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Investigation of the effects of biodiesel aging on the degradation of common rail fuel injection systems

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HIGHLIGHTS

- A test method was developed to compare the effects of biodiesel on the fuel injection system.
- It was demonstrated that biodiesels can be discriminated based on time to failure of the injection system.
- The importance of the fuel TAN value on fuel injection system failure timing was revealed.

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ABSTRACT

Subject of this study is the parametric investigation of the effect of biodiesel aging on the formation of deposits inside common rail Fuel Injection Equipment (FIE). The parameters investigated are key fuel properties and their degradation rate, FAME composition as well as FIE component design. Fuel degradation and deposit formation is simulated in a prototype FIE test rig. A market study was initially performed to monitor market diesel fuel quality in Europe. The sensitivity of the FIE to FAME concentration was investigated with market B7 and B20 test fuel. B20 pre-aging and fuel enhancement with anti-oxidant were studied to assess the impact of fuel degradation speed and level relatively to deposit formation. A selection of EU market B7 fuels with different fresh fuel properties and FAME composition, were comparatively evaluated on the rig as regards their impact on injection flow and pump response deterioration together with their tendency to form deposits. Test rig operation with 2 different injector designs was utilized to further investigate deposit sensitivity. Injection flow deterioration and internal deposits were affected by injector design and fuel aging speed and were found to be related to Total Acid Number. A correlation between initial B7 Rancimat IP and FIE failure due to fuel aging was identified. The methodology developed is proposed as reference test for the evaluation of current and future automotive fuels as regards their tendency to form deposits.

1. Introduction

The European renewable energy Directive (2009/28/EC) sets the target of a minimum 10% share of renewable energy in the transport sector by 2020 for each European Member State, in order to reduce both energy dependency and greenhouse gas emissions [1]. The large diesel car market and biodiesel feedstock availability in Europe constitute strong motivation to promote higher biodiesel blends. Biodiesel can be derived from vegetable oils, waste cooking oil and animal fats via a transesterification process [2] to produce Fatty Acid Methyl Esters (FAME). On one hand, biodiesel blends can help reducing CO_2 emissions and a part of regulated pollutant emissions [3–5] but, on the other hand, they may affect negatively engine operation, emissions and durability, as summarized in Table 1 [6–15].

In order to ensure proper operation of the diesel Fuel Injection Equipment (FIE), fossil (petro) diesel can be blended with EN14214 specification compliant FAME up to maximum of 7% by volume. The resulting diesel fuel properties must comply with the European specifications EN590. However, fuel quality surveys show that not all retail stations provide nominal quality fuels, since samples with very low oxidation stability were found among the samples from the European market (Fig. 1) [15]. Poor fresh market fuel properties are attributed to poor initial properties of the blended FAME [16], the presence of oxidation inducing catalysts

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Table 1
Summary of pros & cons using biodiesel fuels in Diesel engines.

Pros	Better CO_2 balance by reduction of fossil fuels consumption Lower PM emissions due to higher oxygenated compounds Improves lubricity
Cons	Higher NOx emissions due to higher oxygenated compounds Higher PM emissions in case of injector malfunctioning or nozzle deposit Quicker oil degradation & sludge formation due to oil dilution Faster degradation of sealing parts made of elastomers Corrosion of metal parts (higher water content & acidity) Startability issues due to internal deposits in FIE or fuel filter plugging Rough idling due to internal deposits in FIE Power loss due to internal deposits in FIE & lower energy content

in the storage tank (e.g. copper or zinc) or prolonged storage (especially in hot and humid conditions in the presence of oxygen) of fuels having already low oxidation stability [9,17–19].

FAME is known to have poor oxidation stability and is associated with the formation of sediments and gums. The products of fuel aging reactions contribute to a new type of injector internal deposits. Literature shows that when biodiesel is blended with diesel fuel, new types of deposits might be found inside the FIE as summarized in Table 2.

Future emission standards are expected to require further reduction of raw engine out emissions and better fuel economy which will be partly achieved by further development of the injection systems. The higher level of sophistication (e.g. tighter clearances) may increase the injector sensitivity to contaminants and internal deposits originated from biodiesel degradation. Furthermore, the possible increase of injection pressure would contribute to the increase of fuel temperature inside the injection system, which may enhance deposit formation.

Generally, the accumulation of fuel aging sourced deposits depends on fuel degradation level, fuel composition (FAME composition and blend ratio, additives), fuel residence time inside the tank and soaking period, FIE parts design (tolerances, materials, surface roughness) and composition (affinity between deposit and parts) as well as operating time with the same fuel [9–12] The resulting accumulated deposit deteriorates the operation of the moving parts when a certain critical level is exceeded, in particular in critical functional areas such as pump suction control valve, injector control valve, command piston or needle. So far, such internal deposits in the injector nozzle holes are not known to accumulate at a level that could significantly reduce the injector hydraulic flow rate (coking is not considered in this study).

In recent publications, rig test protocols have been proposed to investigate the effect of biodiesel deposit on FIE operation [8–10]. It was shown that brownish lacquered type deposit could be reproduced in the same way as in the field and that different injectors have different sensitivities to deposit formation. Also, the speed of deterioration of the injection rate revealed a possible relation with the Total Acid Number (TAN) for a given injector hardware and fuel composition [9,20]. The current study also considers TAN as a fuel deterioration indicator and attempts a step further towards correlating TAN and injection rate failure: it investigates the effects of multiple parameters such as different FAME content (B7, B20) and compositions, rate of TAN increase, FAME and additivation with anti-oxidant, hardware setup (different FIE designs).

In this context, the objective of the study is to highlight the general fuel aging behavior characterized by the degradation of key fuel properties and its relation with FIE degradation effects such

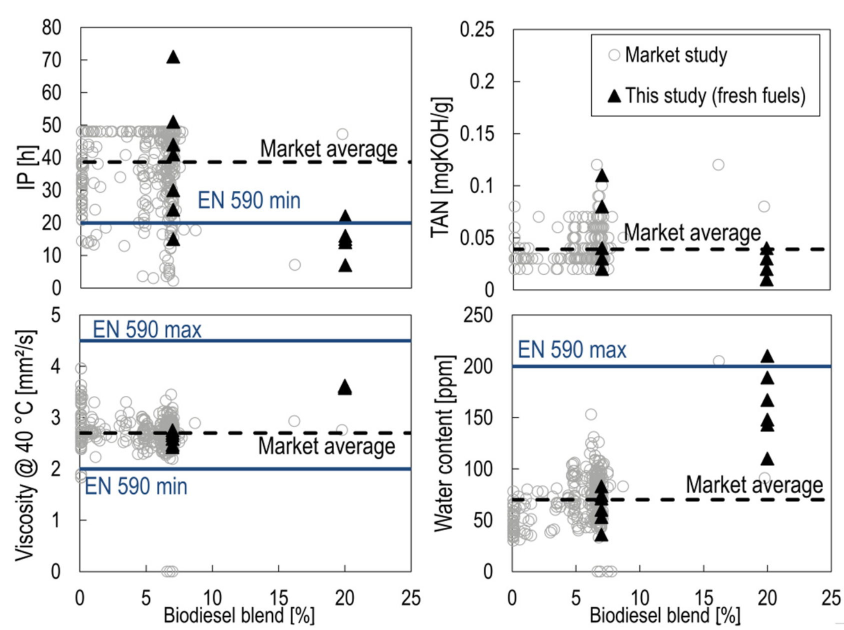

Fig. 1. European market fuels quality survey (2010 to 2013) and comparison with B20 and B7 fuels used in the present study.

Table 2
Summary of deposit types found inside FIE.

Reaction source	Composition	Texture	Appearance	Source
FAME degradation	Fuel oxidation products	Lacquer	Brownish	[9,10,12,16,21,25,27,29]
FAME + detergents (PIBSI)	Amide polymeric organic materials	Lacquer	Brownish	[16,21,22,44]
FAME + metal based contaminants	Sodium or calcium ion containing compounds	Soap, wax	White or yellow	[16,21,26,28,41,44]