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APPLICATION OF AN AUTOMOTIVE LAMBDA SENSOR FOR NO_x DETECTION IN LPG COMBUSTION

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Abstract.
The low-cost technologies demand for developing countries is progressive, especially for small producers lacking practical solutions to address the problems inherent in industrial processes, such as combustion efficiency and pollutants emissions. From this perspective, one of the purposes of this work is to provide access to combustion monitoring technology, considering economic factor and easy applicability in the field. The study has as innovation potential the NO_x detection in the combustion of Liquefied Petroleum Gas (LPG) using an automotive oxygen sensor, the lambda sensor, a cheap and affordable device in the market. A measurement technique based on sensor temperature control and application of electrical voltage pulses at the sensor terminals is used, making possible the NO_x detection in the exhaust gases by sensor discharge curves. In the results obtained in this study it is possible to identify that the discharge curves are distinct for each NO_x concentration emitted in the LPG combustion, but the detection is limited to low NO_x concentrations.

Keywords: *Lambda sensor, Measurement, Combustion, LPG, NO_x emissions*

1. INTRODUCTION

The monitoring and control of the efficiency and pollutants emissions in the combustion processes are one of the serious problems that society faces. The automotive sector and large-scale industries have the means to address these problems, while small-scale industries, such as small-scale farmers, have limitations in resolving them because of the relatively high investment they need to make to acquire or rent combustion monitors (Silva et al., 2018).

The acquisition of combustion monitors has a relatively high cost. In Brazil, the value is around 1,500 to 15,000 USD, and maintenance of these monitors also requires a considerable cost, in addition to being periodic, with need of cells exchange and recalibration (De Lima et al., 2007).

The lambda sensor, also known as a lambda probe, is a device that has been developed to assist combustion control, functioning as an oxygen sensor used in automotive vehicles, installed next to the exhaust system with the function of determining the air mixture and fuel resulting from burning. The air/fuel ratio obtained through this sensor is used by the electronic injection system that controls fuel injection and combustion, in order to allow better engine efficiency, reduce fuel consumption and, consequently, reduce pollutants emissions (Haddad, 2012).

Figure 1. Universal 4-wire lambda sensor. Source: NTK Technical Ceramics.

In this study, a conventional lambda probe is applied for NO_x detection in exhaust gases in the LPG combustion, due to its low cost and because, according to Fischer et al. (2010), this sensor can be operated as a NO_x sensor if a suitable detection technique is used, the Pulsed Polarization Technique. According to the authors, if such a technique is applied in stationary systems, which is the case of the application in industrial combustion plants or waste incinerators, the concentration of two or more gases can be obtained with only one conventional lambda sensor, bringing the possibility of simultaneous detection, for example, O_2 and NO_x.

2. THEORY

A technique for detecting different exhaust gases using YSZ based sensors (yttrium stabilized zirconia) was first approached by Fischer et al. (2009) and Fischer et al. (2010), where the signal behavior of a lambda sensor based on YSZ was analyzed. The self-discharge characteristic of the sensor element after different electrical voltage pulses is used as a measurement parameter that depends on the type of gas and the concentration. NO_x at low concentrations was measured.

The technique consists of the application of a positive charge voltage pulse, where just after the discharge curve is captured in a defined time interval, then the same procedure is repeated, however as an opposite signal voltage pulse (Fischer et al., 2009).

Fischer et al. (2010) emphasize that this detection technique should be seen as an initial approach that shows the feasibility of a new measuring principle. If this method is applied to automotive systems, the cross sensitivity to oxygen, water and carbon dioxide should be investigated, as well as the influence of the exhaust temperature on the sensor operation. The advantage gained in one automotive system is the additional information of another gas concentration, for example NO_x for checking the efficiency of the catalyst. But in the measurement time period, the sensor can no longer operate as a lambda sensor, since its temperature must be reduced. Also, the signal response obtained by the lambda sensor self-discharge method shows a good correlation with the total NO_x concentration, regardless of whether NO or NO_2 is dosed as the test gas. The application of other relevant exhaust components to the sensor simultaneously reduces NO sensitivity. However, it seems feasible to suppress these interference effects by an adapted data evaluation approach, since the discharge curves for different gases exhibit individual characteristics.

Aiming to apply the pulsed polarization measurement technique applied in yttrium stabilized zirconia (YSZ) based sensor devices, Pohle et al. (2017) constructed planar lambda probes to investigate the NO_x detection in diesel exhaust gases. The authors compared the measurement technique used in the sensor built with commercial NO_x sensors, with reference to a gas analyzer.

The results of the studies by Fischer et al. (2010) and Pohle et al. (2017) have shown that the measurement of NO_x concentrations in the combustion exhaust gases can be satisfactorily obtained using sensor elements based on YSZ, which is the case of the lambda sensor, combined with a pulsed discharge operation and signal evaluation proper.

3. MATERIAL AND METHOD

3.1 Material

For the study of NOx detection in exhaust gases using the conventional lambda sensor, it was necessary: a system of combustion of LPG, for the generation of combustion; a conventional lambda sensor; measuring equipment, including two multimeters, an oscilloscope and a gas analyzer, and electronic circuits specially designed for the excitation and temperature control of the lambda probe, which will be explained below.

The LPG combustion system (Figure 2) consists of a liquefied petroleum gas line, a pressurized air line, a cylindrical burner and a data acquisition and monitoring system. The burner has holes for fitting temperature sensors and a chimney where the lambda sensor has been coupled. In the monitoring and data acquisition system it is possible to obtain information on airflow, fuel flow and temperature. Thermocouples are used to measure the temperature in the burner. The combustion system used is present at the Laboratory of Energy Conversion and Atmospheric Emissions (LACEEMA) of the UECE Academic Master Degree Program in Applied Physical Sciences (CMACFA).

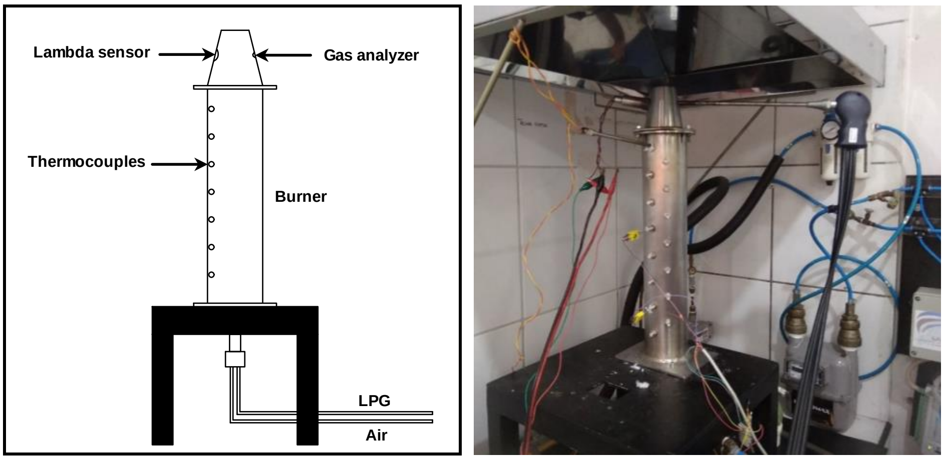

Figure 2. LPG combustion system in which the lambda sensor was installed.

The lambda sensor used to apply the NOx detection technique addressed in this study is a DELPHI four-wire universal lambda sensor, i.e. a HEGO lambda sensor (Heated Exhaust Gas Oxygen Sensor) having two wires intended for the signal and two wires of the heating resistor (heating element) of the sensor.

The Seitron Chemist 903 IR3 gas analyzer was used to carry out measurements of the NOx concentrations emitted in the LPG combustion process and the exhaust gas temperature measurements.

3.2 Method

3.2.1 LPG combustion

In the first moment it was necessary to generate the combustion by means of the burner connected to the liquefied petroleum gas (LPG) line. The lambda probe was installed at the burner outlet, alumina beads were placed in the bed to keep the flame inside the burner, ensuring that the flame did not touch the sensor. The air and fuel fluxes were changed during the combustion process so that there was a variation of the NO_x concentration emitted and thus enabled measurements with the sensor.

The NO_x concentrations, O_2 and the temperature of the burner exhaust gas were monitored during the experimental procedure by the gas analyzer, while the sensor discharge curves were captured on the oscilloscope.

3.2.2 Application of the NO_x detection technique

The DELPHI four-wire lambda sensor was installed in the LPG burner's chimney, where a hole made in the outlet tube was suitably adapted to fit the sensor. On the opposite side of the lambda sensor insert, a hole has also been adapted for insertion of the gas analyzer probe.

The procedure applied to the lambda sensor consists of the application of a pulse of positive charge voltage, where just after the discharge curve is captured in a defined time interval, then the same procedure is repeated, however as the opposite signal voltage pulse. In addition, it is necessary to keep the sensor at a certain operating temperature.

Electronic circuits were designed for the excitation and definition of parameters of the NO_x detection technique using the lambda sensor.

The parameters used in the initial tests were defined considering the experimental procedures of Fischer et al. (2010), using parameters within the ranges defined by the authors. However, during the first experiments it was difficult to differentiate the discharge curves because the sensor did not respond as expected, then the temperature of the lambda probe was increased until the sensor discharge curves presented similar response characteristics to the results obtained by the authors cited.

The parameters defined for the execution of experiments with the lambda sensor installed in the LPG burner are described below: Pulse duration time applied to the sensor element: 100 ms; Discharge time for visualization of the discharge curve after pulse application: 2 s; Amplitude of the voltage pulse applied to the sensor element: 2 V; Sensor operating temperature: 700°C.

In Figure 3, the pulse cycle applied to the lambda sensor is shown from the excitation by the developed electronic circuits. The excitation pulse cycle shown was used in the course of NO_x concentration measurements on the combustion of LPG in the burner.

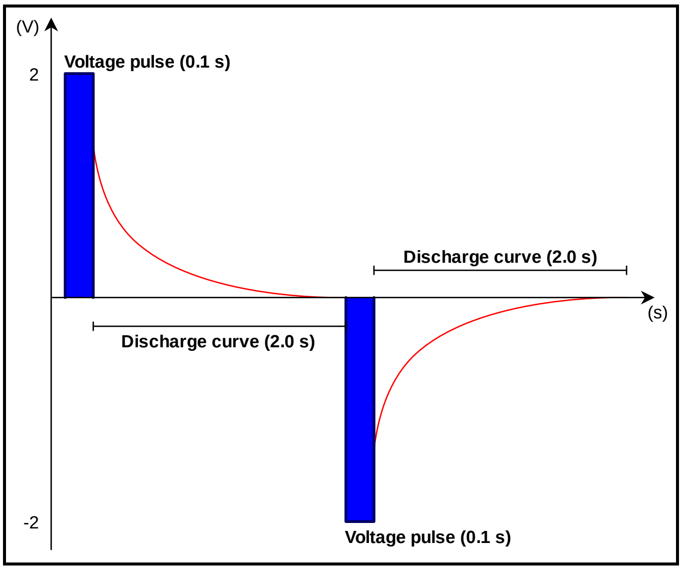

Figure 3. Pulse cycle applied to sensor.

Before starting the combustion experiments, the tests were carried out with the sensor in atmospheric air, being considered as the initial reference for the measurements. The temperature of the sensor was varied from 550°C to 800°C, and the discharge curves were captured for analysis. It was from this analysis that it was possible to define the operating temperature of the sensor at 700°C for combustion experiments.

At the second moment, the discharge curves were recorded through the oscilloscope while the combustion conditions were changed (air and fuel flow) and the NO and NO_2 concentrations measured and stored by the gas analyzer for comparison with the discharge curves obtained in different concentrations of NO_x, being the sum between NO and NO_2.

4. RESULTS AND DISCUSSION

Applying the NO_x detection technique to the lambda sensor, the discharge curves after the pulses of 2 V for 100 ms are captured in the interval of 2 s until the next reverse signal pulse. The electronic system for sensor heating was parameterized to maintain the sensor at 700°C and there was no significant temperature variation (±10°C) to cause interference in the discharge curves. The results were obtained from the capture of the curves by the oscilloscope and by means of the measurements made in the gas analyzer at the same time of the combustion of LPG in the burner used.

It is possible to observe that the discharge curves of the sensor have individual characteristics for the different concentrations of NO_x in the combustion of LPG. However, the maximum NO_x concentration measured at the burner outlet was 42 ppm, thus the discharge curves were analyzed up to this limit.

From the analysis of the discharge curves obtained, it is verified that up to 30 ppm, the response of the sensor is well defined (Figure 4), there being virtually linear variation of the last point of the discharge curve before the next pulse to be applied to the sensor in relation to the NO_x concentration.

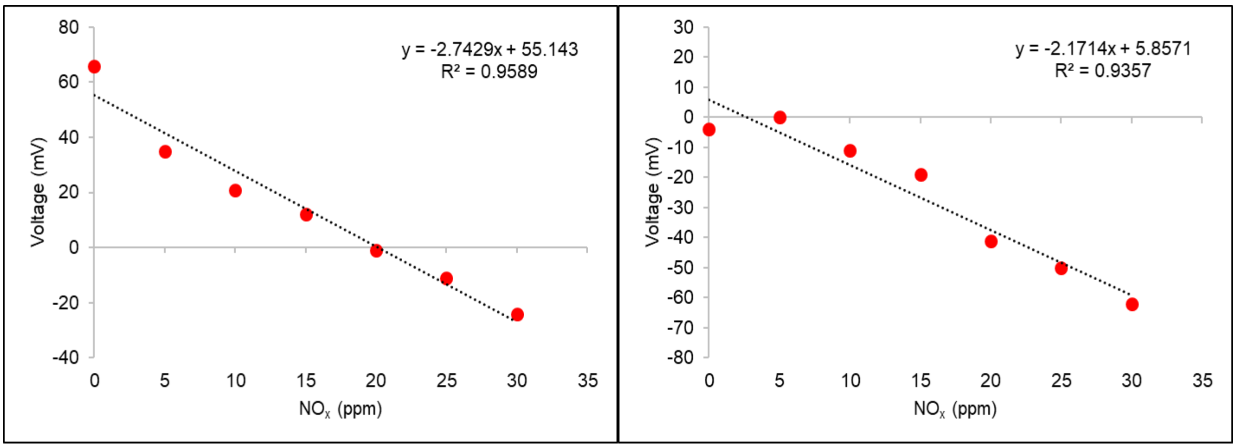

Figure 4. Discharge curves final tension for positive pulse (left) and negative pulse (right).

5. CONCLUSIONS

The proposal to analyze the application of an automotive lambda sensor for NO_x detection in the LPG combustion proved to be satisfactory, as confirmed by the results of the experiments carried out. It is possible to identify that the discharge curves are distinct for each NO_x concentration emitted in the LPG combustion, but the detection is limited to low NO_x concentrations. The detection range of the sensor may be a limitation for use in actual combustion situations. The behavior of the sensor in different fuels such as natural gas and biomass should be analyzed and it is suggested for future work.

6. ACKNOWLEDGEMENTS

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8. RESPONSIBILITY NOTICE