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Experimental investigation of effect of corrosion on injected fuel quantity and spray geometry in the diesel injection nozzles

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ABSTRACT

In this study, effect of corrosion on injected fuel quantity and spray geometry has been investigated experimentally in a piezo-driven common rail diesel injector. We performed the following examination steps on the nozzle parts for the cases prior to corrosion, after corrosion and after cleaning the corrosion material: (i) all important regions of the nozzle parts were photographed, (ii) microscopic pictures of the nozzle tip and interior of holes from outside have been taken with Scanning Electron Microscope, (iii) injection jets were photographed, (iv) injection quantities for different injection pressures and duration were determined and lastly, (v) hydraulic measurement of the nozzle was performed. Hydraulic measurement of the nozzle (in cm^3/30 s@100 bar) showed that injection quantity decreased 26.26% after corrosion because of the corrosion deposits blocking nozzle hole and increased 5.68% after cleaning of deposits due to the enlargement of the holes.

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1. Introduction

In a diesel engine, the design of fuel injection nozzle is an important factor for the improvement of the combustion performance and reduction of emissions because nozzle geometry influences the spray characteristics and air–fuel mixing in the engine [1–6]. For these reasons, a number of studies have been conducted on the effect of the nozzle characteristics on the internal and external spray performances [7–11]. One of the factor that influence nozzle flow characteristics is corrosion.

In the literature, there is no study investigating the effects of corrosion on the injection quantity and geometry; however, some studies investigating the effects of fuel compounds were carried out. These studies are mainly based on biodiesel, ethanol and the amount of sulphur in the fuel.

Quigley and Barbour [12] described a study used to assess the impact of rapeseed methyl ester (RME) fuel on performance parameters such as injector fouling, corrosion, water separation and fuel foaming tendency. The effect on RME quality of treatment with multifunctional diesel fuel additives (containing dispersant, demulsifier, anti-foamant and anti-corrosion components) was also investigated and shown to provide significant improvements to the base properties of fuels. From the laboratory tests conducted by Ohkawa et al. [13], it was made clear that all vegetable hydraulic oils show poor oxidation stability, and two vegetable hydraulic oils show strong corrosion to bronze materials. Three vegetable hydraulic oils containing 0.7%, 0.25% and 0% sulphur have been tested with a high-pressure axial piston pump. The 0.7% S vegetable hydraulic oil resulted in a rapid viscosity increase and serious bronze corrosion in the 32 MPa × 95 mDC pump test. The 0.25% S vegetable hydraulic oil also caused light corrosion, while the 0% S vegetable hydraulic oil did not cause corrosion. Labeckas and Slavinskasthe [14] tested rapeseed oil, which includes many complicated long-side chain fatty acids and a 2.7-fold greater amount of water, which significantly increases its density and viscosity, reduces the cetane number, and stimulates acidity and corrosion activity. Winfried et al. [15] determined that non-esterified free fatty acids and different types of salts (Ca^{2+}, N^{+}, K^{+}) can cause corrosion in an engine and catalyze oxidation processes. The corrosion behaviours of biodiesels produced from various non-edible oils were estimated during a long-duration static immersion test by Kaul et al. [16]. They found that biodiesel with high-sulphur (1600 ppm) caused corrosion on the piston surface and cylinder liner. Caroa et al. [17] showed that corrosive effects of the biofuel component of biofuel/fuel oil mixtures necessitate the use of resistant materials in systems designed to store, transport and utilize these fuels. Specifically any copper and/or brass containing components must be replaced with steel. Grey cast iron showed slight corrosion and is better avoided when designing systems that utilize these biofuels.

Lundberg [18] pointed that in cold climates, careful attention should be paid to the materials of the fuel system. Large temperature variations may cause problems with water, including corrosion. These can be avoided to some extent by the use of additives and careful handling of the fuels.

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Table 1
Some properties of diesel fuel used during the realization of corrosion.

Properties	Value
Density (15 °C)	0.831655 g/cm^3
Viscosity (40 °C)	2.64 mm^2/s
Particulate matter (0.8 μm)	6.65 mg/kg
Water content	39 mg/kg
Flash point	70 °C

Although ethanol was found to be contributing to fuel economy and lower engine wear as a result of the tests performed by Hardenberg (vehicle tests over 1 million kilometres), ethanol was also noted to be the cause of some corrosion problems [19]. The corrosive effects of ethanol were attributed to its quality by Hansen et al. [20]. Rovai reported that ethanol was effective in the corrosion and wear of fuel pump and determined the rate of the corrosion and wear by means of the surface roughness tests which he performed with the Scanning Electron Microscope [21].

In an investigation by Kass et al. [22], a high-resolution corrosion probe was placed within the airhorn section of the exhaust gas recirculation (EGR) loop of a heavy-duty diesel engine. The corrosion rate of the mild-steel probe elements was evaluated as a function of fuel sulphur level, EGR fraction, dewpoint margin, and humidity. No significant corrosion was observed while running the engine using a 15-ppm sulphur diesel fuel; however, high corrosion rates were observed with diesel fuel with 350 ppm sulphur while condensing water in the EGR loop. The rate of corrosion on mild steel elements increased with increasing levels of sulphate in the condensate.

In addition to the above-mentioned studies, it is possible to find many studies about the parameters such as nozzle geometry, cavitation, injection rate, momentum flux, spray penetration, spray cone angle and air entrainment which negatively affect spray characteristics and atomization [23–29].

In this study, effect of corrosion on injected fuel quantity and spray geometry has been investigated experimentally.

2. Test procedure

2.1. Test plans

In these tests, a newly manufactured eight-hole Bosch piezo-injector was used.

The tests fall into three main groups as follows:

- Prior to being corroded –newly manufactured injector.
- After being corroded.
- After removing the corrosion deposits.

Below-mentioned experiments were carried out for each situation stated above.

1. All important regions of the nozzle parts were photographed.
2. Microscopic pictures of the nozzle tip and interior of holes from outside have been taken with Scanning Electron Microscope.
3. Injection jets were photographed.
4. Injection quantities for different injection pressures and durations were determined and finally.
5. Hydraulic measurement of the nozzle was performed.

2.2. Exposing nozzle parts to corrosion

The corrosive environment that the injector is exposed to inside the engine was experimentally realized. Nozzle parts were in turn subjected to the following applications.

- Newly manufactured injector parts were kept waiting in an acidic environment containing water, salt, lemon for one day so that an acidic effect similar to the one occurring inside the engine could be realized because it is known that the sulphur in diesel causes acidic effects after going into several reactions with the moisture in the air.
- Followingly, the parts were kept in EN590 diesel fuel for three days in order to allow the realization of the corrosive effects of the sulphur and other acidic compounds in the fuel.
- The parts were heated up to 300 °C and kept for 30 min in an oven and then their temperature was decreased to 100 °C in 8.5 h in order to realize the conditions occured when the engine operates at full load since 300 °C is the maximum acceptable operating temperature for nozzle in the engine. The condensation of the evaporated gases was ensured by cooling the parts down to 100 °C. After the parts were kept in standard diesel fuel for a short time and then they were perfectly cleaned from any deposits, they were kept at room temperature for seven days.

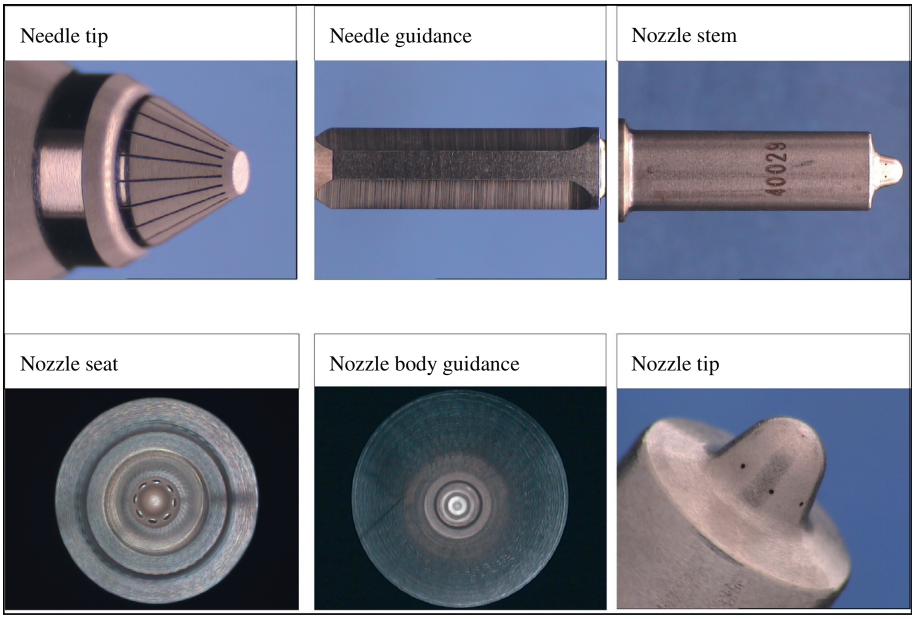

Fig. 1. Nozzle and needle photographs prior to corrosion.

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