Fuel Processing Technology 107 (2013) 50–63

Contents lists available at SciVerse ScienceDirect

Fuel Processing Technology

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

An examination of the effect of ethanol–gasoline blends' physicochemical properties on emissions from a light-duty spark ignition engine

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ARTICLE INFO

Article history:
Received 4 April 2012
Received in revised form 27 June 2012
Accepted 17 July 2012
Available online 7 September 2012

Keywords:
Alternative fuel
Ethanol blends
Regulated emissions
Unregulated emissions
FTIR

ABSTRACT

The addition of ethanol to gasoline has been shown to reduce certain types of emissions, but increase others. Ethanol is rarely used neat as an automotive fuel; blends with standard gasoline are much more common. Low (5%–15%) and higher (85%) ethanol–gasoline blends are currently used; the use of higher blends requires modifications in both the calibration and engine hardware. A series of tests was conducted to determine various physicochemical properties of a range of ethanol–gasoline blends, from E5 (5% ethanol, 95% gasoline) up to E50 (50% ethanol, 50% gasoline). These ethanol–gasoline blends were laboratory tested in an unmodified European passenger car on a chassis dynamometer over the New European Driving Cycle, using a constant volume sampler and analyzers for quantification of both regulated and unregulated exhaust gas compounds. Additionally, particulate mass was quantified by filtering the exhaust gas, and particle number emissions were quantified using a condensation particle counter. The results revealed non-linear changes in response to the addition of ethanol to the base fuel regarding certain parameters; and linear responses regarding others. Regulated emissions, certain unregulated emissions and particulate matter emissions all varied according to the fuel blend employed.

1. Introduction

Ethanol is employed in a wide variety of applications. Knowledge of its suitability for exploitation as a vehicular fuel dates to the conception of the automobile. While geographically its usage is somewhat restricted, ethanol is globally the most widely-used biofuel. Ethanol can be produced from the fractionation of crude oil, but is more commonly produced as a product of the fermentation of biomass; such ethanol is commonly known as 'bioethanol'. Being derived from biomass (and not fossil hydrocarbon deposits), and with the potential to deliver greenhouse gas savings of up to 87% over conventional fossil fuels [1], bioethanol has been identified as a fuel of considerable potential in efforts to make energy consumption in the transportation sector sustainable [2,3]. Bioethanol may be divided into two generations: first generation bioethanol is produced from the fermentation of sugar-rich edible crops, while second generation bioethanol is produced from inedible cellulosic material. As with biodiesel, concern regarding the usage of edible crops as fuel mean that second-generation bioethanol is of great interest. Currently, almost all ethanol is produced from edible crops. Two of the largest global markets are the USA and Brazil. In the USA, corn dominates, while sugar-cane comprises almost all of the Brazilian ethanol market.

Ethanol's properties such as density and octane number make it broadly compatible with modern spark-ignition (SI) engines. Whilst this paper focuses on applications for SI engines, ethanol can also be mixed with Diesel to form blends for use in compression-ignition engines (see, for example, references [3,4]).

Ethanol can be splash-blended with gasoline to form ethanol–gasoline blends, identified by an 'E' followed by the volumetric percentage of ethanol in the blend. (E5, E10, and E85 are common blends.) As early as 2007, nearly 40% of all the gasoline sold in the USA contained added ethanol; [5] blends up to E10 are permitted for sale in the European Union [1].

The physicochemical characteristics of ethanol-containing fuel blends have various impacts on the fuel delivery [5], ignition and combustion processes, and on the temperature and functionality of catalytic after-treatment systems, leading to measurable alterations in the composition of the exhaust gas [3]. One of the distinguishing characteristics of ethanol is that it is an oxygenated fuel, in comparison to gasoline, diesel, LPG etc, none of which contain appreciable quantities of oxygen. The presence of an oxygen atom means that ethanol can be thought of as a partially oxidized fuel [6,7]. The hydroxyl (—OH) group's polar bond makes ethanol a polar molecule. The short carbon chain length (only two carbon atoms) and the total absence of C C bonds further differentiate ethanol from the mixture of hydrocarbons that comprise standard gasoline.

A large number of studies have been conducted on the effect of gasoline–ethanol blends on exhaust emissions from light-duty vehicles featuring SI engines. Studies have examined regulated emissions [8–10], as well as unregulated emissions and speciated hydrocarbons [8,10]. Regarding regulated emissions, the trend observed is for emissions of HC and CO to reduce with increasing ethanol content

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0378-3820/$ – see front matter
doi:10.1016/j.fuproc.2012.07.030

Nomenclature

E5	ethanol–gasoline blend with a nominal ethanol content of 5 Vol. %
Ex	ethanol–gasoline blend with a nominal ethanol content of *x* Vol. %
EUDC	extra-urban driving cycle
FTIR	Fourier Transform Infra-Red
NEDC	New European Driving Cycle (UDC + EUDC)
ppm	parts per million
PM	particulate matter
PN	particle number
UDC	urban driving cycle
vol.%	volumetric percentage proportion

(a review of recent findings can be seen in reference [8]). The situation regarding NO_x is less clear: increased emission of NO_x has been reported when using blends with higher ethanol content [8], but these increases are not consistent [8], and may be statistically insignificant in some cases [11]. The addition of oxygenates to gasoline generally increases NO_x emissions [12], while there are various theoretical reasons to expect emissions of NO_x to decrease with increasing blend ethanol content (discussed in reference [12]).

Increasing interest in as-yet unregulated emissions which may be targeted in future legislation has lead researchers to consider the impact of biofuels and biofuel blends on these emissions. Pollutants of interest in this category include ammonia, particulate matter (PM), nitrous oxide and various hydrocarbons (particularly aldehydes [8,10]). While ethanol is a partially oxidized fuel, it can be further oxidized without combusting completely to produce aldehydes (formaldehyde and acetaldehyde). Even relatively low ethanol blends have been reported to produce substantially greater emissions of aldehydes than standard gasoline; for E85 the increase can be of the order of 100% [10,13,14].

The aim of this study was to obtain further insight into both regulated and unregulated emissions, using an unmodified vehicle and the standard European Union test procedure, with additional measurements for quantification of unregulated emissions.

2. Experimental programme

A series of experiments was performed to determine the effect of increasing the ethanol content of standard European gasoline (E5) on physicochemical properties of the fuel, and the resulting impact on concentrations of gaseous and solid pollutants in the exhaust gas. Four tests were performed for each fuel blend using the equipment described below.

2.1. Test fuel blends and test vehicle

A typical European gasoline was selected and used as the base fuel. This fuel's legal standing was that it met all requirements of EN228, including containing a nominal 5% ethanol. Ethanol-blended gasoline blends E10, E25, and E50 were procured. Samples of all blends were subjected both to a physicochemical analysis and to emissions testing in the test vehicle. An unmodified European passenger car was used as the test vehicle in this study. The vehicle featured an SI engine of approximate displacement 1200 cm^3, and was certified for the Euro 5 emissions standard for its engine type. At the start of testing, the vehicle had a mileage of around 59,000 km. Following preliminary investigations, it was determined that the drivability of this vehicle was unimpaired when running on blends E10, E25 and E50, and so emissions tests were conducted on all four blends (between them covering an order of magnitude of volumetric ethanol content).

2.2. Test laboratory and test cycle

All emissions tests were conducted in the exhaust emission laboratory at BOSMAL Automotive Research and Development Institute Ltd (Bielsko-Biala, Poland). This advanced climate-controlled facility permits quantification of regulated emissions in accordance with the latest European and US legislation; the laboratory is described in detail elsewhere [15]. The test vehicle was tested on the laboratory's chassis dynamometer, which is housed within the climatic chamber, as shown in Fig. 1. The test

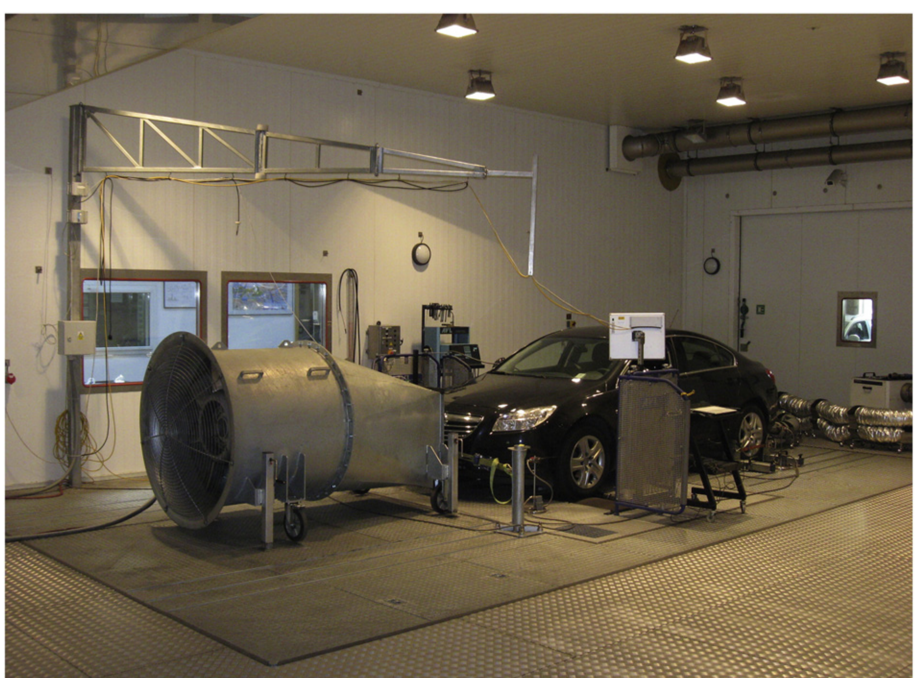

Fig. 1. A vehicle mounted on the chassis dynamometer within the climatic chamber.