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Effects of Waste Cooking Oil Biodiesel Use on Engine Fuel Consumption and Emissions: a Study on the Impact on Oxidation Catalyst and Particulate Filter

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Abstract

The wide use of biodiesel has been driven by its reduction potential on greenhouse emissions from diesel engines without significant technological modifications.
In this study a diesel engine for non-road applications has been fuelled with Waste Cooking Oil biodiesel blended with commercial fossil fuel at 6% and 30% v/v. In line with literature trends, experimental results indicate a significant reduction of PM emissions and only a slight increase in NOx emissions.
This study has been focused on diesel emissions and in particular on the analysis of PM/NO_2 ratio in presence of the Diesel Oxidation Catalyst (DOC). In fact, although the NO_2/NOx ratio on raw exhaust is almost unaffected, the use of biodiesel shows a slight reduction of the NO-NO_2 light-off temperature. This reduction can ensure more favorable operating conditions for the Diesel Particulate Filter (DPF), and has a positive effect on fuel consumption reduction. In order to deeply analyze these issues, a numerical model of an Aftertreatment system (AS) representing the a DOC and a DPF has been developed and validated with experimental data.

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Keywords: Biodiesel; Diesel Oxidation Catalyst; Diesel Particulate Filter; Emissions

1. Introduction

The increased use of biodiesel fuels requires investigations on the related impact on both engine emissions and Aftertreatment System (AS) behavior. Several studies have already proved that biodiesel reduces PM, CO and HC emissions, mainly due to its fuel oxygen content, while higher uncertainty

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regards the increase of NOx emissions, due to several involved factors such as differences in injection and ignition timings, injection parameters, spray formation, soot radiation, EGR rate, etc [1-3].

However few studies have examined the impact of biodiesel use on the AS behavior and only in the last decade some attention has been given to the analysis of DPF performance during loading, passive regeneration and active regeneration processes. With respect to this point, in this paper an experimental study of a non-road Diesel engine coupled to a DOC-DPF system is proposed to analyze several effects of biodiesel blending on the operation of the AS, in terms of PM-NO_X engine-out trade off, NO-NO_2 conversion efficiency of the DOC and soot reactivity.

2. Experimental Setup

Engine tests were performed at the engine test bench of the University of Rome “Tor Vergata” on a non-road 4.0 liter diesel engine DEUTZ “TCD 2012 L4”. The exhaust AS includes a DOC and a DPF. Two different blends, B06 and B30, have been studied by blending fossil fuel and Waste Cooking Oil biodiesel.

Further details on fuel specifications and the emission measurement instruments rig configuration for emissions monitoring can be found in [4].

2.1. Engine test matrix

Steady-state engine emissions and AS behavior over a 3-4 h transient period were evaluated during the repetition of the six engine modes described in [4]. The baseline engine calibration has been hold in order to analyze its different response to attain the defined mode by varying blend.

The DOC steady state conversion efficiency was evaluated performing a repetition of engine modes in order to have an increasing inlet DOC temperature.

3. Results and discussion

3.1. Engine performances and emissions

The biodiesel lower heating value (-3.9%) gives an average increase of 2.8% in brake specific fuel consumption (BSFC) of B30 with respect to B06. On the other side, the lower B30 stoichiometric air-fuel ratio compensates for its lower air/fuel ratio and thus the equivalence ratio is slightly higher (+1.1%).

An increased injection pressure and duration, in order to compensate for biodiesel lower heating value [3], can be considered the reasons for the slight increase of NOx emissions (+2.6%) as reported in [4]. The significant reduction of PM emissions (-6.8%) is primarily due to the higher oxygen content of the B30 blend, as it is proved by the increased emission reduction at high engine load [4], where the combustion is mostly diffusive and local rich zones are more present [5, 6]. Furtherly, no solid conclusions can be drawn about CO emissions (particularly at low load conditions) while a limited increase in CO2 emissions (+1%) is a result of the lower air-fuel ratio [7].

3.2. DOC conversion efficiency

In order to analyze the contribution of NO-NO_2 conversion efficiency on DPF operation, both steady-state and transient analyses have been carried out. The steady-state NO_2/NOx ratio shown in Figure 1 highlights a similar trend upstream of the DOC. The analysis of the downstream ratio gives two main indications:

- Below 190°C the NO-NO_2 conversion efficiency is negative for both the blends, probably due to NO_2 reduction by HC [8]
- Between 255 and 380°C the B30 has a slightly higher efficiency. This increase can be mainly attributed to the well-known HC emissions reduction with biodiesel fuelling in such a way that NO oxidation inhibition is lower [9]. In fact, as a numerical model [10] has also demonstrated, the slight different inlet thermal conditions (mass flow rate and temperature) between the blends don't influence that behaviour.

The transient results confirm that B30 gives a higher conversion efficiency, as it is shown in Figure 1.

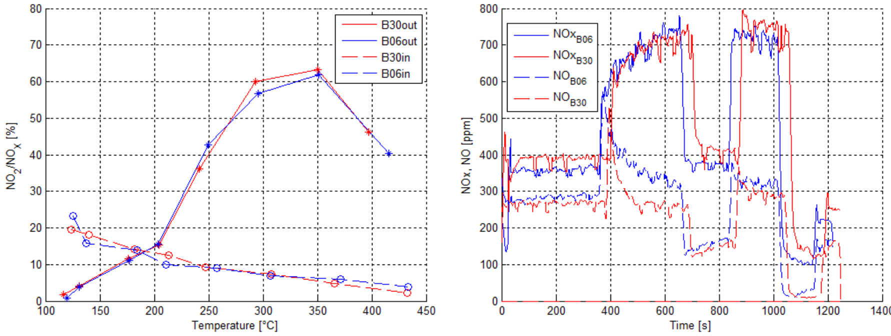

Fig. 1. Steady state (left) and transient (right) NO-NO_2 conversion efficiency of the DOC

3.3. DPF loading and regeneration processes

During the transient engine tests, PM concentration has also been measured in order to understand the biodiesel combined effects on both engine-out PM reduction and NO2 increase at DPF inlet. Indeed a low PM/NO2 ratio can enhance passive DPF regeneration and thus ensure fuel consumption reduction. The analysis of average emissions highlights a 26% PM reduction for B30 with respect to B06. Moreover, the increased NOx emissions (+5%) combined with an increased NO2/NOx ratio (+23%) allows for a total 44% reduction of the PM/NO2 ratio for the B30 blend. This measured parameter can be one of the factors which gives the non linear trend of the B30 DPF backpressure curve of Figure 2, measured during the transient 3-4h period, and that can be related to an enhanced reduction of the trapped PM.

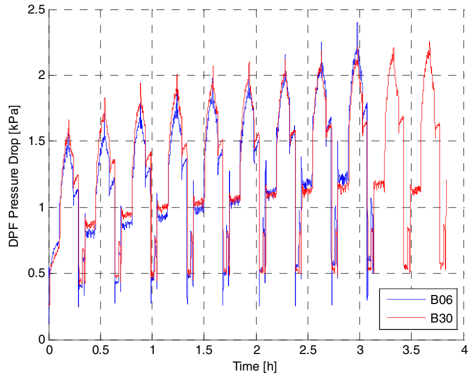

Fig. 2. DPF backpressure curves for the two blends measured during transient tests

Furthermore, the experimental validation of an in-house numerical model [4] has highlighted that, although the lower PM/NO_2 ratio could have enhanced trapped mass reduction, the main factor has to be attributed to a reduction of the activation energy of the passive regeneration. This result – a higher B30 soot reactivity – has been confirmed by a preliminary thermo gravimetric analysis (TGA) of the PM emitted by the two blends [4]. This higher reactivity of the PM emitted by biodiesel combustion has also been confirmed in the literature [11, 12] and is currently under investigation.

4. Conclusions

In this paper several engine tests have been carried out to analyze biodiesel fuelling effects on engine performances and emissions and the Aftertreatment System behavior. A numerical model has been developed and validated in order to understand the main factors affecting the mentioned variations.

The lower heating value of biodiesel can be considered the main reason for the higher BSFC of the B30 blend and the slightly higher NOx emissions, while its higher oxygen content the one for the PM reduction.

Both the combination of the biodiesel effect on PM reduction and increased DOC conversion efficiency can enhance passive DPF regeneration. Moreover, a higher PM reactivity should be taken into account as the main factor in order to explain the significantly higher DPF trapped mass reduction in the B30 case.

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Biography

Matteo Nobile was born in Rome in 1988. In 2012 he graduated cum Laude in Mechanical Engineering at the University of Rome "Tor Vergata". Currently he is a PhD student in Industrial Engineering at the same University. His research activities concern experimental and numerical analysis toward innovative solutions for sustainable transportation technologies such as: power management optimization of Plug-In Hybrid Electric Vehicles and advanced aftertreatment solutions for the integrated use of biofuels in Diesel engines.