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# Vision based algorithm for automated determination of smoke point of diesel blends

Guilllermo Rubio-Gomez, Lis Corral-Gomez, Jose Antonio Soriano, Arantzazu Gomez, Fernando J. Castillo-Garcia*

*School of Industrial Engineering, University of Castilla-La Mancha, Av. Carlos III, Real Fabrica de Armas, 45071 Toledo, Spain*

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ABSTRACT

Current regulations restrict NOx and particulate emissions (PM) produced by new vehicles. One solution for reducing these emissions, mainly PM, is focused on the use of cleaner fuels. In this sense, the smoke point test (SP) has been proved to be a fast tool when comparing the sooting tendency of fuels. As manual SP determination can imply an error owing to the inherent uncertainty of visual flame observation, the updated ASTM D1322-18 has stated that the new commercial equipment SP10 Automated Smoke Point Analyser is the reference for SP determination. However, its high cost has motivated this work where a vision based algorithm for automated determination of SP without wick-fed modifications is proposed. Experimental results demonstrate the accuracy and repeatability of the proposed method.

## 1. Introduction

Along the history, compression ignition engines have shown higher energy conversion efficiency than spark ignition engines but a higher production of nitrogen oxides (NOx) and particulate matter (PM), not only in mass terms but also in number, are observed in both, steady state and transient conditions [1]. However, although PM was not concerning in spark ignition engines, nowadays the new direct injection engines show a quite high particulate emission [2]. In this way, the current regulations Euro 6 and the US 2010 restrict NOx and PM emissions produced by new vehicles, in Europe and USA, respectively [3,4].

One solution for reducing vehicles pollutant emissions, mainly PM, is focused on the use of cleaner fuels. Although the opacity and, therefore, engine particle emissions, depend on the fuel and engine conditions, the smoke point (SP) test has been proved to be a fast tool when comparing the sooting tendency of different fuels [5–8].

Smoke point is defined as the height in millimetres of the highest flame produced without smoking when the fuel is burned in a specific wick-fed test lamp. Therefore, as higher is the flame height, lower is the tendency to smoke of the tested fuel [9].

Manual SP determination can imply errors due to the inherent uncertainty of visual flame observation. In order to narrow down the error, the Test Method D1322 for measuring manually the smoke point fixes a repeatability between results obtained by the same operator of 2 mm, whereas the reproducibility (difference between results obtained by different operators) must be lower than 3 mm [9].

However, uncertainties can be minimized if direct visual observation is avoided by means of an automatic determination of the SP. Watson et al. [10] developed a test based on the fuel uptake rate (determined using an analytical balance) and image analysis of videos recorded with a webcam, rather than the height of the flame. In this work a conventional Logitech 9000 webcam is used for estimating flame height at 20 frames per second. The acquired images are processed using Matlab. A binarization of the color image is used before determining tip position and the flame height on the black and white image. A rod is inserted into the wick sheath for image calibration purposes. Results showed that reproducibility was improved. However, the smoke point lamp was to be redesigned.

Graziano et al. [11] also used the fuel uptake rate but the commercial webcam was replaced by a CCD camera for registering soot luminosity using a recording interval of 1 s. This work establishes that using a fixed intensity threshold significantly affects the flame detection and an intensity gradient approach is therefore used to perform the image processing.

An automated determination of the SP was also developed by Pino et al. [12] but a Gulder burner was used instead of an ASTM wick-fed lamp. Recently, ASTM D1322-18 has stated that the new commercial equipment, *SP10 Automated Smoke Point Analyser* is the reference for SP determination. This equipment uses a vision system and a balance for

* Corresponding author.
*E-mail address:* Fernando.Castillo@uclm.es (F.J. Castillo-Garcia).

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determining SP value.

Some other methodologies for estimating the sooting tendency of fuels can be also found in literature for avoiding visual observation uncertainties, but they are not based on smoke point measurements [13–15].

In this work, a new approach for automation of an ASTM smoke point lamp has been developed. The proposed method is based on image processing not only for measuring the flame height, as FURTI based methods [10,11], but also for determining the flame tip deformation during the experiments, without requiring any additional equipment as analytical balance for SP determination. The novel commercial equipment, *SP10 Automated Smoke Point Analyser*, provides accurate SP values but is a high cost equipment since the proposed method here only implies slight and cheap lamp modifications.

This paper is structured as follows: Section 2 details the experimental platform and the vision based algorithm for obtaining SP since Section 3 shows the experimental results and the discussions.

## 2. Materials and methods

The main part for SP determination is ASTM D1322 standardized test diffusive lamp (see Fig. 1).

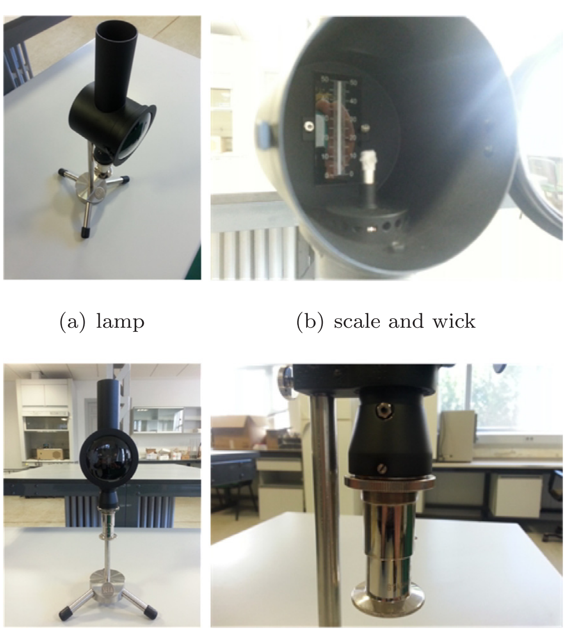
A conventional experiment is performed by the following procedure:

- Fuel tank is filled with diesel fuel to be characterized.
- Wick is lighted.
- Fuel tank nut is manually rotated to increase flame height.
- Operator watch the flame attempting to note when it starts producing smoke.

Following this procedure, Smoke Point is the last value of flame height before smoke is produced [9].

Obviously, ASTM D1322 norm take into account the inherent observer errors and establishes a sensibility of 0.5 mm, i.e. the observed SP must be rounded to the nearest 0.5 mm scale line (see Fig. 1b). In addition, the experiment must be carried out 3 times and, if these values vary over a range greater than 1.0 mm, the test must be rejected.

It is important to mention that ASTM D1322 norm describes all the overall requirements before experiments (ambient specification, lamp orientation, etc.) and the procedure to calibrate it (see [9] for more details).



(a) lamp (b) scale and wick

(c) lamp (d) fuel tank

**Fig. 1.** ASTM D1322 standarized lamp.

The aforementioned normalized test lamp has been adapted in order to automate the smoke point test procedure, that used to be carried out manually as specified in [9]. No modification to the lamp is made during the adaptation process, this is due to its normalized specifications and calibration. A novel image processing based algorithm has been developed to automatically determine smoke point after recording the flame evolution process.

The main goal of this automation is to carry out the test at a steady and controlled speed while automatically recording the flame evolution. Irregularities in test speed, due to its manual, cause sudden variations in flame height that difficult the SP automatic detection process. This adaptation also allows to isolate the lamp from air perturbations that could come from the surroundings, by placing the platform inside a container. The user can control the test externally via PC by means of a *Matlab* application.

### 2.1. Materials

In order to implement this platform, a mechanical actuator is attached to the lamp nut. The required speed for lamp actuator has been determined to lay between 1 and 3 rpm and the needed torque to rotate lamp actuator is about 3 Nm. Taking into account the requirements of the lamp, low speed and relatively high torque, the selected mechanical actuator is a continuous rotation servomotor [16] model *SM-S4303R* from *SPRINGRC*. This servomotor is shown in Fig. 2, and provides the characteristics required by the lamp.

To attach the servomotor to the lamp actuator, a reduction gearbox has been designed, both to adapt the speed of the servomotor (5–50 rpm) to the lamp speed and to amplify the torque given by the servomotor (0.4 Nm). The gearbox was designed to give a speed reduction of 15.6: 1. A sketch of the design can be seen in Fig. 3. The gearbox has been built by 3D impression in Polylactic Acid (PLA). Pictures of the printed gearbox can be seen in Fig. 4. This mechanical device is controlled by means of an *Arduino*™ board model *Mega 2560*.

The hardware used to record the flame evolution during the test is a web camera model *C270* from *Logitech*®, see Fig. 5. It offers a resolution of 1280 × 960. The image format employed is *RGB24*.

Finally, all the materials are attached to the normalized test lamp. The camera is placed in the top of the gearbox, attached by a structure that keeps it firmly aligned with the lamp at a distance of 20 mm. This fastening device was printed in PLA and is shown in Fig. 6.

Another gear, attached to the lamp nut, has been built to transmit the movement from the gearbox. A sheet of steel is used to give strength and stability to all components of the automated smoke point test platform. The final assembly can be seen in Fig. 7.

### 2.2. Smoke point detection algorithm

A new image processing based method for automated smoke point detection is proposed. Other works which applied computer vision for

**Fig. 2.** *SM-S4303R* servomotor from *SPRINGRC*.