Applied Energy 88 (2011) 4989–5001

Contents lists available at ScienceDirect

Applied Energy

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

Effects of 30% v/v biodiesel/diesel fuel blend on regulated and unregulated pollutant emissions from diesel engines

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ARTICLE INFO

Article history:
Received 13 April 2011
Received in revised form 27 June 2011
Accepted 28 June 2011
Available online 23 July 2011

Keywords:
Biodiesel emissions
Particulate matter
PAHs
Aldehydes
Carcinogenic risk evaluation
Ozone formation potential

ABSTRACT

Two Euro 3 commercial trucks fuelled with a 30% v/v biodiesel/diesel fuel blend (B30) and pure diesel fuel were tested in laboratory under the standard driving conditions (UDC and EUDC driving cycles) and the CADC "URBAN" test cycle, in order to evaluate the fuel consumption, regulated (CO, HC, NO_x, PM) and unregulated emissions (aldehydes and polycyclic aromatic hydrocarbons).

After substitution of diesel fuel with B30 the following results were observed.

The fuel economy increased proportionally to the deficit of the fuel heating value; so the average efficiency of the engine can be considered almost unchanged.

In partial disagreement with the literature data, CO and HC emissions showed a slight increase, whereas NO_x emissions did not vary. It must be noted that these variations did not pass the statistical significance test.

On the contrary, PM, soot fraction and particle number showed a significant reduction; furthermore, nearly 90% of the emitted particles had an aerodynamic diameter less than 0.1 μm.

The formaldehyde emission markedly increased for both vehicles, whereas acetaldehyde emissions showed ambiguous trends. Since the remaining aldehydes were under the instrumental detection limit, the ozone formation potential analysis with B30 showed a raise almost proportional to the formaldehyde emission increase.

Moreover the lightest and most abundant PAHs species (3–4 benzene rings) showed high increases even if to different extent for the two vehicles. The species with 4–5 rings (such as benzo(a)pyrene) showed a net reduction, often under the instrumental limit. Finally, the carcinogenic risk evaluation of PAHs exhibited a clear toxicity reduction, specially in the cold start cycle, when the catalytic converter's efficiency was not fully reached.

1. Introduction

The use of biofuels have been stimulated by European Commission with EN 2003/30/CE directive [1], which imposed the 5.75% based on energy content of biofuels (both biodiesel and bioethanol) in the automotive fossil fuels.

The use of biodiesel in modern engines with advanced injection systems has been widely tested in recent years; this led to the definition of the EN 14214 [2] standard regarding minimum quality requirement of biodiesel and laboratory test methods for its characterization.

At present in Europe, biodiesel is blended up to 30% with diesel (B30 blend), but only B7 is considered interchangeable with conventional diesel.

Many studies and experimentations have been carried out to investigate the effects of biodiesel on engine performance and emissions [3–15]. The results, however, are widely scattered and often controversial, mostly because of the characteristics of test engines, test cycles, and the biodiesel feedstock. Nevertheless, some trends can be drawn, as shown in review [3]. The carbon monoxide (CO), the unburned hydrocarbons (HC) and the particulate matter (PM) decrease with an increase in biodiesel content in a blend. The reason of this behaviour is the oxygen content of the biodiesel, which allows a more complete combustion and soot oxidation. The nitrogen oxides (NO_x), on the contrary, increase with biodiesel rate, even if many experimentations show the opposite [3]. The most popular theory explains this behaviour with the advanced combustion phase as a consequence of the advanced injection caused by the lower compressibility (i.e. higher bulk modulus) of biodiesel; this results in higher peaks of temperature and higher thermal NO_x production [3].

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doi:10.1016/j.apenergy.2011.06.045

The biodiesel causes an increase in fuel consumption proportional to its lower Net Heating Value (NHV), but the engine efficiency does not significantly decrease [3].

Recent research developments focused on performance and emissions of biodiesel derived from new feedstock [16], from tallow [17], and from waste cooking oil [18]. Biodiesel was also studied as blend with methanol [19] and as pilot fuel in Dual-fuel compression–ignition engines [20].Other research developments focused on the emission reduction by acting on the injection system parameters [21,22] or by using additives [23]. Performance ands emissions of raw vegetable oils were also investigated [24,25].

In the unregulated emissions category many classes of chemical compounds are included: monoaromatic hydrocarbons (MAHs), polycyclic aromatic hydrocarbons (PAHs), the N-PAHs, aldehydes. Several medical studies proved the dangerousness of these compounds as carcinogenic and mutagenic agents. The International Agency for Research on Cancer (IARC) classified many chemical compounds on the basis of their carcinogenic risk level to humans and grouped them into the following five groups [26]:

Group 1: The agent is *carcinogenic to humans.*
Group 2A: The agent is probably carcinogenic to humans.
Group 2B: The agent is possibly carcinogenic to humans.
Group 3: The agent is not classifiable as to its carcinogenicity to humans.
Group 4: The agent is probably not carcinogenic to humans.
Following IARC's classification, the exhausts of a diesel engine belong to Group 2A, formaldehyde and some PAH belong to Group 1.

The unregulated emissions are not yet widely investigated; some recent papers dealt with them without giving conclusive answers [27–41].

Turrio-Baldassarri et al. [27] measured the regulated and unregulated emissions in a EURO 2 engine fuelled with B20 and diesel running on ECE R49 stationary cycle. Regulated emissions, PAH and N-PAHs of B20 blend showed slight reduction, which however did not result statistically significant; formaldehyde, on the contrary, increased by 18%. Mutagenic and toxicological tests showed similar behaviour with the two fuels.

Comparing two types of biodiesel and fossil diesel in stationary tests, Cardone et al. [28] found a 80% reduction in total PAHs, nearly independently from engine load, and increase in total aldehyde production variable between 27% and 90%.

Correa and Arbilla [29] measured emissions of B20 on an engine running at constant speed and found reductions of 20% for MAHs and 17% for PAHs. The same authors measured also the carbonyl compounds emitted from a diesel engine fuelled with a B20 blend at three different speeds and found increments of 35% of formaldehyde and 22% acetaldehyde [30]. Also Guaireiro et al. [31] observed a 16% increase in formaldehyde emission, but a reduction of 35% for acetaldehyde when testing pure biodiesel at constant speed. On the other hand, they found acrolein emission increased by about 340%. Opposite trends are shown by Peng et al. [32]: waste cooking oil biodiesel blend B20, on a 2.8 L engine running on a US transient cycle protocol, produced 23% less aldehydes than traditional diesel. Lin [33] found strong reduction of PAHs (90%) for pure palm biodiesel on a stationary engine running at 75% load. In an investigation analogous to the present one, Karavalakis et al. [34] tested a light vehicle on a chassis dynamometer using NEDC and CADC standard cycles. They found that some PAH increases, N-PAH and aldehydes decreases with biodiesel.

As regards the influence of the wear on emission level, slight increase in CO and HC emission level and a decrease of NO_x and PAH with mileage was observed [35–37]. Peng et al. [32] showed that the effects of increasing mileage on aldehyde emissions are insignificant.

When biodiesel is used in boilers, it shows analogous emission behaviour as in engines, except for slight reduction in NO_x sometimes recorded [42]; for unregulated emissions strong reduction in PAH content and strong increase of formaldehyde were found [43].

The likely future penetration of biodiesel poses the question about its emission levels on the road. At present, non regulated emissions cannot be measured with on board techniques, so it is necessary testing vehicles on chassis dynamometer using standard cycles: ECE, EUDC, NEDC in Europe, FTP '75 in USA. However, these cycles are not representative of the performance and emissions in real-world driving conditions. In fact, they show low load levels, in particular of the "relative positive acceleration" far from typical values of the urban and extra-urban traffic conditions [44]. For this reason, more realistic cycles were studied, such as Artemis cycle, which was developed by the European Commission Artemis Project [45].

Since the aim of this paper is to supply reliable values of on-road consumption and emissions of biodiesel blend, both standard emission testing cycles and "URBAN" Artemis cycle were used to test two light duty vehicles. This vehicle class was chosen because it is spread in urban areas for bill of goods and foods.

The core of this paper is the measurement of regulated emissions (CO, NO_x, HC and PM) and of two classes of unregulated emissions: PAHs and aldehydes.

This work was carried out at the Test Laboratories of Stazione Sperimentale per i Combustibili (Experimental Fuel Station – Public Institute operating within the framework of the Italian Ministry of the Economic Development).

2. Experimental

2.1. Test vehicles

Two Euro 3 Light Duty vehicles (category N1), equipped with a common-rail direct injection diesel engine, were tested in this investigation; in Table 1 their main characteristics are reported. The Euro 3 emission Standard was chosen because it is representative of the greater part of the Italian fleet of commercial diesel vehicles in the next 4–5 years. Both vehicles are equipped with oxidation catalyst (DOC) and exhaust gas recirculation (EGR).

2.2. Test fuels

The test vehicles were initially fuelled by a commercial diesel meeting the fuel quality requirements (EN 590, [46]) for diesel vehicles; afterwards they were fuelled by a blend of the same

Table 1
Main characteristics of the two test vehicles.

Vehicle	Renault Master	Renault Trafic
Model	120 dCi	100 dCi
Type approval	Euro 3	Euro 3
Mileage	~66,000 km	~101,000 km
Weight	1930 kg	1810
Displacement	2463 cc	1870 cc
No. cylinders/no. valves/cyl	4/4	4/2
Power	84 kW @ 3500 rpm	74 kW @ 3500 rpm
Torque	290 N m @ 1600 rpm	240 N m @ 2000 rpm
Intake air system	TC	TC
Fuel delivery system	*Common rail*	*Common rail*
Antipollution devices	Oxydation catalyst (DOC)	Oxydation catalyst (DOC)