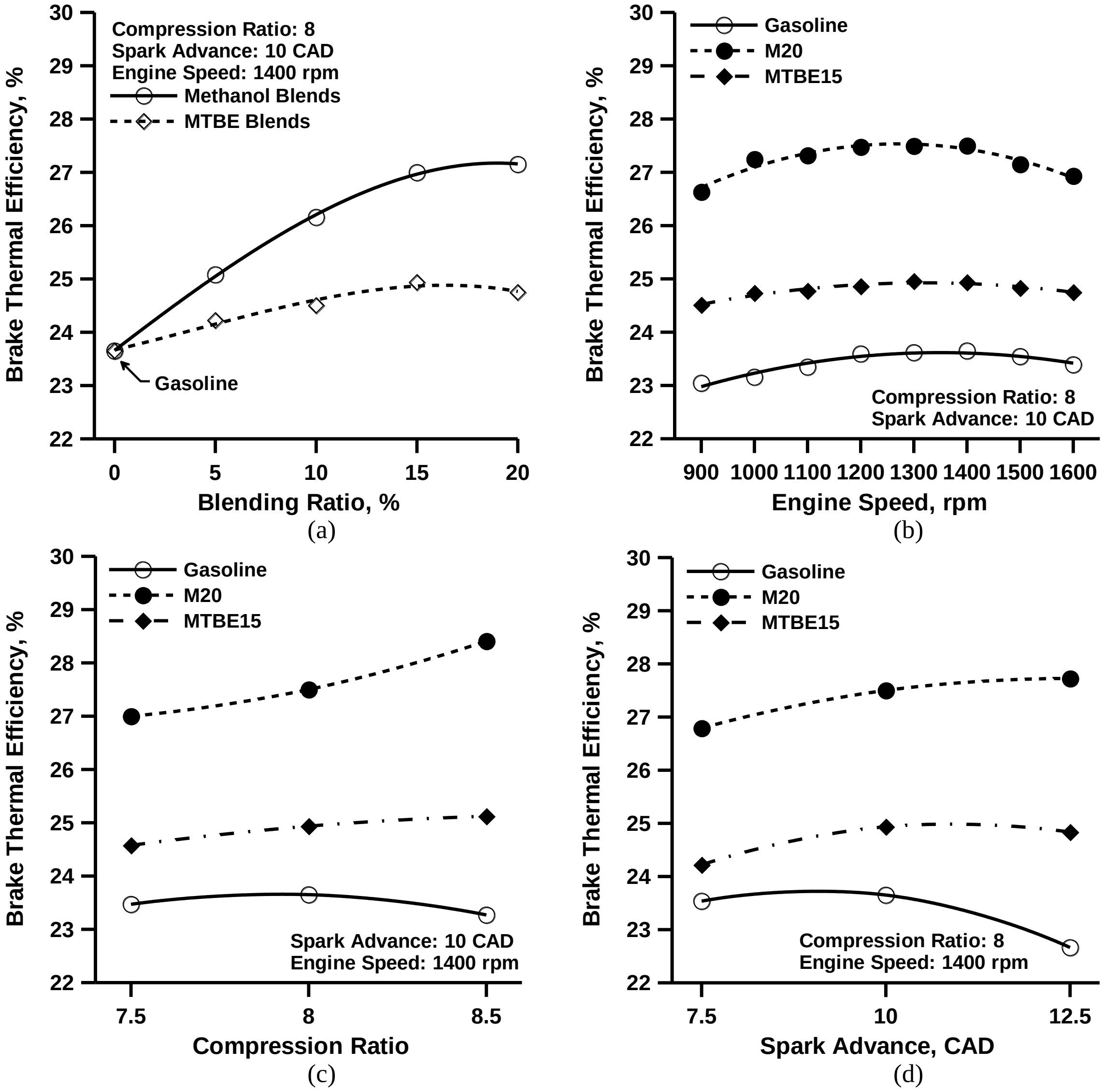
(a) (b)

(c) (d)

Figure 3. Variations of bmep for various operating conditions.

Brake Thermal Efficiency (bte)

Variations of the bte with blending ratio, engine speed, CR, and ST were given in parts a-d of Fig. 4, respectively. As shown in Fig. 4a, bte values increase with increasing blending ratio up to 20% for methanol and 15% for MTBE. Thus, the M20 and MTBE15 are the best performers among methanol and MTBE blends, respectively. Methanol blends have higher bte values than MTBE blends for all blending ratios. The worst bte is obtained with gasoline. The dependency of the bte to engine speed for M20, MTBE15, and gasoline was shown in Fig. 4b for a CR of 8 and an ST of 10^o BTDC. The M20 gives the highest bte values, while gasoline has the lowest ones for the speed range tested. Variations of bte values with respect to CR were given in Fig. 4c. The bte values increase with increasing CR for the M20 and MTBE15 blends. Lower knock resistance of gasoline compared to the blends causes the reduction in bte as a result of the knocking combustion. Variations in bte values with ST were given in Fig. 4d. As is known, increases in ST beyond an optimum value lead to knocking combustion gradually. In this study, this tendency was observed at spark timing of 12.5^o BTDC, especially for gasoline. There were no significant reductions observed in bte values for M20 and MTBE15 blends. The increments in bte obtained with M20 and MTBE15 blends are about 14.8 and 4.6% compared to gasoline, respectively.



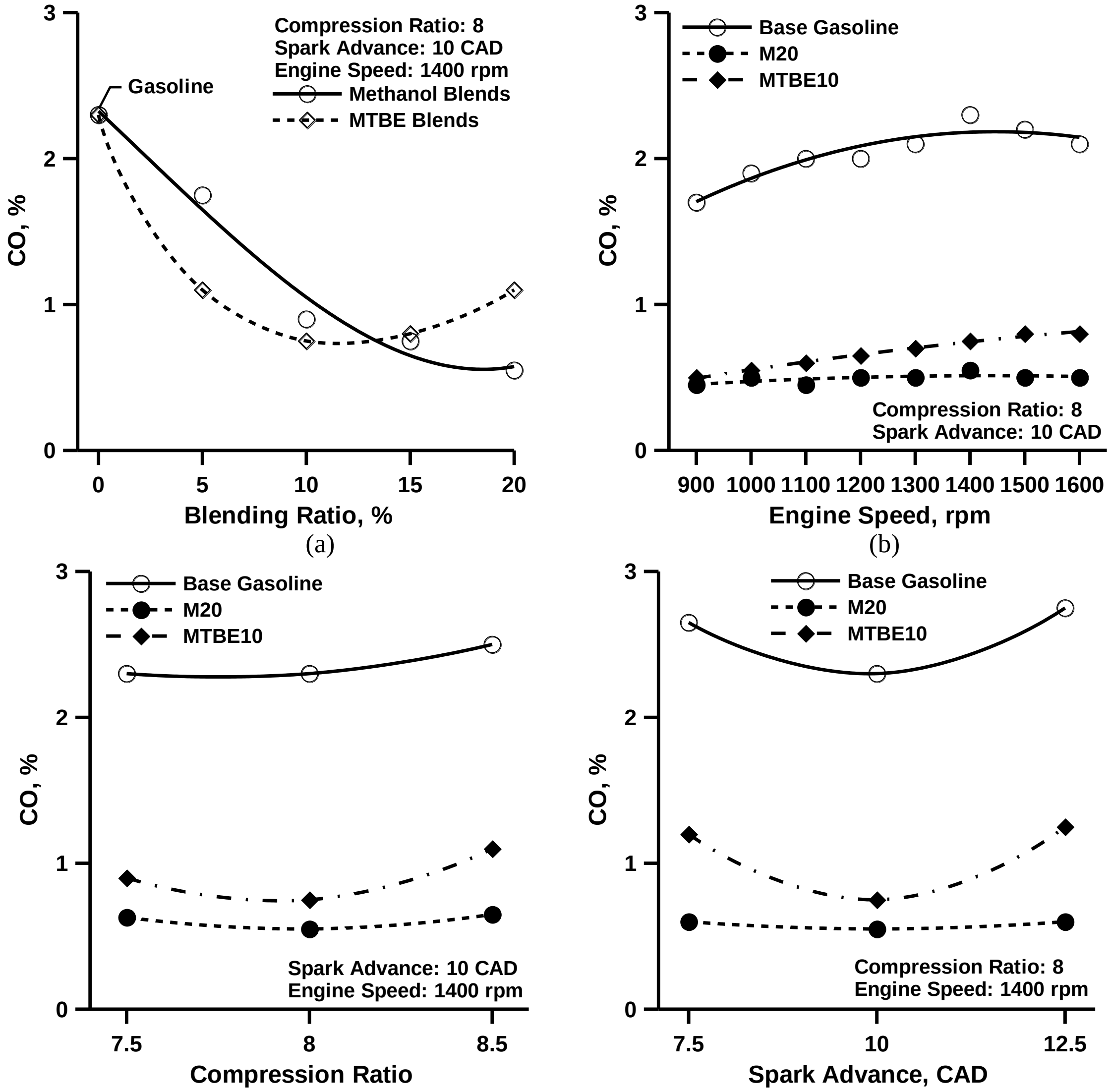
(a) (b)

(c) (d)

Figure 4. Variations of bte for various operating conditions.

CO Emissions

Variations of the CO emissions with blending ratio, engine speed, CR, and ST were given in parts a-d of Fig. 5, respectively. As shown in Fig. 5a, CO emissions decrease by increasing blending ratio up to 20 and 10% for methanol and MTBE, respectively. Thus, the M20 and MTBE10 give the minimum CO values among blends. Additionally, MTBE blends have a less CO emissions than methanol blends up to 10% blending ratio, then the CO emissions are lower for methanol blends. This indicates that MTBE is efficient for reduction of the emissions even the lower blending ratios. The variation of CO emissions with engine speed is given in Figure 5b. As can be seen in the figure, CO emissions slightly increase with increasing engine speed for gasoline and MTBE10 blend, while they slightly decreases for M20 blend. Variations of CO emissions with CR and ST are shown in parts c and d of Figure 5, respectively. As shown in the figure, the minimum CO emissions are generally obtained for the operating conditions of a CR of 8 and an ST of 10° BTDC. Figure 5 clearly shows that the M20 and MTBE10 blend give important reductions in CO emissions. The decrements gained with the M20 and MTBE10 blends are about 76% and 67% compared to that of gasoline, respectively. The reductions in CO emissions can be attributed to the explanations about AEC and bte variations. Methanol and MTBE addition to gasoline up to a certain level improves the combustion quality because of the leaning and decreases CO emissions, but, further MTBE addition causes drawbacks in combustion as declared in (Hamdan and Al-Subaih, 2002).



(a) (b)

(c) (d)

Figure 5. Variations of CO for various operating conditions.

CONCLUSIONS

The presented study investigates comparatively the addition of methanol and MTBE to gasoline in terms of engine performance CO emissions and fuel cost. The following conclusions can be summarized in lights of results obtained.

1. Both methanol and MTBE addition to gasoline improve the engine performance up to a specific blending ratio. The M5 and MTBE10 blends are the best performer in terms of brake mean effective pressure. The increment ratios (Δbmep/bmep$_g$×100) for M5 and MTBE10 are about 1.4 and 0.7% compared to gasoline, respectively. Further addition of methanol and MTBE causes the reduction in engine output because of the lower LHVs of these fuels.

2. Addition of methanol and MTBE also increases the brake thermal efficiency of the engine. M20 and MTBE15 blends yield the best improvements in engine thermal efficiency. The increment ratios in bte (Δbte/bte$_g$×100) obtained with M20 and MTBE15 are about 14.8 and 4.6% compared to gasoline, respectively.

3. Moreover, methanol and MTBE addition to gasoline significantly reduce CO emissions. The reductions are about 76 and 67% for M20 and MTBE10 blends, respectively.

4. Unfortunately, in spite of the improvements in engine performance and efficiency, the costs of blending agents are very high in Turkey compared to gasoline. The cost of methanol-gasoline blends increases with increasing methanol percentage and increments ($\Delta F/F_g \times 100$) are about 18.86, 36.95, 54.20, and 73.01% for M5, M10, M15, and M20, respectively. The cost of MTBE-gasoline blends are much higher than methanol-gasoline blends and increments arise approximately 79.15%, 159.4%, 235.3% and 320.6% for MTBE5, MTBE10, MTBE15 and MTBE20, respectively. This makes uneconomic using of methanol- and MTBE-gasoline blends in Turkey, for the current prices of blending agents.

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