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Development of a particulate matter sensor for diesel engine

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Abstract

A resistive soot sensor for diesel particulate filter (DPF) failure detection was developed in previous works. By measuring the conductance between two Pt electrodes, this sensor is able to detect a low leakage from the DPF but only provides soot mass information. In this study, we have characterized and determined the key parameters that influence the sensor response, *i.e.* the conductance with the aim to build a model that could provide soot number measurements. First results show a dependency of the sensor response with the soot mass concentration and the polarization level of the electrodes.

Keywords

Soot sensor, On-board diagnostics (OBD), Diesel particulate filter monitoring

1. Introduction

Emission legislations for diesel engine become more and more stringent and now, limits take in consideration the particulate number (PN) of soot emitted. In order to meet the next European standards for particulate matter (PM) emissions of diesel light duty vehicles, an on-board diagnostic sensor to detect diesel particulate filter (DPF) failures will be required. Therefore, the development of a cheap sensor effective for the measurement of both mass and PN concentration is necessary. Resistive sensors are good candidates for that purpose [1-4]. The objective of this study is the determination of key parameters of such sensors to perform PN concentration measurement.

2. Experimental

The sensor was developed in a previous work in collaboration with Electricfil Automotive Company [1]. It is based on the measurement of the conductance between two platinum electrodes. The sensor is made of an alumina substrate where the sensing side consists in interdigitated platinum electrodes deposited by screen-printing and laser engraving technics [1,5]. Using this latter method, the space between the two Pt electrodes is 20 µm. Then, the conductance between these two electrodes is recorded as a function of the time and the amount of collected soot. On the other side of the alumina substrate, a platinum resistance is screen-printed (heater) to perform active regenerations of the sensor and is also used as a temperature sensor. To improve the sensor response a polarization tension is applied between the two sensing electrodes, leading to the formation of soot bridge between the two electrodes [1].
Tests of the sensors have been performed on a synthetic gas bench described elsewhere [6]. Soot particles were produced by a mini Combustion Aerosol Standard burner (miniCAST, Jing Ltd. Switzerland). Soot particles are formed within a co-flow diffusion flame due to the hydrocarbon pyrolysis (C_3H_8 was used as a fuel) which takes place as a consequence of the heat provided by the oxidation at the flame front. The produced flame is quenched by a stream of N_2 that enables at the same time both, the pyrolysis of the fuel and the escape, without being oxidized, of the generated particles. The fuel to air ratio can be customized in order to obtain a broad range of flame conditions and consequently different types of soot particles (PN and size distribution) [7]. The soot particles flow was preheated in a tubular furnace. The temperature control was performed by a retrofitted closed loop control system which controls the temperature at the exit of the oven (inlet of the sensor). The sensor is placed after the oven, perpendicularly to the pipe with the sensing side in the opposite direction to the flow. The PN and the size distribution were measured by an engine exhaust particle sizer spectrometer (EEPS model 3090, TSI Inc.) which can quantity PM size from 22 to 560 nanometer with a sizing resolution of 16 channels per decade (*i.e.*, total 32 channels). This apparatus monitors the size distribution and PN at a frequency of 10 Hz allowing a real time analysis. In addition, a Multi-angle Absorption Photometer (MAAP) has been used to analyze the black carbon concentration. Three injection diluters (2 Palas VKL 10, 1 Palas VKL 100) were used in order to obtain soot levels below the upper measurement range of the EEPS and the MAAP. The overall dilution ratio was found to be 19800.

Finally, a PEGASOR analyzer was placed after the first diluter (VKL 10 diluter, dilution ratio 13) to follow the soot mass concentration.

3. Results

The soot produced by the soot generator depends on the richness of the propane/air mixture corresponding to the MiniCAST operation point (OP). When the richness increases, the PM decreases (see Table 1 and Figure 1). Four OPs have been defined. OP1 and OP1B have a similar PM size distribution (Figure 1), but with a lower mass and PN for OP1B (Table 1). Therefore, the sensor response variation to the soot mass concentration can be monitored by using OP1 and OP1B. Two others OPs (OP4 and OP5) allow to generate different size distributions.

Table 1. Soot characteristics produced by the soot generator (MiniCAST) depending the operating point (OP).

Operating Point	**Richness of propane/air mixture**	**PN (EEPS)** particles/cm³	**PM (PEGASOR±)** mg/m³	**Carbon black (MAAP¥)** mg/m³
OP1	0.97	1.7 E+8	94	143
OP1B*	0.97	1.2 E+8	61	81
OP4	1.00	2.5 E+8	91	70
OP5	1.02	2.1 E+8	55	22

**OP1B is generated with the same richness than OP1 but with a lower propane/air flow to decrease the PM concentration.*
±PEGASOR is measuring the mass concentration estimated from the escape current of charged PM
¥Multi-angle Absorption Photometer is measuring the mass concentration given by the measurement of the light absorption.

The variation of the sensor conductance with time during the soot loading period for different OPs upon a polarization voltage of 60 V is given on Figure 2. The conductance measurements are performed during several cycles (soot loading phase / regeneration phase) under steady state conditions (gas flow temperature fixed at 180 °C). During the soot loading phase, a threshold time is required to observe a significant increase in the conductance. This corresponds to the generation of first PM bridges between the two Pt electrodes. This threshold time was minimal for OP4, approximately 3 minutes, and was never reached for OP5 even after 20 minutes. After few minutes on stream, the conductance reaches a plateau, except for OP5. The maximum conductance value depends on the carbon black mass concentration (see Table 1).

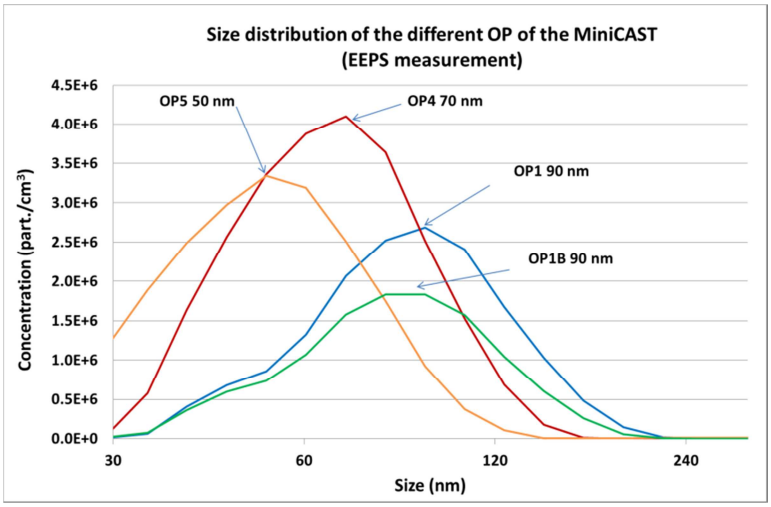


Figure 1: Size distribution of the soot produced by the MiniCAST for various OPs measured with an Engine Exhaust Particle Sizer (EEPS).

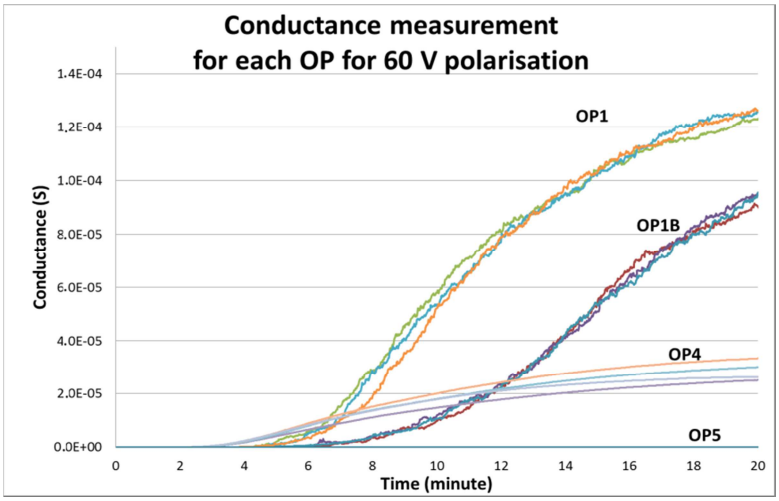


Figure 2: Conductance measurement during soot load for different OP under 60 V of polarization

The response signal variation with time depends on the polarization voltage (Figure 3). For instance, the response time is shorter and the sensitivity higher upon 30 V for OP1B. However, this optimal voltage depends on the mini-CAST OPs, suggesting a strong dependence of the signal response with the size distribution and chemical nature of PM.

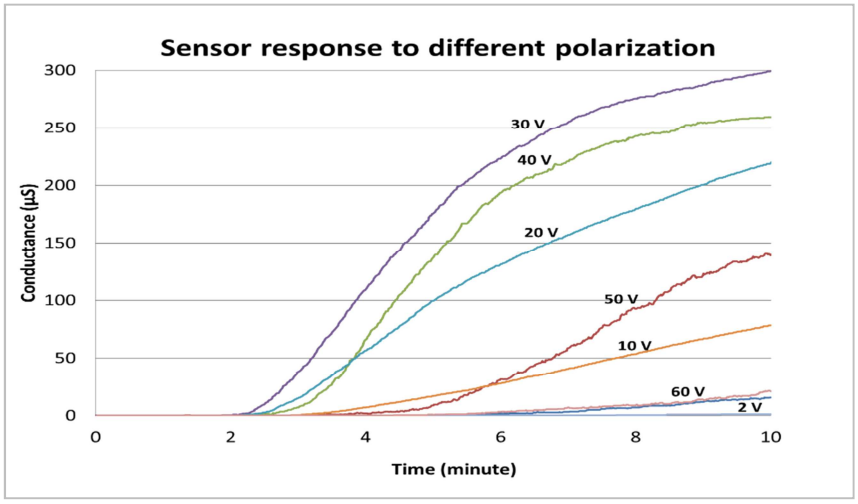


Figure 3: Polarization effect on the sensor response for the OP1B with the gas flow at 180 °C.

4. Conclusions

This study underlines that the sensor response depends on the soot mass and number concentration as well as on the polarization level between the two electrodes. The soot collection rate shows an optimum depending on the polarization. In order to go further to get information on PN, a physical model based on soot collection between polarized electrodes is under development.

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