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A quantitative methodology to measure injector fouling through image analysis

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Abstract

The use of vegetables oils in a compression ignited internal combustion engine presents some critical issues as the large amount of carbon deposits on the tip of injectors, which significantly influence emissions and engine performance. A previous draft methodology was developed by the authors, based on images capture and post-processing. The carbon deposit was correlated with the number of pixels in the gray scale, so it was possible to determine a Fouling Index. First results showed interesting perspectives and some limits: the aim of the present work is the optimization of the test bench and methodology. At first an improvement of image acquisition, increasing sampling frequency and image resolution, is performed, replacing the old camera with a digital microscope and improving both injector and microscope positioning. The test bench prototype has been realized with the aid of 3D printing, obtaining fundamental mechanical components. Also an alternative methodology is proposed to evaluate carbon deposits volume through a Volumetric Index. The new methodology validation was done using images sampled with the previous test bench. The performances of the Fouling index and of the new Volumetric Index were compared and fouling was examined in the real case of a diesel engine, fed with diesel and sunflower oil. Results show a greater reliability of the new Volumetric Index.

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Keywords: ICE (Internal Combustion Engine), Injector, Fouling, Tip, Pixel, Index

Nomenclature

CCD	Charge-Coupled Device
EDS	Energy Dispersed X-ray Spectroscopy
FESEM	Field Emission Scanning Electron Microscopy
FI	Fouling Index
GC/MS	Gas Chromatography/Mass Spectrometry
ICE	Internal Combustion Engine
SEM	Scanning Electron Microscopy
VI	Volumetric Index

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1. Introduction

Crude and waste vegetable oils represent a renewable fuel for internal combustion engines [1-7], but the use of these fuels is limited because of carbon deposits formation on the injector's tip, caused by higher viscosity, incomplete combustion and exposition to high temperature that affect the deposit solubility [8], and indirectly to an increase in particulate emissions [9]. Deposits may be measured through visual analysis, like high-speed spray imaging or SEM analysis while their characterization can be made through energy dispersive X-ray fluorescence spectroscopy (EDS) and compositional analysis as Fourier Transform Infrared Spectroscopy (FTIR) or Gas chromatography coupled with mass-spectrometer namely GC/MS, which is able to identify and quantify volatile compounds [10].

Galle et al. 2012 [11] carried out an investigation based on SEM analysis, which revealed different causes of injectors failure, including plastic deformation, erosion and clogging of the injector's passages, affected by chemical and physical composition of the fuel. Liaquat et al 2013 [12] evaluated through EDS analysis the deposits at the injector tip of a diesel engine, single cylinder, after 250 operation hours, comparing the fossil diesel fueling and a mixture with 20% of biodiesel: results showed a significant increase in the carbon percentage of the deposit. Injection technology has evolved because of more stringent regulations on emissions and the engines have become more sensitive to the deposits formation changing the fuel quality [13]. Some authors [14, 15] evaluated the variation of the spray pattern with the accumulation of deposits at the injector tip highlighting many differences especially in terms of opening angle of the cone and its penetration inside the chamber, leading to an alteration of combustion quality and loss of engine's efficiency. Magno et al. [16] investigated the injection and the combustion evolution inside an optical single cylinder compression ignition engine through a non intrusive 2-D digital imaging measuring: the jets length, the luminous intensity along the jets axis and the pollutant formation. Most of the actual research evaluates chemical and physical fouling with costly and time consuming approaches.

For a fast method for fouling measurement Peterson et al. [17] estimated the fouling at the tip of the injectors through analysis of images captured in a photographic bench equipped with a specific injector housing, a CCD camera (Charge-Coupled Device) and a lighting system placed behind the area of the tip [18, 19]. The study led to the definition of a fouling index called CI (Cocking Index) and given by the ratio between the fouling area of the i-th fuel and the same area of the diesel as the reference fuel.

A similar approach was followed in a first work, presented by the authors [20], to determine a Fouling Index, capturing images with a low cost camera (Panasonic Lumix TZ5) and post-processing the acquired data. In this work the new test bench for image acquisition, based on the use of new mechanisms and a digital microscope, is described together with a new methodology and a new index (Volumetric Index). The performances of the VI and the FI are compared at first using artificial deposits and then with a real case of combustion performed on a diesel engine fed with fossil diesel and sunflower oil.

2. Materials and method

2.1 Design and construction of the new test bench

A first low cost test bench, see [20]; was built with a fixed CCD camera positioning and a specific guide hole for the injector, its rotation was checked by implementing the bench with 12 notches placed at 30 degrees and the injector with a single reference notch. The rotation and images capturing were manual, which implied high uncertainty, a slow image capturing process and errors due to light infiltration and overlapping of images.