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Investigating Criteria and Organic Air pollutant Emissions from Motorcycles by Using Various Ethanol-Gasoline Blends

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ABSTRACT

Studies on the correlation between ethanol-gasoline blends and pollutant emissions of small engine motorcycles are scant. This study examined the effects of ethanol-gasoline blends, containing various ethanol contents, on air pollutant emissions from two four-stroke fuel-injection motorcycles without engine adjustment. Three test blends, separately containing 15 (E15), 20 (E20), and 30 vol% (E30) ethanol in gasoline, were used to power the test motorcycles. Commercial unleaded gasoline was used as the reference fuel (as RF). The motorcycles were tested on a chassis dynamometer by using the Economic Commission for Europe test cycle. The target pollutants investigated in this study included criteria pollutants, volatile organic compounds (VOCs) and six species of organic air toxics. The results revealed that the emissions of CO, THC, total VOCs, alkanes, alkenes, and aromatic groups reduced when the ethanol-gasoline blends were used to fuel the motorcycles. E30 demonstrated approximately 1.2-fold increases in carbonyl group emissions compared with RF. Emissions of the target air toxics demonstrated a reduction potential on benzene, toluene, ethylbenzene, and xylene (BTEX), but increased the emissions of formaldehyde and acetaldehyde by 65% and 330%, respectively. Results also showed that the emission changes from fuel-injected motorcycle were generally smaller than the value of carburetor motorcycle. Fuel injection engine fueled with ethanol-gasoline blends may lead to emission reductions to CO, THC, and BTEX.

Keywords: Fuel-injection motorcycle; Small capacity engine; Renewable energy; Volatile organic compounds; Organic air toxics.

INTRODUCTION

Changing gasoline compositions can reduce vehicle emissions because certain gasoline modifications enable engines to perform at their optimal levels. In the United States, the 1990 federal Clean Air Act Amendments established that cities with the worst smog pollution must use reformulated gasoline (RFG) from the beginning of 1995. Ethanol and methyl tertiary butyl ether (MTBE) have been the two most commonly used oxygenates that add oxygen to gasoline. However, numerous states have taken actions to ban MTBE because the spillage and leakage of MTBE-containing gasoline at gas stations may pose environmental and health concerns. Therefore, ethanol has become the oxygenate of choice in the RFG program (RFA, 2015). Ethanol is also applied as an alternative fuel as well as a renewable fuel and is the most extensively used fuel in spark-ignition engines among alternative fuels (Niven *et al.*, 2005; Giakoumis *et al.*, 2013; Iodice and Senatore, 2014). Ethanol represents the vast majority of the renewable energy contribution of global energy demand for the transport sector. An estimated 74% of biofuel global production was fuel ethanol. Global production of fuel ethanol increased by 4% between 2014 and 2015, the production is to 98.3 billion liters (REN21, 2016).

Numerous countries have established or planned to promote ethanol gasoline. Using 10% ethanol-blended gasoline (E10) is mandatory in some states and cities in the United States. Moreover, since 2007, Brazil has set the legal ethanol-gasoline blend as 25% ethanol and 75% gasoline (RFA, 2010) and encouraged car makers to produce engines running on pure hydrated ethanol (100%) (Goldemberg, 2007). Over 27 cities have been using E10 as engine fuel from 2003 in China and more than ten million tons of ethanol-blended gasoline are produced annually (Li *et al.*, 2015).

Gasoline vehicles are important contributor of the air pollution in urban areas (Tsang *et al.*, 2008; Ho *et al.*,

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2013). Ethanol contains 35% oxygen; adding oxygen to fuel results in a relatively complete fuel combustion and can reduce tailpipe air pollutant emissions. The possibility of using ethanol-blended gasoline as fuel for vehicles and air quality management tools has increased. Several researchers have focused on the correlation between ethanol-gasoline blends (3–85 vol%) and pollutant emissions from spark-ignition engines. Air Quality Improvement Research Program (AQIRP) and European Program on Emission, Fuels, and Engine Technologies (EPEFE) have been the two most extensive and relevant studies (MacKinven and Hublin, 1996; AQIRP, 1997). Most studies have analyzed the relationship between ethanol-gasoline blends and pollutant emissions by using passenger cars. The results of such studies have generally indicated that ethanol-gasoline blends were associated with lower exhaust carbon monoxide (CO) and total hydrocarbon (THC) emissions compared with unleaded gasoline; however, the blends were associated with comparable or higher nitrogen oxides (NO_x) emissions compared with unleaded gasoline (He *et al.*, 2003; Yüksel and Yüksel, 2004; Anderson, 2009). Considering air toxics, in addition to acetaldehyde, adding ethanol to gasoline has generally been observed to reduce benzene, 1,3-butadiene, toluene, and xylene emissions (Poulopoulos *et al.*, 2001; Niven, 2005). However, adding ethanol demonstrates adverse effects such as increased fuel consumption and the presence of unburned ethanol and increased aldehyde emissions (Poulopoulos, 2001; He *et al.*, 2003; Anderson, 2009).

In contrast to research on passenger cars, studies on the effects of ethanol-gasoline blends on pollutant emissions from motorcycles with small engine capacities (less than 150 cm^3) are scant. Based on our best approach to search for the literatures, such studies are mainly from Taiwan and China (Jia *et al.*, 2005; Yao *et al.*, 2009, 2011; Yang *et al.*, 2012; Li *et al.*, 2015). The test motorcycles are four-stroke with carburetor system and ethanol content in the test fuels ranged from 3 to 20 vol% in gasoline in all of the literatures. Motorcycles are one of the most dominant modes of transportation in numerous Asian countries, including China, India, Taiwan, Thailand, and Vietnam. Motorcycles constitute 50%–70% of the total number of vehicles in these countries. Four-stroke engine motorcycles with small engine capacities (50–125 cm^3 displacement) are currently the most dominant motorcycle type in these countries, and the number of such motorcycles should increase in the future (The Freedonia Group, 2013). The emission of pollutants from motorcycle engines into the atmosphere is becoming an increasing concern for regulatory agencies and the public because motorcycles are responsible for urban air pollution.

As mentioned, data regarding the effects of ethanol-gasoline blends on exhaust emissions from motorcycles are scant as well as on fuel-injected motorcycles. Emissions from cars and motorcycles are different because of the dissimilar engine and fuel supply systems. An expansion of the relevant small engine capacity motorcycle emission factors caused by ethanol-gasoline blends was deemed necessary. Since 2008, Taiwan has approved only motorcycle models equipped with fuel injection engines because of fuel economy and environmental considerations. Consequently, this study investigated the effects of using ethanol-gasoline blends in fuel-injected motorcycles on engine exhaust emissions. Varied ethanol contents in gasoline, 15, 20, and 30 vol% ethanol, were used as test fuels. Criteria air pollutants (CO, THC, and NO_x), organic air pollutant groups, and air toxics from two new fuel-injected four-stroke motorcycles with 125 cm^3 displacement were studied. The results were then compared with those from same test motorcycles but using commercial gasoline as fuel.

EXPERIMENTAL METHODS

Fuels

Four test fuels were used in this study. Three ethanol-gasoline blends, separately containing 15% (E15), 20% (E20), and 30% (E30) ethanol by volume, and one commercial fuel (as RF), prepared by the largest petroleum refinery (China Petroleum Corporation, CPC) in Taiwan were used. Ethanol replaces methyl tert-butyl ether (MTBE) as the oxygenated additive in gasoline, and the corresponding fuel oxygen contents were 5.4, 7.4, and 10.1% by weight, respectively. Gasoline with research octane number (RON) 95 is the most popular fuel for motorcycles in Taiwan. Consequently, the RONs of the ethanol-gasoline blends were controlled at a relatively constant value (approximately 95). Table 1 shows the compositions of the test fuels.

Table 1. Properties of the test fuels.

Test fuel property	RF[*1]	E15[*1]	E20[*1]	E30[*1]
Ethanol (wt%)	0	15.8	21.5	29.3
Oxygen content (wt%)[*2]	2.0	5.4	7.4	10.1
Aromatics (vol%)	31.3	25.1	15.5	5.2
Paraffins (vol%)	10.6	7.9	8.1	9.2
Isoparaffins (vol%)	30.6	35.8	39.3	43.1
Olefins (vol%)	10.1	10.5	11.2	8.7
Naphthenes (vol%)	7.0	5.5	6.2	6.9
Benzene (vol%)	0.6	0.5	0.3	0.1
Net heating value (J/g)	44280	42040	42360	41540
Research Octane Number (RON)	95.0	95.3	95.2	94.9

[*1] RF is a commercial unleaded gasoline with RON 95; E15, E20, E30 have 15, 20, 30% v/v ethanol in the gasoline.
[*2] the oxygenated additive is methyl tert-butyl ether (MTBE) for RF and is ethanol for E15, E20, and E30.

Commercial unleaded gasoline containing MTBE as the oxygenated additive was used as the reference fuel (shown as RF in Table 1); the corresponding fuel oxygen content was 2.0 wt%. This fuel was purchased from a gasoline station operated by the CPC.

Test Motorcycles

Exhaust emission criteria and organic air pollutants were measured using two motorcycles tested on a chassis dynamometer. The two tested motorcycles were new four-stroke motorcycles with a 125-cm^3 displacement and were equipped with a fuel-injected engine. To accentuate the effects of the ethanol-gasoline blend, the motorcycles were operated without any engine adjustment and were equipped with a non-catalyst model tailpipe (without three way catalytic converter) during the test. All test motorcycles were in optimal mechanical condition to ensure that their engine combustion chamber deposits were stabilized. A total of eight tests involving various test fuels and motorcycles were conducted to detect gaseous air pollutants.

Test Procedures

A legislative test procedure, CNS 11386, was used for the motorcycle emission test. The test procedure is the same as that of the Economic Commission for Europe test cycle. One complete test cycle (780 s) includes idle (240 s), acceleration (168 s), cruising (228 s), and deceleration (144 s) stages. The total distance of the test was 4 km, with average and maximum speeds of 19 and 50 km h^{-1}, respectively. The emission tests were conducted on a chassis dynamometer in the certified laboratory of a local motorcycle manufacturer. The main system comprised a chassis dynamometer (MEIDEN, 20KW), dilution tunnel, constant volume sampler unit (HORIBA, CVS-51S), and exhaust gas analyzer (HORIBA MEXA-7200).

The schematic of sampling equipment used for estimating air pollutants in this study was the same as that used in our previous study (Yao *et al.*, 2011; Yao *et al.*, 2013). The CO, THC, and NO_x contents in the exhaust filter samples were measured using a nondispersive infrared analyzer, flame ionization detection analyzer, and chemiluminescence detection analyzer, respectively. A vacuum box containing a 10-LTedlar bag was used to sample the organic air pollutants from the entire ECE cycle. Hydrocarbon species (carbon number greater than 3) were quantified using a gas chromatography/mass spectrometer (Varian Star 3600 GC plus with a Varian Saturn 2000 MS). Compounds with carbon contents ranging between 2 and 4 were analyzed using gas chromatography/flame ionization detection (Hewlett Packard 6890 GC/FID). Carbonyl components in the exhaust were collected using a commercial cartridge filled with 2,4-DNPH (Supelco). The cartridge was extracted at first with an aliquot of 2 mL acetonitrile (Merck) in the laboratory and then the extraction solution was injected into a high-performance liquid chromatography (Hewlett Packard 1100 series HPLC) equipped with an automatic sampler (Hewlett Packard G1313A) and an ultraviolet-visible detector (Hewlett Packard). A total 65 volatile organic compounds (VOCs), namely alkanes (25 species), alkenes (9 species), aromatics (16 species), and carbonyls (15 species), were analyzed. The R-square (r^2) values of the calibration curves of the VOC compounds were generally higher than 0.995, and the relative standard deviation was less than 10%.

RESULTS AND DISCUSSION

Emission Factors of Criteria Air Pollutants

Table 2 shows criteria air pollutant emission factors of the fuel-injection test motorcycles for the entire test cycle. The relative difference between two tests is ranged from 17.3–23.9% for CO, 6.3–16.5% for THC, and 10.2–28.6% for NO_x of each test fuels. The CO emissions for the ethanol-gasoline blends ranged from 2.20 to 2.39 g km^{-1}, and that for RF was 2.55 g km^{-1}. The CO emissions dropped by 6%–14% for the fuel-injected engine compared with those of the reference fuel (Fig. 1). For the ethanol-gasoline blends, the THC emissions for E15 (0.48 g km^{-1}), E20 (0.44 g km^{-1}), and E30 (0.41 g km^{-1}) decreased by 13%, 20%, and 26%, respectively, as compared with those of RF (0.55 g km^{-1}). The NO_x emissions demonstrated a decreasing or comparable trend when the ethanol-gasoline blends were used. The NO_x emission decreased by 5% for E30 (0.30 g km^{-1}) and increased by 2% for E15 (0.32 g km^{-1}) and E20 (0.32 g km^{-1}) compared with those of the reference fuel (0.31 g km^{-1}).

Table 2. Criteria air pollutant emission factors of the test fuels in the two fuel-injected motorcycles.

Test Fuel	Fuel oxygen content (wt%)	Test MC	Emission Factor (g km^{-1})		
			CO	THC	NOx
RF	2.0	FI-1	2.25	0.59	0.27
		FI-2	2.85	0.5	0.35
		Average (n = 2)	2.55	0.55	0.31
E15	5.4	FI-1	2.10	0.46	0.27
		FI-2	2.67	0.49	0.36
		Average (n = 2)	2.39	0.48	0.32
E20	7.4	FI-1	2.11	0.42	0.29
		FI-2	2.51	0.45	0.34
		Average (n = 2)	2.31	0.44	0.32
E30	10.1	FI-1	1.99	0.38	0.28
		FI-2	2.40	0.43	0.31
		Average (n = 2)	2.20	0.41	0.30

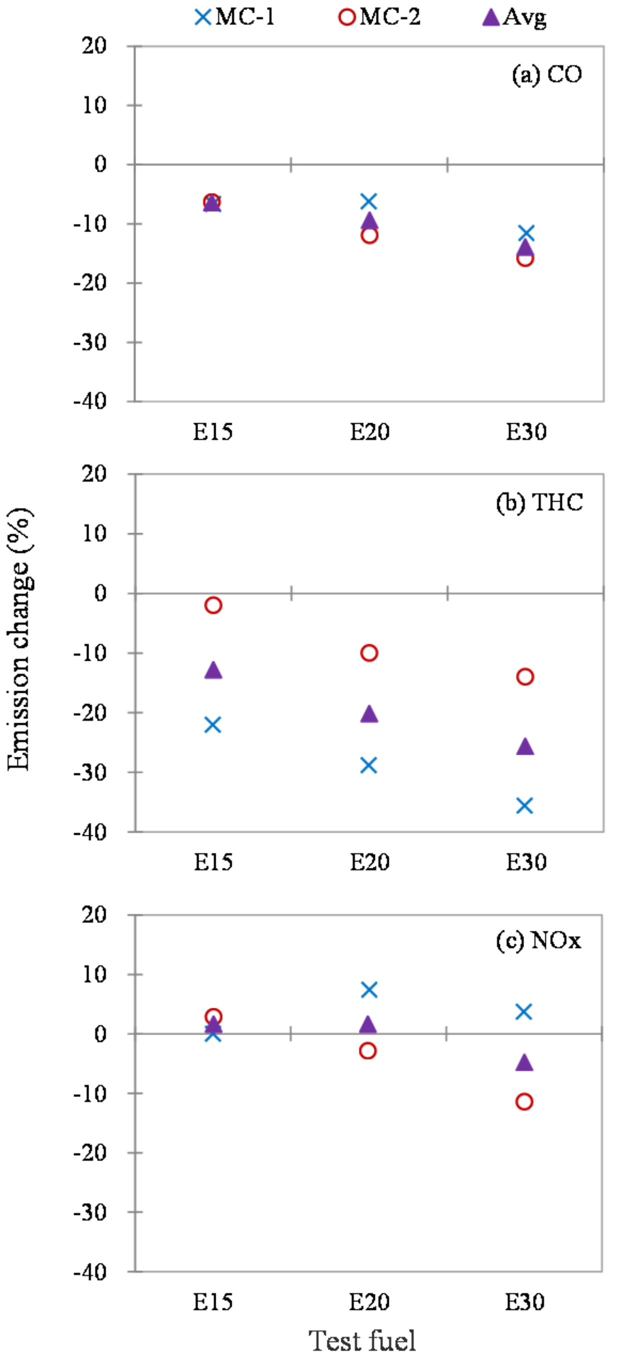


Fig. 1. Emission change (%) of criteria air pollutant of the ethanol-gasoline blends compared with those of the commercial fuel (RF); (a) CO, (b) THC, and (c) NO_x.

To substantiate the influence of each fuel compositions, the correlations between target pollutant emission and the fuel composition (oxygen, aromatics, benzene, naphthenes, olefins, and paraffins contents) are evaluated. The results of correlation coefficients (r) between the emission and each fuel composition showed that the CO and THC were related to the fuel oxygen, aromatic, and benzene contents with a strong correlation ($r > 0.7$), the values of r are ranged from –0.998 to 0.975 (CO), and –0.991 to 0.960 (THC). NO_x were related to olefins content in fuel.

The observations in this study revealed that using ethanol-gasoline blends may result in a decrease in exhaust CO and THC emissions; however, the emission of NO_x did not change considerably. The E30 blend exhibited the lowest criteria air pollutant emissions among the test fuels and the greatest emission reduction compared with RF.

Emission Factors of Organic Air Pollutant Groups

The 65 species of analyzed organic compounds were divided into four groups: alkanes (25 species), alkenes (9 species), aromatics (16 species), and carbonyls (15 species). Emissions of total VOCs, alkanes, alkenes, and aromatics groups also decreased when the ethanol-gasoline blends were used in the test fuel-injected motorcycle. Table 3 shows the organic air pollutant group emission factors of the two test motorcycles when RF and three ethanol-gasoline blends were used. E30 resulted in a lower total VOC emission (191 mg km^{-1}) than that of RF (250 mg km^{-1}) in the test motorcycles, followed by E20 (204 mg km^{-1}) and E15 (217 mg km^{-1}).The oxygen content in E30 was higher than that in RF, whereas aromatic, olefins, and benzene content levels in E30 were lower than those in RF.

The organic air pollutant group emission factors of the ethanol-gasoline blends, except for the carbonyls, were lower than those of RF. The reduction values (Fig. 2), which were calculated according to the emission factor per distance, were 18/19/29% (alkanes), 10/27/23% (alkenes), and 14/25/31% (aromatics) for E15, E20, and E30, respectively. By contrast, emissions of the carbonyl group increased considerably; the emissions for the group increased by approximately 59%, 78%, and 122% for E15, E20, and E30, respectively, compared with the reference fuel. Among the carbonyl compounds, acetaldehyde constituted the highest proportion of increasing emissions from the test vehicle exhaust. Ethanol can be directly dehydrogenated to become acetaldehyde during the combustion process through the partial oxidation of ethanol (Poulopoulos *et al.*, 2001). Furthermore, alkenes play a major role in the formation of aldehydes (Grosjean *et al.*, 1996), and a considerable decrease in alkene emissions with increasing ethanol level was observed in the present study. Acetaldehyde is a compound with high ozone formation potential. The use of ethanol-gasoline may lead to a dramatic increase in the emissions of acetaldehyde which will increase the photochemical reactivity and may lead to significant impacts on the regional and global oxidants: O_3 and PAN as well as the air quality (Jacobson, 2007; Anderson, 2009).

In brief, results implied that total organic air pollutant emission was reduced when the ethanol portion increased up to 30% in the blend in fuel-injected motorcycles without any engine adjustment. The emissions of total organic compound, alkanes, alkenes, and aromatics chemicals decrease in motorcycle exhaust and carbonyl group may increase when ethanol fuels are used.

Emission Factors of Selected Air Toxics

Six major air toxics, namely benzene, toluene, ethylbenzene, xylene (BTEX), formaldehyde, and acetaldehyde, were selected as target pollutants. Table 4

Table 3. Emission factors of organic air pollutant groups of the fuel-injected motorcycles.

Test fuel	Emission factor (mg km^{-1})				
	Alkanes	Alkenes	Aromatics	Carbonyls	Total VOC
RF	133.6	27.4	79.9	8.8	249.7
E15	110.1	24.6	68.5	14.0	217.2
E20	108.1	20.1	59.8	15.7	203.6
E30	95.2	21.1	54.8	19.5	190.5

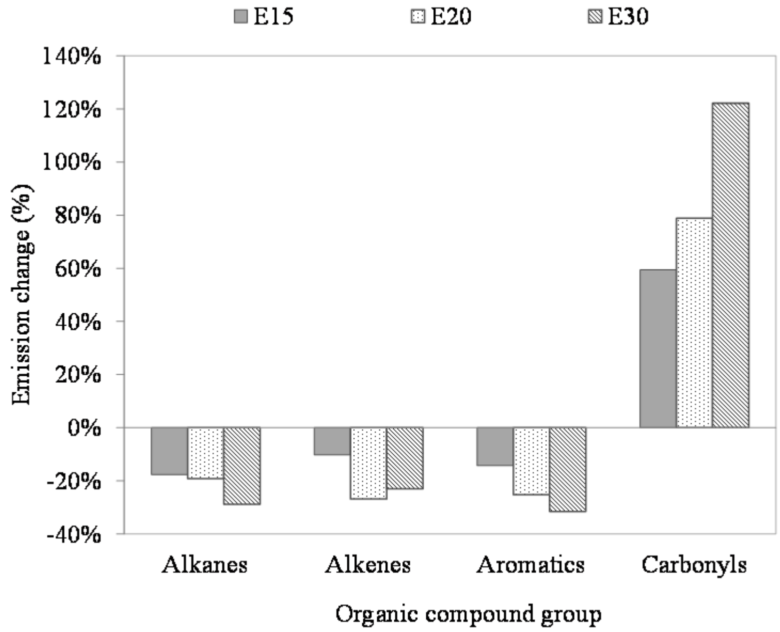


Fig. 2. Emission change (%) of organic group of the ethanol-gasoline blends compared with those of the commercial fuel (RF).

Table 4. Emissions (mg km^{-1}) of air toxics from the four-stroke motorcycle for the ethanol-gasoline blends.

Air toxics	Emission factor (mg km^{-1})			
	RF	E15	E20	E30
Benzene	8.9	6.9	6.1	4.2
Toluene	13.8	11.8	11.2	6.7
Ethylbenzene	4.9	4.2	3.8	3.6
Xylene	11.9	10.4	9.2	8.4
Formaldehyde	2.0	2.1	2.7	3.3
Acetaldehyde	3.3	6.6	8.0	14.2

shows the emissions (mg km^{-1}) of air toxics from the fuel-injected motorcycles for the ethanol-gasoline blends. In general, toluene demonstrated the highest emissions among the target air toxics in all the test fuels for the test motorcycles. The emission factors of toluene were 11.8 and 11.2 mg km^{-1} for E15 and E20, respectively, and 13.8 mg km^{-1} for RF. Xylene also exhibited a higher emission than other detected aromatic compounds for all test fuels in the test motorcycle exhaust. The emissions of xylene ranged from 8.4 mg km^{-1} (E30) to 11.9 mg km^{-1} (RF).

The results of correlation coefficients (r) between the emission and each fuel composition showed that the 6 air toxics were related to the fuel oxygen, aromatic, and benzene contents with a strong correlation, the values of *r* are ranged from –0.942 to 0.981.

The emission change of selected air toxics for the ethanol-gasoline blends was calculated relative to the reference fuel, and Fig. 3 shows the results. BTEX emissions decreased when the ethanol-gasoline blends were used. E30 resulted in a lower BTEX emission among all test fuels in the test motorcycles. However, formaldehyde and acetaldehyde emissions increased as the ethanol content in the gasoline increased. Among all the test fuels, the highest aldehydes emissions were observed in E30.The emission factors were 3.3/2.0 mg km^{-1} of formaldehyde and 14.2/3.3 mg km^{-1} of acetaldehyde for E30 and RF, respectively. The exhaust acetaldehyde emissions for the ethanol-gasoline blends were 1.0- to 3.3-foldhigher than those for RF, because acetaldehyde may be produced through the partial oxidation of ethanol in the ethanol-gasoline blend fuel. Both formaldehyde and acetaldehyde is the compound with high ozone formation potential. Formaldehyde is also classified as a human carcinogen by the International Agency for Research on Cancer and the U.S. Environmental Protection Agency. In the view of ozone formation potential and public health, the application of ethanol-gasoline blends needs more studies to evaluate the overall potential impact on environmental quality.

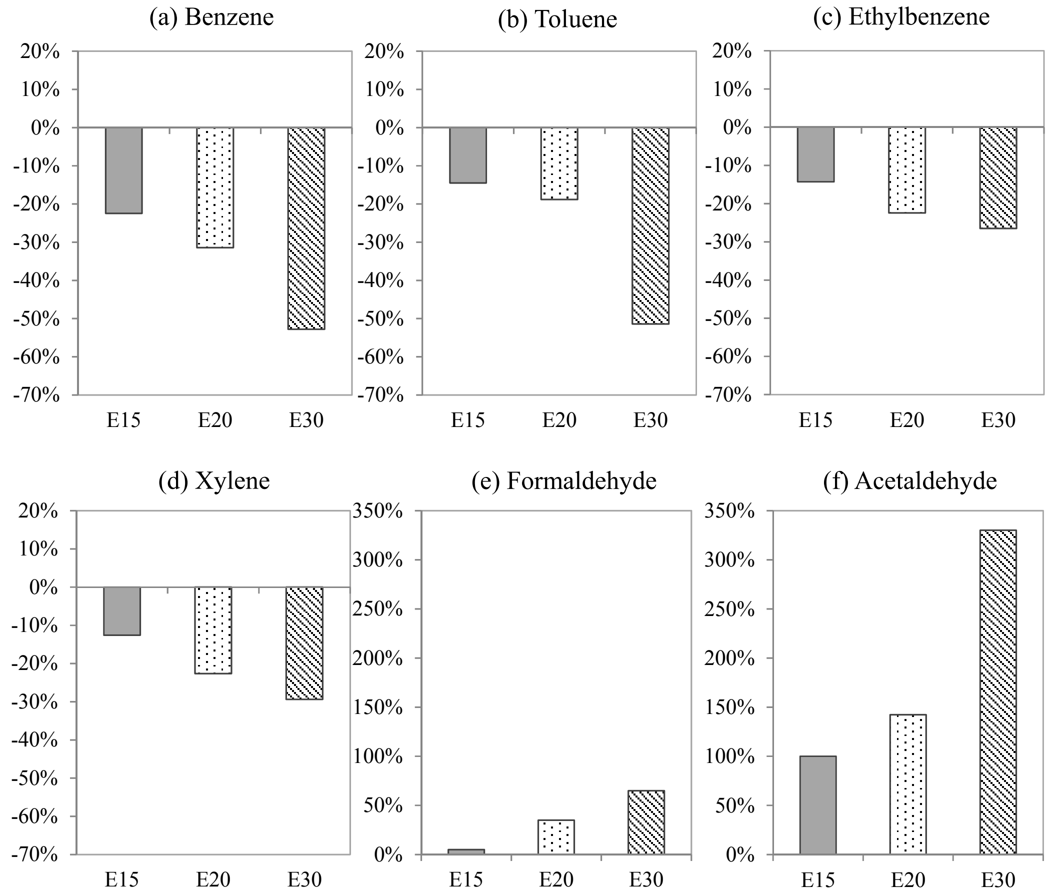


Fig. 3. Emission change (%) of the air toxics for the ethanol blends (E15, E20, and E30) compared with that of RF; (a) benzene, (b) toluene, (c) ethylbenzene, (d) xylene, (e) formaldehyde, and (f) acetaldehyde.

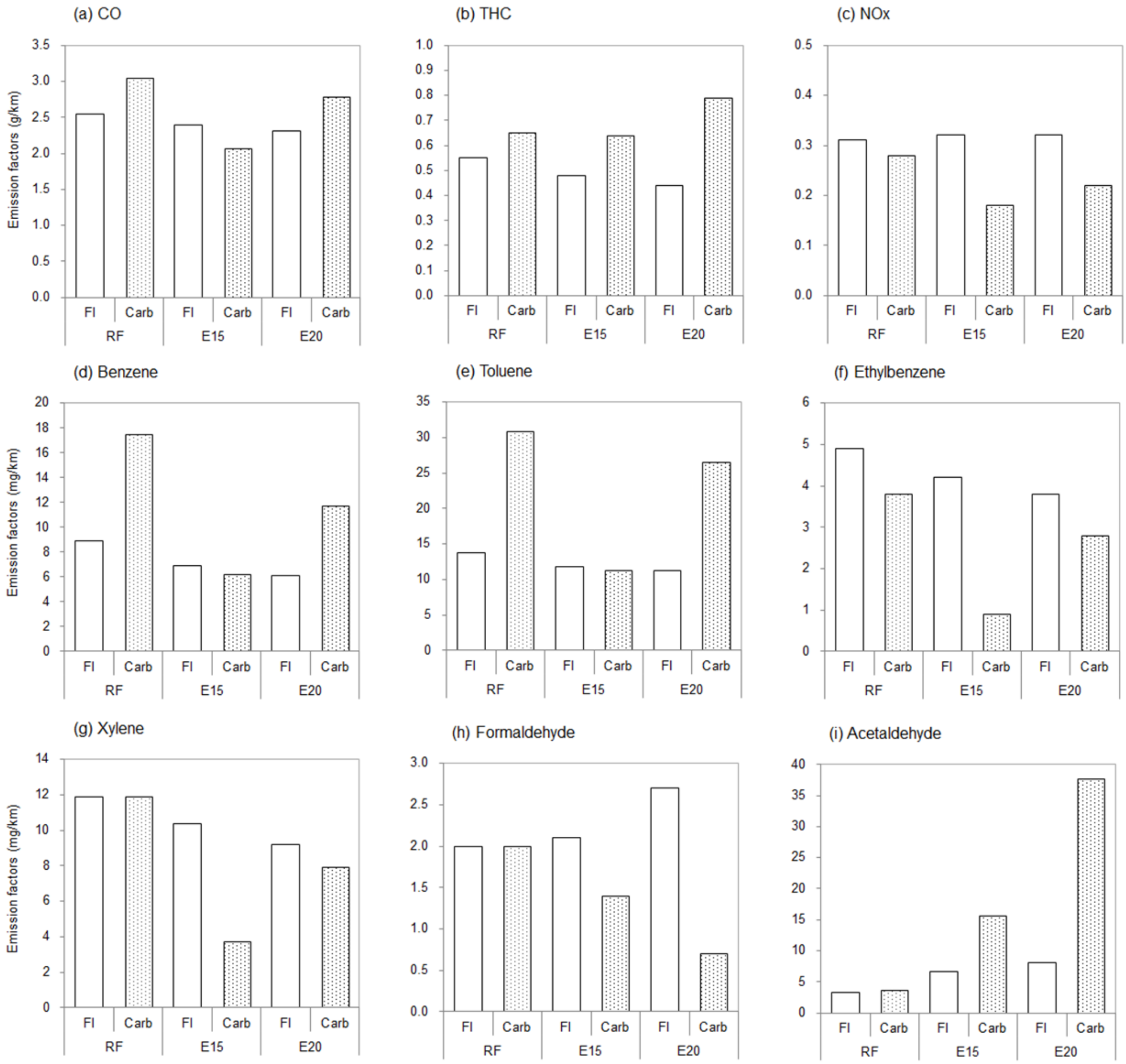
Emissions of Fuel-Injection and Carburetor Motorcycles

Fig. 4 shows the emissions of criteria pollutants and organic air toxics for the fuel-injection and carburetor motorcycles when applying ethanol-gasoline blends (E15 and E20) and commercial unleaded gasoline as fuel. The air pollutant data of carburetor motorcycles was from the experimental data of our pervious study (Yao *et al*., 2009, 2011). The test fuels (E15 and E20) applied in carburetor motorcycle and fuel-injection motorcycle were blended by follow the same procedure in the same laboratory in the largest petroleum refinery in Taiwan. The experimental conditions of those tests, including test procedures, sampling and analysis of exhaust, and the certified laboratory which performed the chassis dynamometer tests, are same except the test motorcycles.

Emission change of criteria pollutants and selected air toxics for E15 and E20 fuels was calculated as compared to the reference fuel, and the results are shown in Fig. 5. In general, the impact of E15 and E20 compared to RF are shown as decreases in CO, THC, and BTEX emissions from both of fuel-injected and carburetor motorcycles. A comparable treads of NO_x emissions were observed in the fuel-injected motorcycles when use ethanol-gasoline fuels. A decreasing by 36% and 21% for E15 and E20 as compared those from RF, respectively, were showed in the carburetor motorcycles. The emissions of acetaldehyde were most strongly linearly related to ethanol content in fuel, particularly for carburetor motorcycles (Fig. 4(i)). The acetaldehyde emissions were 3.3- to 9.4-times and 1.0- to 1.4- times higher than those for the RF for carburetor and fuel-injected motorcycles, respectively. Air toxics emission changes are larger in carburetor motorcycle than those of fuel injection one.

From the results in previous section, the low emissions of CO, THC, and BTEX were observed when the high-ethanol content blend (E20) was used to fuel the fuel-injection motorcycles. However, the E20 exhibit higher emissions of most of target pollutants than those of low content blends (E15) in carburetor motorcycles. In carburetor engine motorcycles, the air-fuel ratio (AFR) is not always optimal due to the manufacturer design and may resulted in a poor combustion efficiency of the motorcycle when using high oxygen content fuels. The high excess air ratio values in the high-ethanol content blend causes the engine to have a lean mixture and lead to an incomplete combustion occurs in the combustion chamber. This in turn certainly influences the exhaust of motorcycles. In contrast, fuel-injected engine is a computerized fuel injection system, the amount of fuel supply can be adjusted immediately according to the combustion condition and can be optimize the mixture ratio of air and fuel inside the engine cylinders.

In brief, results showed that the both of fuel injection



[*1] data of fuel injection motorcycle are from this study and data of carburetor motorcycle are summarized from Yao *et al.*, (2009, 2011).
[*2]. RF is a commercial unleaded gasoline; E15, E20, E30 have 15, 20, 30% v/v ethanol in the gasoline.

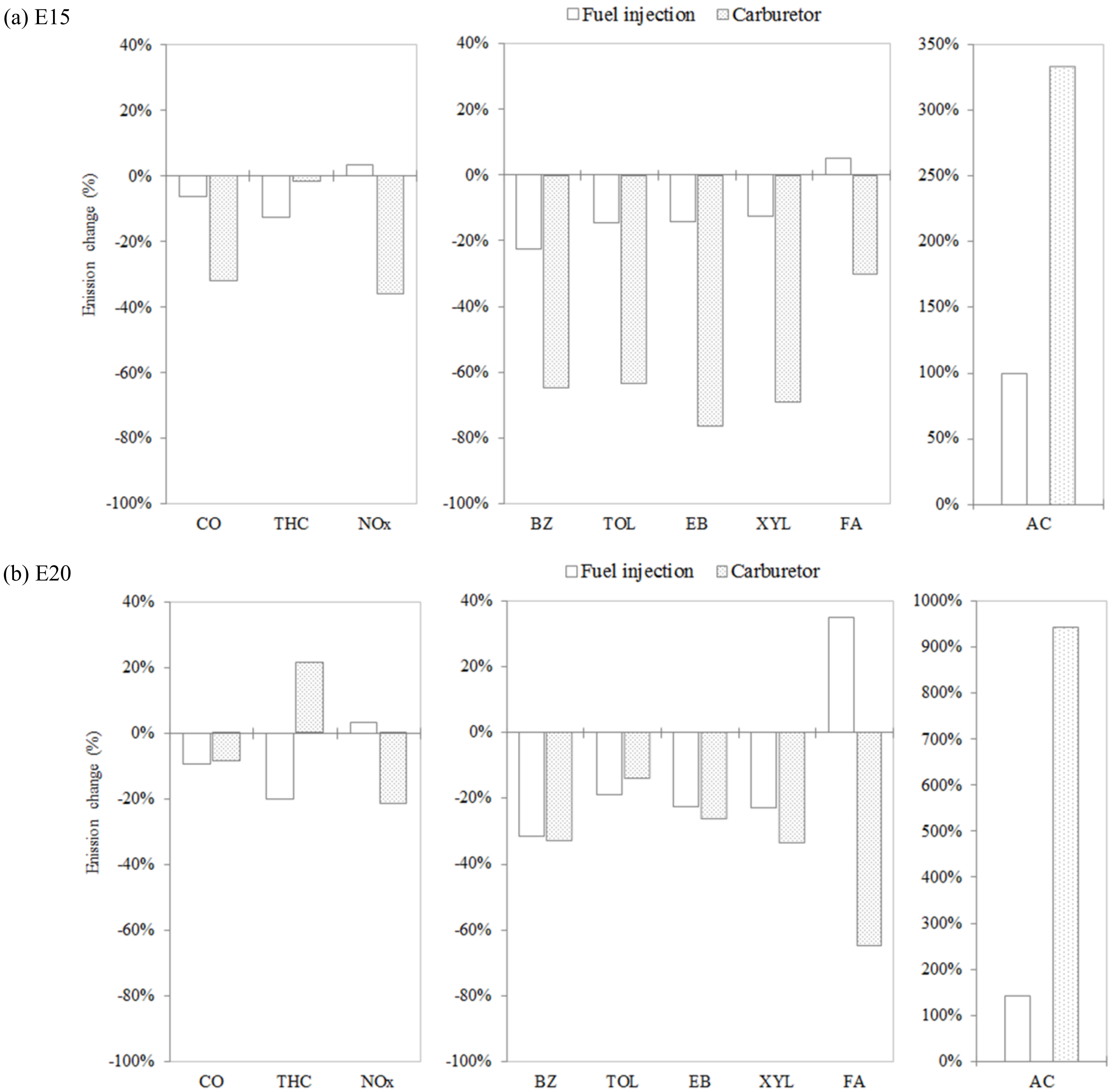
Fig. 4. Emission factors of gaseous pollutants from fuel-injection and carburetor motorcycles fueled with different gasoline.

and carburetor motorcycles fueled with E15 at a constant octane number may generally lead to emission reductions to CO, THC, and BTEX. The high-ethanol content blend (E20) results in higher emissions of CO, THC, and BTEX than those of low content blends in carburetor motorcycles, but lower emissions in fuel-injected motorcycles.

CONCLUSIONS

This study investigated the influence of ethanol-gasoline blends on criteria and organic air pollutant (VOCs and carbonyls) emissions of motorcycles. Ethanol blends with various ethanol contents (i.e., 15, 20, and 30% v/v) and commercial gasoline (with MTBE), serving as the reference fuel, were tested in this study. Two new four-stroke fuel-injected motorcycles were tested. The two test motorcycles operated adequately on the ethanol blends, with an operational performance of up to 30 vol%, implying that ethanol-gasoline blends can be applied in fuel-injected motorcycles without engine adjustment.

Lower CO and THC emissions were observed from the test motorcycles when the ethanol-gasoline blends were used compared with the reference fuel; however, NO_x emissions showed no considerable variation. A decreasing



Note: BZ, benzene; TOL, toluene; EB, ethylbenzene; XYL, xylene; FA, formaldehyde, AC, Acetaldehyde.

Fig. 5. Emission change (%) of gaseous pollutants for ethanol blends compared to RF; (a) E15 and (b) E20.

trend was observed for the organic air pollutant group emissions as the ethanol content was increased in the test motorcycles, except for the carbonyls. BTEX emissions decreased when the ethanol-gasoline blends were used as the fuel; nevertheless, formaldehyde and acetaldehyde emissions increased as the ethanol content in gasoline increased. E30 exhibited a higher emission reduction potential compared with E15 and E20. However, E30 demonstrated a higher emission of aldehydes, particularly for acetaldehyde, which may increase the adverse effects of the emissions in the exhaust on health. Fuel injection engine fueled with ethanol-gasoline blends may lead to more emission reductions of target air pollutants than those of carburetor motorcycles.

In summary, applying ethanol-gasoline blends in motorcycles reduced the emissions of CO, THC, alkane, alkene, and aromatic groups as well as those of BTEX compared with those of the reference fuel, but increased carbonyl emissions, particularly for acetaldehyde. For the purpose of criteria air pollutant emission reduction, the ethanol-gasoline blends are recommended for use as an alternative fuel in motorcycles. However, formaldehyde and acetaldehyde emissions increased as there was an increase in the ethanol content in the gasoline. In the view of ozone formation potential and public health, the application of ethanol-gasoline blends needs more evaluation.

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