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Exhaust and evaporative emissions from motorcycles fueled with ethanol gasoline blends

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HIGHLIGHTS

- Both exhaust and evaporative emissions of three motorcycles were investigated.
- Results of motorcycles fueled with E10 compared with that of motorcycles fueled with gasoline
- THC and CO from exhaust emissions of E10 decreased, while NOx increased.
- Carbonyls in exhaust emissions of E10 increased, while VOCs decreased.
- The evaporative THC of E10 was comparable with that of gasoline, while BTEX increased.

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ABSTRACT

The emission characteristics of motorcycles using gasoline and E10 (90% gasoline and 10% ethanol by volume) were investigated in this article. Exhaust and evaporative emissions of three motorcycles were investigated on the chassis dynamometer over the Urban Driving Cycle (UDC) and in the Sealed Housing for Evaporative Determination (SHED) including regulated and unregulated emissions. The regulated emissions were detected by an exhaust gas analyzer directly. The unregulated emissions including carbonyls and volatile organic compounds (VOCs) were sampled through battery-operated air pumps using tubes coated with 2,4-dinitrophenylhydrazine (DNPH) and Tenax TA, respectively. The experimental results showed that the emission factors of total hydrocarbons (THC) and carbon monoxide (CO) from E10 fueling motorcycles decreased by 26%–45% and 63%–73%, while the emission factor of NOx increased by 36%–54% compared with those from gasoline fueling motorcycles. For unregulated emissions, the emission amount of VOCs from motorcycles fueled with E10 decreased by 18%–31% while total carbonyls were 2.6–4.5 times higher than those for gasoline. For evaporative emissions of THC and VOCs, for gasoline or E10, the diurnal breathing loss (DBL) was higher than hot soak loss (HSL). Using E10 as a fuel does not make much difference in the amount of evaporative THC, while resulted in a slightly growth of 14%–17% for evaporative BETX (benzene, toluene, ethylbenzene, xylene).

1. Introduction

China has a rapid development on vehicular industry in the past decades. Currently, there are more than 224 million motor vehicles in China, almost half of which are motorcycles. China has the largest number of motorcycles in the world, for the desirable quantities of motorcycles, such as high maneuverability, agility, parking-friendly and inexpensive (Yang et al., 2012). The increasing number of motor vehicles caused a severity in air pollution issue. In 2012, 5.902 million metric tons of carbon monoxide (CO), 0.754 million metric tons of hydrocarbons (HC) and 0.105 million metric tons of nitrogen oxide (NOx) were released (MEP, 2013). The emission performance of motorcycles is poor due to the use of carburetor and the lack of advanced after-treatment system (Yao et al., 2013). Controlling pollutant from motorcycles received considerable attention due to the deteriorating air quality as well as stringent emission restrictions.

The crisis of fossil fuel makes fuel supply capacity decreased obviously, especially for internal combustion engines. In the process of developing alternative fuels, alcohol was regarded as a more prominent engine fuel at present stage for its outstanding physical and chemical properties. Blending ethanol, a kind of renewable and clean oxygenated fuels, with gasoline (ethanol lower than 50% by volume) can be applied in gasoline engines directly without modifications and can reduce criteria air pollutants, such as total hydrocarbons (THC) and CO (Alberto et al., 2002; Garcı'a et al., 2010; Piotr et al., 2013). In China

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over 27 cities have been using E10 as engine fuel from 2003. Every year across the country there are more than ten million tons of ethanol–gasoline blended produced. The consumption of ethanol gasoline accounts for 20% of the national gasoline consumption, which makes China the third largest country of producing ethanol gasoline blends among the world, just after Brazil and USA.

Mostly previous researches were related to the emission (for both regulated and unregulated emissions) from vehicles or engines fueled with ethanol–gasoline blended as gasohol have been widely used in vehicle engines (Graham et al., 2008; Koc et al., 2009; Dutcher et al., 2011; Georgios et al., 2012). But investigations on the effects of ethanol blended gasoline on air pollutant emissions from motorcycles are rarely reported. To our best knowledge, such studies are mainly from Taiwan. Yao et al (2009) investigated the organic air toxic emissions from a motorcycle fueled with four blends containing 3%, 10%, 15%, and 20% (vol) ethanol in gasoline. Experimental data indicated that addition of ethanol may reduce emissions of selected air toxics, except those of acetaldehyde. The high ethanol–gasoline blend ratio (20%) resulted in a less emission reduction than those of low ratio blends (e.g. 15%, 10%, 3%). The results by Yang et al. (2012) showed that average emission factors of CO and THC decreased, NOx, CO_2 and carbonyl emission increased using E3 (97% gasoline and 3% ethanol by volume) substituted for E0 (100% gasoline and 0% ethanol by volume).

Evaporative emission is mainly affected by the ambient temperature and can cause serious air pollution and economic losses. Previous studies showed that the THC (including VOCs and carbonyls) from evaporative emissions were comparable to or higher than that from tailpipe when advanced after-treatment technology was applied (Schifter et al., 2011; Yamada, 2013). However, all these researches were performed on vehicles, and none reports pertaining to evaporative emission from motorcycles.

Because the fuel tank of motorcycle is directly exposed, more fuel in motorcycles than in vehicles tends to be volatile. Therefore, it's necessary to study the evaporative emission from motorcycles. In this study, three four-stroke motorcycles with different displacements, fueling with E10 and gasoline, respectively, were tested on chassis dynamometer to evaluate the characteristics of the exhaust emissions and evaporative emissions.

2. Materials and methods

2.1. Fuels

Two fuels were used: commercial 93# (research octane number) gasoline and E10 ethanol gasoline. The commercial 93# gasoline from China Petroleum Company, the most widely used in China, was used as the basic fuel. E10 was produced by mixed the commercial 93# gasoline with industrial grade ethanol (10% by volume). Blends of up to 10% ethanol can be used without modifying most vehicles (Yang et al., 2012). The properties of fuels are listed in Table 1.

Table 1
Properties of fuels.

Fuel	93#	E10
Vapor pressure (at 37.8 °C, kPa)	69.0	73.6
Distillate temperature (°C)		
10 vol.%	51.6	47.9
50 vol.%	95.4	68.8
90 vol.%	157.5	159.4
Final boiling point (FBP)	187.2	187.7
Aromatic hydrocarbon content (%)	28.6	15.8
Ethanol content (%)	0	9.92

2.2. Testing motorcycles

Three motorcycles manufactured by three companies with the most overall sales were tested in this study. All these motorcycles had four-stroke engines with carburetor systems. The displacements of these motorcycles are 110 mL, 125 mL and 150 mL, respectively. For convenience, three motorcycles are named A, B and C, respectively. Each motorcycle was tested with commercial 93# gasoline and E10 separately. Since E10 is designed for use in vehicles needing not modifications, the fuel systems of motorcycles were no modified. Before each test, the fuel tank was drained and the motorcycles run with test fuel for at least 1 h to minimize the effect in the process of switching the fuel.

2.3. Testing cycle for measurement of exhaust emission

The motorcycles were tested on the chassis dynamometer (ACD-030B66MC, Shin Well Tokki, Xi'an). The cycle employed was the UDC which consists of six nonstop ECE (Economic Commission for Europe) cycles, lasting for 1170 s and traveling 6.087 km. Before running the test cycle, the motorcycles were conditioned at a temperature range of 20–30 °C over a period of 6–36 h until the difference between the temperature of lubricating oil or coolant and the ambient was within 2 °C.

2.4. Sampling and analysis

Fig. 1 showed the schematic diagram of the measurement system for motorcycle exhaust emissions. The exhaust gas was diluted with indoor air by the CVS system (CVS-7100, Horiba, Japan) and collected to the sampling bags. The regulated emissions were analyzed by an exhaust analyzer (MEXA-7200, Horiba, Japan), where CO was measured by non-dispersive infrared analyzer, total hydrocarbon (THC) was measured by flame ionization detector (FID), and NOx was measured by chemiluminescence analyzer (CLD).

According to the U.S. Environmental Protection Agency (USEPA) technical standard TO-11A, carbonyls were collected by air sampling pump (Air Check2000, SKC, America) using 2,4-dinitrophenylhydrazine DNPH coated with silica cartridges (Supelco, USA). In order to ensure that the carbonyls can fully react with 2-4 DNPH, sampling flow and time were set for 1000 mL/min and 20 min, respectively. After extraction by acetonitrile, fourteen kinds of carbonyls in the sample, namely, formaldehyde, acetaldehyde, acrolein, acetone, propionaldehyde, crotonaldehyde, methyl ethyl ketone, methacrolein, butyraldehyde, benzaldehyde, valeraldehyde, tolualdehyde, cyclohexanone and hexanaldehyde were measured by high performance liquid chromatography (HPLC) (HPLC1200, Agilent, USA).

According to the U.S. Environmental Protection Agency (USEPA) technical standard TO-17, VOCs were collected by air sampling pump using stainless steel sorbent tubes coated with Tenax TA (Markes, UK). In order to ensure that the VOCs can fully absorbed by Tenax TA, sampling flow and time were set for 500 mL/min and 20 min respectively. After thermal desorbed (TD), nine kinds of VOCs including benzene, toluene, ethylbenzene, m-xylene, p-xylene, o-xylene, styrene, n-butylacetate, and n-undecane were measured by gas chromatography mass spectrometer (GC–MS) (GC–MS, Agilent, USA).

Parameters setting and methods for HPLC, TD and GC–MS were illustrated in previous research (Dai et al., 2013).

2.5. Evaporative emission test procedure

Evaporative emission consists of diurnal, hot-soak, running, resting and refueling losses. This study was based on evaporative emission test measurement regulated by China's national standard GB20998—2007, which only focuses on DBL and HSL. HSL is generated