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Characterization of light duty Diesel engine pollutant emissions using water-emulsified fuel

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Abstract

In this work, the effect of water–oil emulsions on the engine performance and on the main pollutant emissions, NO_x, total hydrocarbons (THC), soot, particulate matter (PM) and its composition, was studied. A turbocharger intercooler indirect injection (IDI) Diesel engine was tested under five different steady state operating conditions, selected from the transient cycle for light duty vehicles established in the European Emission Directive 70/220. Tests were performed using a commercial fuel as a reference and an emulsified fuel for each operating condition. Results reported here suggest that the water emulsification has a potential to slightly improve the brake efficiency and to significantly reduce the formation of thermal NO, soot, hydrocarbons and PM in the Diesel engine.

Keywords: Diesel engine; Water–oil emulsified fuel; Pollutant emissions

1. Introduction

The trend towards more stringent regulations on emissions has been an important driving force in the search for internal combustion (IC) engines more environmentally friendly. The literature on this topic can be classified into three groups. The first group contains works dealing with the development of systems to improve fuel mixture and combustion [1]. The second group of works addresses the study of alternative fuels and additives for conventional ones [2]. The third group of recently published papers report on new post-treatment devices [3].

The present work belongs to the second group of studies reporting an experimental investigation about the influence of water–oil emulsifying on the main pollutant emissions, namely particulate matter (PM), total gaseous hydrocarbons (THC) and NO_x, in an IDI Diesel vehicle engine tested under different operating modes, selected as characteristic conditions of the European cycle for the certification of light duty engines. The PM emissions have been studied in more detail, analysing the emulsification-induced changes in the amount, morphology and composition of these particularly toxic emissions.

All the reviewed works about preparation and use of water–Diesel emulsions have been focused on different aspects of the effects of this fuel on the engine performance and emissions. In general, the main conclusions of these works can be summarized as follows:

1.1. Physical properties and ther effects on injection and mixing processes

The main affecting properties are density, viscosity and bulk modulus of elasticity. In all cases, an increase of the value of these properties with water concentration was observed. In case of viscosity, Sawa et al. [4] observed an increase proportional to the ratio between surface area Sp/Se. Se is the surface area of emulsified fuel and Sp is the sum of surface area of distributed water droplets, both areas being assumed spherical. In case of density, the authors concluded that emulsion density is a little smaller than that

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obtained from averaging the fuel and water densities. The emulsion density value depends on the amount air bubbles in the emulsion as a result of the preparation process. Likewise, the authors concluded that an increase of air bubbles carries a decrease of bulk modulus.

The increased viscosity of emulsified fuel tends to advance injection timing in some injection systems due to the modification of the dynamics of the command hydraulic system. This effect is mainly due to the flow variations through the control circuit [4–6].

With the use of emulsions an improvement in mixing process was observed. This improvement is caused by two confirmed phenomena. The first, consists of an additional momentum in jet behaviour [6,7]. The second and more important, is based on the internal droplet micro-explosions of water, which produce a secondary atomisation, thus improving the mixing process. [8–13]. The mentioned micro-explosion phenomenon is induced by the volatility difference between the water and the fuel [14,15].

1.2. Effect on combustion process and emissions

In an important number of reviewed studies, the authors have observed that an increase of water concentration in the emulsion produce a significant increase in the ignition delay, due to the heat absorption by water vaporisation in the fuel jet [5,7,8,10,13,16–20].

Another proven benefit of the emulsion as Diesel fuel is that the heat absorption by water vaporization causes a decrease of local adiabatic flame temperature and therefore reduces the chemical reaction in gas phase to produce thermal NO, depending, in some cases, of engine operation mode [6,7,10,12,18,21–23].

The improvement on vaporization and mixing processes leads to a shorter combustion reaction. This effect can help to reduce soot, PM, CO and HC formation [4–10,12,13, 16–21,23,24].

1.3. Effect on engine performance

The effects of the emulsified fuel on the engine performance are different from one study to another. The obtained results depend, mainly, on the engine operation mode [5,6,10,12,16,19,25–28], type and tuning of the injection system [17,18,22], and finally, on the optimised combustion chamber configuration [29]. When the emulsified fuel is used, the most probable reason to obtain improvement in specific fuel consumption or thermal efficiency is the reduction of heat losses [30,31].

2. Fuel properties

Two fuels were tested: a commercial fuel and the same fuel after emulsification with a 10% w/w of water. Their main characteristics are summarized in Table 1 [32].

Table 1
Chemical characteristics and properties of emulsified fuel and commercial Diesel fuel

Fuel	Diesel	Emulsified fuel
Density (kgm^{-3})	839.3	850.0
Cetane number	52.4	44.5
Viscosity (cSt)	2.869	3.210
Lower heating value (MJkg^{-1})	42.97	40.51
Sulphur content (ppm w)	294	265
Distillation T50 (°C)	276.2	248.6
Final boiling point (°C)	371.8	344.6
Elemental analysis		
C (% w/w)	86.120	77.510
H (% w/w)	12.970	12.780
S (% w/w)	–	–
N (% w/w)	0.060	0.054
O (% w/w)	–	8.888
Aromatic content (% w/w)	30.03	27.03
Polyaromatic content (% w/w)	0.53	0.48
Molecular weight (gmol^{-1})	212.4	193.0
Summarized formula	$C_{15.243}H_{27.548}N_{0.009}$	$C_{15.243}H_{27.548}N_{0.009}$ + 10% w/w H_2O
Adiabatic flame temperature (K)	2740.2	2714.4

In particular, the changes in density, viscosity and heating value respect to the commercial fuel must be noticed. The density is a measure of the mixture efficiency. The viscosity must be close to that of the reference fuel in order to avoid problems with the injectors. The heating value affects the effective power.

The summarized formula of both fuels is calculated from the elemental analysis and the molecular weight.

2.1. Production of emulsified fuel

Fig. 1 shows a scheme of the device used for the preparation of the emulsified fuel. This fuel was produced using a Hartmann whistle [33] coupled to a gear pump and two tanks, one for water and the other for the Diesel fuel with the surfactants recommended by Repsol-YPF company (polyethylenglycole monoleate and sorbitole sesquioleate).

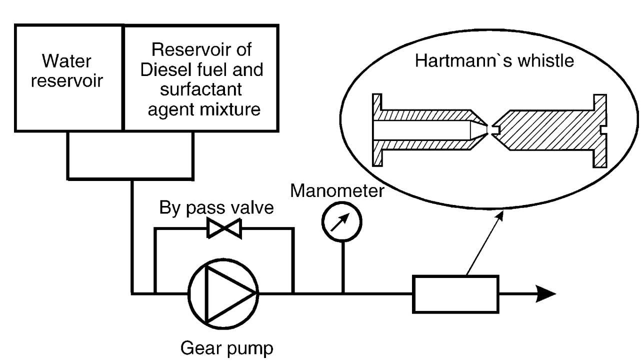

Fig. 1. Scheme of the device used for the preparation of emulsified fuel.