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Impact of hydrocracked diesel fuel and Hydrotreated Vegetable Oil blends on the fuel consumption of automotive diesel engines

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ABSTRACT

The present paper describes the results of a research activity aimed to assess the potential of hydrocracked fossil oil (HCK) and Hydrotreated Vegetable Oil (HVO) blends, as future premium diesel fuels, on fuel consumption (FC) reduction of the modern automotive diesel engines.

Three fuels have been formulated and tested in a light duty four-cylinder diesel engine, Euro 5 version, equipped with closed loop control of the combustion. The set of fuels comprised three experimental fuels formulated *ad hoc* by blending HVO and HCK streams, and an EN590-compliant commercial diesel fuel representative of the current market fuel quality.

A specific test procedure based on a sequence of New European Driving Cycle (NEDC) and ARTEMIS cycles on an engine dyno test bed was applied in order to carry out accurate fuel consumption measurements versus fuel quality, so reproducing the fuel effects on FC for long mileage use of the vehicle.

Results of the experimental activity proved that HCK-HVO blends give a benefit on both FC and CO_2 saving. Taking into account the strong similarity in terms of combustion system design between Euro 5 and Euro 6 engines, the estimated trends can be considered valid also for Euro 6 vehicles equipped with the same class of engines. In a next step, it is planned to validate these results by carrying out also WLTP and RDE emission tests.

1. Introduction

Biofuels use as alternative fuels in diesel engine have been largely investigated in the last decade and a lot of papers have been dedicated to study their potential, benefits and drawbacks [1,2]. In the recent years, there has been a "boom" in biobased diesels interest in almost all the world that involved different biofuel types, according to the prevalent feedstock availability of each country. The real potential of biofuels use in diesel engine might be evaluated taking into account, at the same time, the state of art of current engine technology and the overall life cycle emissions of the fuel. Moreover, fuel technology has made great strides in the last years and different biobased fuels show more interesting characteristics than the fatty acid methyl ester fuels (FAME). These last, in fact, present drawbacks in terms of deposits in the injection systems, engine oil dilution, biofouling, and, in some cases, feedstock competition with food production, and cannot be considered as an absolute panacea to the fossil fuel dependency problem [3–6], particularly if their percentage in conventional fuels is higher than the current maximum limit of 7% v/v as defined in European EN 590 standard.

Hydrotreated Vegetable Oil (HVO) has become an attractive industrial-scale alternative to ester-type biodiesel. It can be produced from many kind of non edible vegetable oils, animal fats, waste oils and consists of a mixture of paraffinic hydrocarbons in diesel boiling range, free of sulfur, oxygen and aromatics. Regardless of the feedstock, neat HVO has high cetane number and low density. Its bulk modulus and material compatibility is similar to petroleum diesel. Good cold properties can be obtained by adjusting the isoparaffin/normal paraffin ratio in the isomerisation step of the production process. Adequate lubricity can be achieved by treating with lubricity improver additives. Differently from FAME, the HVO properties do not depend on the adopted production feedstock and many proprieties are very similar to the gas-to-liquid (GTL) and biomass to-liquid (BTL) diesel fuels produced by Fischer-Tropsch (FT) synthesis [7]. HVO based fuels can be used without affecting fuel logistics, engine and exhaust after-treatments [8] [9].

According to a recent literature survey, the use of neat HVO contributes to a reduction of regulated and non-regulated emissions and of greenhouse gases from both Heavy Duty (HD) and Light Duty (LD) engines [10].

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Definitions/abbreviations

BMEP	brake mean effective pressure
BP	boiling point
BSFC	brake specific fuel consumption
BTL	biomass-to-liquid
CAV	CAV-weighting acoustic curve accounting “airborne noise pressure outside the engine” (as reported in the AVL indicating system manual)
CI	cetane improver
CN	cetane number
CLCC	Closed-Loop Combustion Control
CO	Carbon Monoxide
COV_IMEP	coefficient of variability of indicated mean effective pressure
dBA	A-weighed acoustic curve
DPF	diesel particulate filter
DOC	diesel oxidation catalyst
ECU	engine control unit
EUDC	extra-urban driving cycle
EGR	Exhaust Gas Recirculation
FAME	fatty acids methyl esters
FC	fuel consumption
FC_v	volumetric fuel consumption
FIS	Fuel Injection System
FSN	Filter Smoke Number
FT	Fischer-Tropsch
GTL	gas-to-liquid
HCK	Hydrocracked fossil oil
HD	Heavy Duty
HR	Heat Release
HVO	Hydrotreated Vegetable Oils
IMEP	indicated mean effective pressure
LD	Light Duty
LHV	Lower Heating Value
LNT	Lean NOx Trap
MFB50	angular position corresponding to the 50% of burned fuel mass
NEDC	New European Driving Cycle
NOx	Nitrogen Oxides
NVH	Noise, Vibration and Harshness
PAH	Polycyclic aromatic hydrocarbon
PM	Particulate Matter
RDE	Real Driving Emission
RoHR	Rate of Heat Release
SCR	Selective Catalyst Reduction
SOI_{main}	start of main injection
SOI_{pil}	start of pilot injection
TDC	top dead center
THC	total hydrocarbons
UDC	urban driving cycle
WLTP	Worldwide harmonized Light vehicles Test Procedure

Concerning the light duty automotive engines, it was found that even if HVO characteristics are quite different from commercial fossil fuels, it does not affect in a significant way the spray pattern evolution in the hot environment of the combustion chamber of LD engines [7,11,12].

In terms of pollutant emission, Noise, Vibration and Harshness (NVH) performances, it was assessed that unburned total hydrocarbons (THC) and Carbon Monoxide (CO) can be significantly reduced using HVO as pure fuel or in blending in all engine-operating conditions [7,1]. The use of pure HVO as automotive fuel is regulated by the EN 15940 standard. Having a cetane number higher than 70, the HVO used as diesel blending component in this study is classified by EN 15940 as class A type paraffinic diesel fuel.

Even if a general trend on Particulate Matter (PM) reduction burning HVO or its blends can be carried out from the literature survey, the relative gains with respect to a generic commercial fossil fuel strongly depend on the engine technology and the operating conditions [11,12]. On the contrary, Nitrogen Oxides (NOx) emissions do not seem to show a consolidated trend. A slightly higher NOx formation, which is likely related to the higher adiabatic flame temperature of the HVO paraffinic fuels [7], was found only at very high engine loads where Exhaust Gas Recirculation (EGR) is usually not employed [11]. Therefore, also considering the most recent development trends fostering the EGR application in the widest possible engine working area, this should not affect the real in-use emission performance of the vehicle. However, in consideration of the growing concern about the gap between emission certification limits of Euro 5 standards (measured in laboratory testing) and “real-world” emissions of diesel cars when driven on the road, a follow-up study is being planned to confirm these results with the recently introduced Worldwide harmonized Light vehicles Test Procedure (WLTP) and Real Driving Emission (RDE) tests.

The above indicated trends were carried out by means of experimental studies addressed to the comparison between conventional fossil diesel fuels (according to the EN590 specifications) and HVO in steady state conditions, transient conditions as well as test cycle as the New European Driving Cycle (NEDC) [7,11–17].

Looking at the next future, the employment of premium fuels for future ultra-low emission vehicles seems more and more attractive as the diesel powertrain system becomes more complex, expensive and sensitive to the fuel quality. The problems related to the biodiesel use are emblematic of this latter aspect.

In addition to HVO, also Fischer-Tropsch fuels from either gas, biomass or coal and hydrocracked fossil fuels (HCK) can be used as blendstocks for premium fuels that meet the requirements of modern and near-future powertrains [18]. However, notwithstanding the technical maturity of the production process and the operation of a few large-scale production plants, in terms of market availability and costs, FT fuels are deemed to be only a medium/long term solution. So, in the short-term, a broader use of HCK streams, which are produced by well-established refining processes in very modern large-scale refineries, represents the most cost-effective option. In this context, authors have considered the blends of HVO and HCK as viable formulation of premium fuels. More in detail, HCK is a well-established catalytic chemical process used in petroleum refineries for converting the high-boiling fractions of petroleum crude oil or streams from other conversion units to more valuable lower-boiling middle-distillate products such jet fuel and diesel oil. The process takes place in a hydrogen-rich atmosphere at elevated temperatures (260–425 °C) and pressures (35–200 bar). The process cracks the high-boiling, high molecular weight hydrocarbons into lower-boiling, lower molecular weight olefinic and aromatic hydrocarbons and then hydrogenates them. Most sulfur and nitrogen present in the hydrocracking feedstock are also hydrogenated and form gaseous hydrogen sulfide (H2S) and ammonia (NH3) which are subsequently removed. The result is that the HCK products are essentially free of sulfur and nitrogen impurities and consist mostly of paraffinic hydrocarbons [19]. The HCK blendstocks were produced at the Eni's Sannazzaro oil refinery.

A detailed analysis of the correlations among HVO/HCK based premium fuel properties, engine operating conditions and global NEDC emissions in real modern automotive diesel engines has recently been published by the same authors [20]. A clear positive impact of the use of HVO/HCK blends (at different blending ratios) on pollutant emissions was observed. Moreover, benefits on FC and CO_2 emissions could also be estimated, but their magnitude was within the limits of the