Fuel Processing Technology 122 (2014) 64–71

Contents lists available at ScienceDirect

Fuel Processing Technology

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

Pollutant emissions from New European Driving Cycle with ethanol and butanol diesel blends

Octavio Armas *, Reyes García-Contreras, Ángel Ramos

Escuela Técnica Superior de Ingenieros Industriales, Universidad de Castilla La Mancha, Edif. Politécnico, Av. Camilo José Cela, s/n, 13071 Ciudad Real, Spain

ARTICLE INFO

Article history:
Received 22 June 2012
Received in revised form 21 March 2013
Accepted 21 January 2014
Available online 9 February 2014

Keywords:
Diesel engine
Ethanol–diesel blends
Butanol–diesel blends
Pollutant emissions
NEDC
Transient operation

ABSTRACT

In this study, regulated gaseous emissions, smoke opacity and particle concentration derived from diesel fuel and two blends with alcohols (10% of ethanol and 16% of butanol) have been studied. A turbocharged, direct injection (DI), diesel engine equipped with common rail, injection system and EGR strategy was tested in test bench with road load simulation (RLS) during the New European Driving Cycle (NEDC). The tests were carried out always measuring upstream of the diesel particle filter (DPF). Results show slight increases in NO_x and THC emissions with alcohol blends whereas CO emissions were reduced with these fuels. Particle mass (PM) was estimated from both the smoke opacity and particle size distributions. In both cases, important benefits are observed with alcohol blends.

1. Introduction

The interest and use of alcohol blends have increased in recent years. The alcohol most widely used (in blends) in diesel engines is ethanol due to its renewable origin (it can be produced by alcoholic fermentation of must from sugared or starchy vegetable materials) and its high oxygen content. However, the use of high percentage of ethanol in blends with diesel is limited because this alcohol has low cetane number, low heating value, low lubricity, high volatility and poor miscibility with diesel fuel. The stability of ethanol–diesel blends depends on the temperature, the percentage of ethanol and moisture [1]. Usually, at temperatures below to 10 °C it is necessary to incorporate additives to ensure the blend stability [2].

Numerous studies with ethanol–diesel blends (called e-diesel) have been carried out and important reductions in smoke opacity and PM emissions (with respect to diesel fuel) have been obtained [3–5], especially at high load [6,7]. Usually higher THC emissions were observed (especially in cold conditions) [8,9] whereas no clear trends are observed in NO_x emissions. Although only a few works have studied the effect of these blends under controlled transient conditions, benefits were also observed in smoke opacity [10] and in particle concentration (accumulation mode) [11] without remarkable penalty in NO_x emissions [12]. During on-board studies, smoke opacity reductions were also observed in both steady and transient sequences [13].

Butanol has become the strongest competitor of ethanol for use in diesel engine. Traditionally, butanol has been produced from petrochemical feedstocks but new routes to obtain this alcohol from renewable raw material are being studied. Bio-butanol could be produced by acetobutylicum fermentation and nowadays one of the aims of biorefineries is to produce higher alcohols from shorter alcohols. In this process, ethanol and methanol are produced by via fermentation and biomass gasification, respectively, and later these alcohols are converted into higher ones via the Guerbet reaction [14]. Butanol has higher heating value and cetane number, less volatility and it is less hydrophilic than ethanol. Also, butanol is less polar than shorter alcohols which favor miscibility with diesel fuels [15]. All these properties are closer to diesel fuel which makes butanol an alternative to ethanol as fuel (in blend with diesel) in compression ignition engines.

Despite the mentioned advantages of butanol, only some studies about performance and emissions with these alcohols have been carried out, in all of them highlight the notable reduction in smoke opacity with respect to diesel fuel, this reduction being higher as the percentage of butanol in the blends increases [16–18].

Related to transient conditions with butanol–diesel blends, Rakopoulos et al. [19,20] observed lower smoke opacity values with alcohol blends (with respect to diesel fuel) and slight increases in NO_x emissions during hot starting and during different acceleration tests, respectively. Miers et al. [21] studied the performance and emissions of two butanol–diesel blends (20% and 40% of alcohol) in two American driving cycles. In this work, as the percentage of butanol

---

* Corresponding author.
E-mail address: octavio.armas@uclm.es (O. Armas).

0378-3820/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.fuproc.2014.01.023

Table 1
Main vehicle and engine characteristics.

Vehicle		Transmission	
$C_d * A$ (m^2)	0.83	Type	Manual 6 gears
Weight (kg)	1608	1st gear ratio	3.727
Engine		2nd gear ratio	2.043
Cylinders	4	3rd gear ratio	1.322
Displacement (cm^3)	1994	4th gear ratio	0.947
Bore (mm)	84	5th gear ratio	0.723
Stroke (mm)	90	6th gear ratio	0.596
Power max. (kW)	110 at 4000 min^{-1}	Differential ratio	4.266
Torque max. (Nm)	323 at 2000 min^{-1}	Tires	
		Code	215/65R16

increased, THC and CO emissions were higher whereas an important reduction in smoke opacity was observed with respect to diesel fuel.

The benefits observed, mainly in smoke opacity and PM, with ethanol and butanol blends with respect to diesel fuel, have been commented previously, but the literature regarding the comparison of both alcohols is limited. Sukjit et al. [22] studied the effect of these alcohol blends (with addition of biodiesel) on the emissions in steady conditions, observing notable reductions of soot with these blends, the results with the butanol one being slightly lower. However, in the work of Rakopoulos et al. [23], the benefits in smoke opacity were slightly higher with ethanol–diesel blends than those corresponding to butanol–diesel blends in some test conditions, while similar smoke opacity results were observed in the study developed by Pepiot et al. [24]. Engine start test, at cold and warm conditions, with the same alcohol blends than those used in this work, was carried with benefits in smoke opacity and PM emissions in warm conditions but no significant differences were observed between both blends [25]. Certification cycles are also commonly used to compare the effect of fuels on emissions. Some studies have been carried out under New European Driving Cycle (NEDC) using biodiesel and/or Fischer Tropsch fuels [26,27], but references using this certification cycle or similar cycles for comparing alcohol blends have not been found. The aim of this work is to evaluate the influence of ethanol–diesel and butanol–diesel blends (10% of ethanol and 16% of butanol (in volume)) on regulated emissions. These blends show notable benefits in CO and PM emissions with non important penalties in THC and NO_x emissions.

Table 2
Accuracy and time response of gaseous emission analyzers.

Gases	Accuracy (provided by manufacturer)	Total response time (measured) (s)
CO	±0.02 v/v	~3.3
CO_2	±0.32 v/v	~3.3
THC	±20 ppm	~2.4
NO_x	±30 ppm	~0.7

2. Experimental setup and procedure

2.1. Test engine and equipment

The experimental work was carried out in a 4 cylinder, 4-stroke, turbocharged, intercooled, with common-rail injection system, 2.0 L diesel engine (NISSAN, model M1D). The engine was equipped with cooled exhaust gas recirculation (EGR), oxidation catalyst (DOC) and a regenerative wall-flow type diesel particle filter (DPF). The engine was linked to an asynchronous electric dynamometer system (Schenck Dynas III LI 250) provided with Road Load Simulation (RLS) tool. This tool has the capability for reproducing or simulating the load of a concrete vehicle, in an engine test bed. In this work, a NISSAN Qashqai 2.0 dci was simulated during the tests. The main characteristics of both the vehicle and the engine are shown in Table 1. Besides, RLS allows to simulate different driver behaviors, in this case a calmed (neither hard nor soft) driver has been selected.

The INCA PC software and the ETAS ES 591.1 hardware were used for the communication and management of the electronic control unit (ECU). Fuel injection strategy was not externally controlled during the tests.

Downstream of the DOC, the exhaust pipe was modified including a by-pass (one line with DPF and the other one without DPF as shown in Fig. 1), in order to measure pollutant concentrations with and without the effect of diesel particle filter (DPF). To study the effect of fuel composition on emissions, in this work the exhaust gas always flowed through the line without DPF. A general scheme of the experimental installation is presented in Fig. 1.

CO and NO_x gaseous emissions were measured with a heated non-dispersive infrared analyzer and with a zirconia sensor respectively,

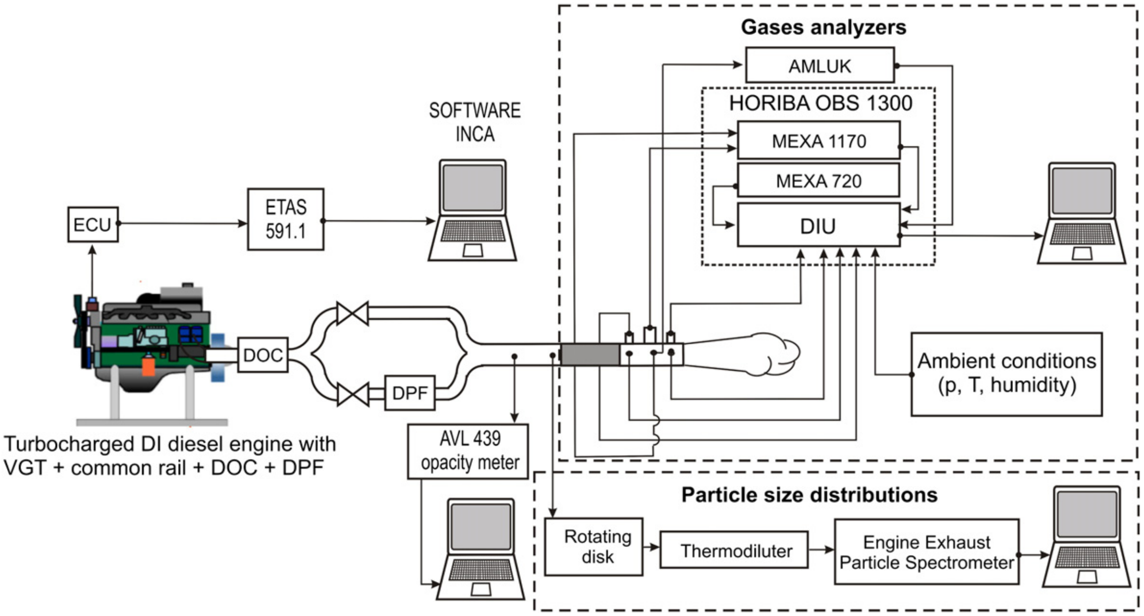

Fig. 1. Experimental installation.