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Bioethanol/gasoline blends for fuelling conventional and hybrid scooter. Regulated and unregulated exhaust emissions

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HIGHLIGHTS

- Hybrid scooter ensured stoichiometric AFR even with maximum bioethanol content.
- Fuel containing at least 20% bioethanol involves misfires in conventional scooter.
- Effects of bioethanol use in conventional scooter are THC increasing and PN reduction.
- Both vehicles suffer the aldehyde emission increase when increasing bioethanol.

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ABSTRACT

The aim of this experimental activity was to evaluate the influence of ethanol fuel on the pollutant emissions measured at the exhaust of a conventional and a hybrid scooter. Both scooters are 4-stroke, 125 cm^3 of engine capacity and Euro 3 compliant. They were tested on chassis dynamometer for measuring gaseous emissions of CO, HC, NOx, CO_2 and some toxic micro organic pollutants, such as benzene, 1,3-butadiene, formaldehyde and acetaldehyde. The fuel consumption was estimated throughout a carbon balance on the exhaust species. Moreover, total particles number with diameter between 20 nm up to 1 μm was measured. Worldwide and European test cycles were carried out with both scooters fuelled with gasoline and ethanol/gasoline blends (10/90, 20/80 and 30/70% vol). According to the experimental results relative to both scooter technologies, the addiction of ethanol in gasoline reduces CO and particles number emissions. The combustion of conventional scooter becomes unstable when a percentage of 30%v of bioethanol is fed; as consequence a strong increasing of hydrocarbon is monitored, including carcinogenic species. The negative effects of ethanol fuel are related to the increasing of fuel consumption due to the less carbon content for volume unit and to the increasing of formaldehyde and acetaldehyde due to the higher oxygen availability. Almost 70% of Ozone Formation Potential is covered by alkenes and aromatics.

1. Introduction

In order to enhance a net green-house gases saving, European Directive 2009/28 promoted the use of sustainable biofuels in the transport sector. The directive set the target of 10% (as minimum share the use of energy from renewable sources) by 2020. Bioethanol is considered the most suited fuel for spark ignition (SI) engines. It can be produced from renewable energy sources such as sugar and cereal crops (1st generation) and lignocellulosic biomass (2nd generation) (Sarkar et al., 2012). The main advantage of bioethanol fuel is related to anti-knock potential better than gasoline, which allows to reach higher compression ratio (Koç et al., 2009; Balki et al., 2014; Ghadikolaei, 2016). As consequence, bioethanol reduces regulated gaseous emissions, such as carbon monoxide (CO), total hydrocarbons (THC) and green-house gas (GHGs) emission (Clairotte et al., 2013; Prati et al., 2014).

Recently a lot of research activities were carried out for evaluating the influence of bio-ethanol/gasoline blends on the emissions of powered-two-wheelers. A strong interest was arising to assess the contribution to urban air pollution of this vehicle class, due to the high number of motorcycles circulating in South European and South Asian countries and also to their less sophisticated after

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treatment devices. Some papers indicate that up to 15%vol of ethanol content, ethanol/gasoline blend can be used without any adjustment on the engine, obtaining CO and HC reduction despite of a significant increasing of acetaldehyde (Yao et al., 2009, 2013; Li et al., 2015). Increasing of aldehydes emissions, in fact, constitute the principal disadvantage of using a fuel with a major oxygen content (Yang et al., 2012). Regarding NOx, experimental observations assess that thermal NOx formation is the dominant mechanism, promoting an emission increasing when high bio-ethanol content are fuelled in SI engines (Masumn et al., 2013).

The aim of this paper is to evaluate the influence of bio-ethanol fuel on the exhaust emissions of a conventional and a hybrid (electric/gasoline) scooter, throughout chassis-dynamometer transient tests. Particular attention will be given to carcinogenic compounds (benzene, 1,3-butadiene and formaldehyde) and greenhouse gases (GHG, methane and carbon dioxide) emissions. This last topic assumes a strong interest for the hybrid vehicle, already designed for energy consumption saving and GHGs abatement.

2. Materials and methods

Scooters were tested on a two-wheeler chassis dynamometer (AVL Zollner 20″ – single roller) able to simulate vehicle inertia (from 80 to 450 kg) and road load resistance according to the procedures laid down in Directive 2003/77/EC and Regulation 2013/168/EC. A driver's aid displays speed trace of the driving cycle to be followed with a tolerance of ±3.2 km/h and ±1 s. For simulating actual operating conditions, a variable speed cooling blower is positioned in front of the two-wheelers vehicle. During the tests, the exhaust gases were diluted with ambient purified air by a dilution tunnel connected to a Constant Volume Sampling with Critical Flow Venturi (AVL CFV-CVS) unit. The concentration of carbon monoxide (CO), unburned hydrocarbons (HC), nitrogen oxides (NOx) and carbon dioxide (CO_2) were continuously measured in diluted exhaust by an exhaust gas analysis system (AVL AMA 4000); simultaneously, the average values were measured in a sample bag filled during the test. Particle number (PN) in the dimensional range of 20 nm and 1 μm, was continuously measured by using a Condensation Particle Counter (TSI CPC-P-Track). Unregulated organic pollutants sampled during this experimental activity include some Volatile Organic Compounds (VOC) and carbonylic compounds. A part of diluted exhaust gases sampled in bags was used for measuring VOC from C1 to C7. Chemical analysis was performed with gas chromatography with a flame ionization detector (GC-FID, HP 5980). Carbonylic compounds were trapped on DNPH-cartridge then extracted with acetonitrile and analysed by High Pressure Liquid Chromatography coupled with UV detector (360 nm). Among micro-organic pollutants, some compounds assume a special concern due to their associated risk for human and environmental health. In particular, according to the classification of International Agency of Research on Cancer (IARC), benzene, 1,3 butadiene and formaldehyde are classified as carcinogenic to humans and ethylbenzene and acetaldehyde as possibly carcinogenic to humans (IARC, 2013). Moreover, methane is a very strong GHG. Ozone Potential Formation (OFP) of the measured organic volatiles was estimated throughout Maximum Incremental Reactivity methodology (Carter, 2009).

2.1. Vehicles and fuels

Experimental activity was carried out on a conventional and a hybrid (electric/gasoline) Euro 3 scooter. Concerning exhaust emissions, these scooter belong to the worst and best technology class of circulating two wheelers vehicles. Table 1 summarizes the main characteristics of both vehicles.

Conventional scooter is classified as motorcycle and is equipped with a 4-stroke 125 cm^3 spark-ignition engine. Hybrid motorcycle is a plug-in vehicle. It is equipped with a 4-stroke SI engine (124 cm^3 of displacement) which works in parallel with an electric engine (2.6 kW). During operation electric engine supplies power by using the energy stored inside a Lithium battery (12 V, 2–20 Ah). The battery is externally charged or recover energy during the vehicle braking. The presence of electric propulsion justify the higher weight of hybrid scooter in comparison with the conventional one.

Beside propulsion technology, the two vehicles differ for fuel injection system. The conventional one is equipped with a carburettor whereas the hybrid with an electronic fuel injection. Moreover, the conventional scooter uses an oxy-catalyst for the exhaust pollutant abatement whereas the hybrid vehicle uses a more sophisticated exhaust after-treatment system which includes a lambda sensor and a three-way catalyst.

Both vehicles were fuelled with gasoline and gasoline/ethanol blends. In order to study the effect of oxygen addition coming only from bio-ethanol, an oxygen free base gasoline was used to prepare the blends. In such way, the vapour pressure limit of alternative fuels stated by European legislation is respected. Bio-ethanol was obtained from grape pomace and was provided by I.M.A. s.r.l. Trapani (Italy). Four fuels were tested: Gasoline (G0), bio-ethanol/gasoline blend 10/90% v/v (G10), bio-ethanol/gasoline blend 20/80% v/v (G20) and bio-ethanol/gasoline blend 30/70% v/v (G30). All the fuels were prepared throughout the splash blending procedure, i.e. the bioethanol was simply added to gasoline. Since current legislation allows a maximum content of ethanol in gasoline of 10% vol (equivalent to a maximum oxygen content of 2.7%w), this experimental activity investigated about the use of a legislative fuel (in terms of maximum allowable oxygen content) and two high oxygen content fuels.

2.2. Driving cycles

Exhaust emissions were measured over 2 repetitions of type approval transient driving cycles (DC). In particular, European type approval (ECE) and Worldwide harmonized Motorcycle emission Test Cycle (WMTC) were carried out. They were performed in cold start conditions. Even though both cycle could be used for the homologation, they are different for kinematic characteristics. In particular WMTC is more dynamic than ECE, presenting few time in steady-state conditions. Each DC was divided into two sampling phases (cold and hot) and for each phase, emission factors were measured. In particular, ECE_cold lasts 390 s whereas ECE_hot 780 s since the first includes the repetition of 2 base modules whereas the second includes 4 modules. Both phases are characterised by a maximum speed of 45 km/h and a mean speed of 19 km/h. WMTC_cold and hot have the same duration because they correspond to the same driving cycle consecutively repeated. Their duration is 600 s, the maximum speed 60 km/h and the mean speed 24.2 km/h.

3. Results

3.1. Regulated emissions

In this section, regulated emissions are discussed. Fig. 1 summarizes CO, THC and NOx emissions (expressed as g/km) measured over the ECE and WMTC driving cycles for both scooter. Data are the average values of two repetitions and the variability is explained by the standard deviation bars.

CO emissions states a great difference between the two vehicles. CO emissions of hybrid scooter are much lower than those of conventional one and the relative type-approval legislative limit