Applied Energy 89 (2012) 281–286

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Effects of ethanol-blended gasoline on emissions of regulated air pollutants and carbonyls from motorcycles

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ARTICLE INFO

Article history:
Received 11 January 2011
Received in revised form 17 July 2011
Accepted 18 July 2011
Available online 23 August 2011

Keywords:
Ethanol–gasoline blend
Motorcycle
Carbonyls
Durability test
Paired *t*-test

ABSTRACT

The emission characteristics of regulated air pollutants and carbonyls from motorcycles using gasoline blended with 3% ethanol (E3) and gasoline (E0) were investigated in this study. Nine motorcycles were operated on a chassis dynamometer and driven according to the ECE driving cycle for air pollutant measurements. In addition, durability testing was performed on two brand-new motorcycles of the same model, using E3 in one and E0 in the other, to assess the effects of E3 usage on motorcycle emissions. The results show that average emission factors of CO and THC decreased by 20.0% and 5.27%, respectively, using E3 fuel. However, NO_x and CO_2 emission increased by 5.22% and 2.57%. The results of paired *t*-tests indicate that only the reduction of CO emission is statistically significant (p-value = 0.006). The emission factors of $\sum$15 carbonyls for the nine test motorcycles were 1289 ± 502 and 1579 ± 368 μg/km for E0 and E3, respectively. Carbonyl emission increased by 22.5% using E3 substituted for E0. However, the differences in $\sum$15 carbonyl emission between E0 and E3 were not statistically significant (p-value = 0.137). Among the 15 analyzed carbonyls, only the emission of acetaldehyde was significantly higher (p-value = 0.014) with E3. The results of durability tests show that deterioration coefficients for E3 were 1.50, 1.45, 0.84, 0.94 and 1.06 for CO, THC, NO_x, CO_2 and carbonyls, respectively. Statistical tests exhibit that using E3 as fuel does not increase the regulated air pollutants, nor carbonyl emissions for the durability test.

1. Introduction

Due to the increasing demand for energy and stringent air pollution regulations, nations worldwide are actively researching and developing alternative clean fuels. Ethanol-blended gasoline ("gasohol") is one of the widely employed renewable alternative fuels used for vehicles [1]. Back in 1930, the US had suggested the use of ethanol as a fuel source. However, it was not until after 1970 that ethanol was more widely used [2]. Numerous previous studies have assessed the feasibility of employing ethanol as an additive in automobile engine fuel due to its high octane value [3–6] and the ability of ethanol to increase the octane value of gasoline [7]. Furthermore, the high flammability and evaporation heat for ethanol–gasoline blends pose positive effects on engine performance [8].

Another important property of ethanol is the high oxygen content in its chemical structure, which promotes complete combustion of fuels within engine cylinders and reduces the emission of most air pollutants [9]. Hsieh et al. investigated the air pollutant emissions from a spark ignition engine. The results showed that CO and HC emissions decreased dramatically by using an ethanol–gasoline fuel blend [7]. The study by He et al. also showed that E30 (30% ethanol in gasoline) reduced emissions of HC, CO and NO_x drastically [10]. Pang et al. used E10 as fuel in a gasoline engine. Their results agreed with the above studies; i.e., HC and CO emissions were reduced for E10 in comparison with gasoline [11]. The study by CELİK also showed that addition of ethanol reduces air pollutant emissions from a gasoline engine. The results showed that emissions of CO, CO_2, HC and NO_x decreased 53%, 10%, 12% and 19%, respectively, using E50 [12].

Although most air pollutants can be reduced, carbonyls (ketones and aldehydes) might be formed by using ethanol-blended gasoline. Poulopoulos et al. investigated the air pollutant emissions from a gasoline engine and found that acetaldehyde emissions are appreciably increased for ethanol-containing fuel [13]. Pang et al. found that in gasoline engine tailpipe emissions, total carbonyls from E10 were 3.0–61.7% higher than those from gasoline [11]. Some carbonyls are toxic, mutagenic and carcinogenic [14]. They also play an important role on the tropospheric chemistry and are precursors to the formation of ozone and peroxyacylnitrates [15]. Therefore, carbonyl emissions from vehicles are of special importance for study.

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0306-2619/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apenergy.2011.07.035

Motorcycles are the most popular transportation in Taiwan, due to desirable qualities, such as high maneuverability, agility, parking-friendly, and inexpensive. They account for 67.8% of the total number of motor vehicles in Taiwan. The contributions of air pollutants from motorcycles are significant in Taiwan and other countries with a high number of them. Very few studies in the literature investigate the effects of ethanol-blended gasoline on air pollutant emissions from motorcycles. To the best of our knowledge, only Jia et al. and Yao et al. have measured the emissions from motorcycles [16,17]. The results by Jia et al. indicate that using E10 can reduce CO and HC emission in comparison with gasoline, but there is no significant difference for NO_x emission. Their study also shows that using E10 produces more ethylene and acetaldehyde [16]. The results by Yao et al. show that ethanol addition decreased the exhaust CO and NO_x emissions [17].

All previous studies (for both automobile and motorcycle) were conducted with only one single vehicle or engine, and no assessments of multiple motorcycles on the same topic were found in the literature. In addition, effects on air pollutant emissions brought by continuous usage of ethanol-blended gasoline are not well-known. It is necessary to perform durability tests and evaluate effects under long-term driving using gasohol. This study investigates the emissions of regulated air pollutants and carbonyls from nine motorcycles using E3 and gasoline. In addition, durability testing was performed on two brand-new motorcycles with the same model using E3 and gasoline, respectively, to assess the effects of E3 consumption on motorcycle emission for long-term driving.

2. Materials and methods

2.1. Fuels

Both unleaded gasoline (E0) and an unleaded blend with 3% ethanol (E3) were tested in this study. Blends of up to 10% ethanol can be used without modifying most vehicles, so E3 can be used safely. Although percentages higher than 10% have been used in some countries, other countries such as Taiwan are using E3 and do not need to modify existing vehicles. The properties of these two fuels are listed in Table 1. Their octane values are very similar. The vapor pressure for E3 is 56.4 kPa, which is lower than that of E0 (60.5 kPa). For heat value, E0 (10574 cal/g) is slightly higher than that of E3 (10234 cal/g). Overall, the difference in properties between E3 and E0 is small, possibly due to the small amount of ethanol added to gasoline.

2.2. Test motorcycles and mileage accumulation

Nine motorcycles manufactured by three companies in Taiwan with the most overall sales were tested in this study. All nine were four-stroke motorcycles. Manufacture and sale of two-stroke motorcycles are not allowed in Taiwan, due to their high air-pollutant emissions. The fuel systems for the nine tested motorcycles are all carburetor systems since most motorcycles use carburetor, whether in Taiwan or other countries. The displacement volumes were from 100 cc to 150 cc and all were manufactured after 2005 with pre-testing mileages between 733 and 15800 km. Since E3 is designed for use in vehicles needing not modification, the test motorcycles were not modified and all motorcycles had the same after-treatment device—a two-way catalytic converter. The motorcycles were tested with E3 and E0 separately. Before each test, the fuel tank was drained and the vehicle run with test fuel for at least 1 h to avoid the shadow effect of the old residual fuel.

In addition to these nine motorcycles, two brand-new motorcycles of the same manufacturer and model were durability tested with E3 and E0, respectively. In this study, the test procedure was conducted following the regulation "motorcycle durability testing method and procedure" in Taiwan. The driving modes were comprised of idling, acceleration, cruise and deceleration to simulate real-world deterioration within a short period of time. The running mileage was about 500 km everyday until they accumulated 15000 km. Air-pollutant emissions were measured every 2500 km up to 15000 km. The motorcycles were inspected and maintained following the manufacturer's instructions. Air-pollutant emissions were measured at 5000 and 10,000 km both before and after maintenance.

Table 1
Properties of fuels.

Properties	E3	E0
Density (at 15 °C, kg/L)	0.745	0.731
Octane value	95.6	95.7
Vapor pressure (at 37.8 °C, kPa)	56.4	60.5
Lead content (g/L)	<0.0025	<0.0025
Distillation temperature (°C)		
Initial boiling point	39.3	34.9
10 vol.%	51.8	51.1
50 vol.%	92.6	93.3
90 vol.%	168.7	157.9
Final boiling point	210.9	202.9
Net heating value (cal/g)	10234	10,574
Carbon content (wt.%)	88.55	88.62
Hydrogen content (wt.%)	11.2	10.4

2.3. Chassis dynamometer and test cycle

The motorcycles were driven on a chassis dynamometer (Schenck GS-530 GS 30) for air pollutant emission measurements. The dynamometer system was comprised of a fan, dynamometer, dilution pipe, constant-volume sampling (CVS) system (HORIBA, CVS-51S), gas analyzer (HORIBA, MEXA-7200), and a computer work station (Fig. 1). The European driving cycle (ECE), the legistive cycle for automotive emission certification in Taiwan, was conducted for this study. One complete ECE test cycle (780 s) included the term of idle (240 s), acceleration (168 s), cruising (228 s) and deceleration (144 s), and four different cruising speeds (15, 32, 35 and 50 km/h) were applied in the test.

2.4. Measurements of regulated air pollutants

The motorcycle tailpipes were connected directly to the sampling systems during the entire test cycle. Exhaust gas was directed to the CVS system, diluted with indoor air, and then conducted to a Tedlar sampling bag (SKC Inc.) and analyzed (Fig. 1). In the gas analyzer, CO and CO_2 were measured by non-dispersive infrared absorption (NDIR). The instrument was a HORIBA, Model AIA-120 analyzer. HC was measured by a HORIBA FIA-125 heated flame ionization detector (FID) and NO_x was measured by chemiluminescence using a HORIBA CLA-155. The background concentrations of indoor air were also analyzed routinely and deducted from the test results.

2.5. Sampling and analysis of carbonyls

After sample collection, the diluted exhaust was drawn from the Tedlar bag into a pre-coated DNPH (dinitrophenylhydrazine) cartridge (LpDNPH S10 Cartridge, Supelco Inc.) at a sampling rate of 1 L/min for 20 min. The cartridges were then capped and stored until analysis. Before analysis, each cartridge was extracted with 5 mL of acetonitrile. Then the extract was passed through a 0.45 μm filter to remove particles during the extraction. Analysis was performed by a high-performance liquid chromatography/