

TDLAS OXYGEN SENSOR FOR MEASUREMENT ON FLOW-PACKED PRODUCTS

L. Cocola ¹, M. Fedel ¹, G. Tondello ^{1,2}, L. Poletto ¹

¹ CNR - Institute of Photonics and Nanotechnologies, Via Trasea 7, 35131 - Padova, Italy, luca.poletto@ifn.cnr.it

² LPRO srl, Via del Lavoro 1, 36043 - Camisano Vicentino (VI), Italy

Abstract – Tunable Diode Laser Absorption Spectroscopy has been applied to the realization of an instrument for the non-invasive contactless measurement of gaseous oxygen concentration inside sealed food containers. The device performs in-line measurements on samples which are passing on a conveyor belt and has been applied to the measurements on mozzarella cheese bags sealed in modified atmosphere, in which the target oxygen concentration is required to be below 5%. We describe the realization, calibration and validation of the device.

Keywords: Tunable Diode Laser Absorption Spectroscopy, Wavelength Modulation Spectroscopy, Modified Atmosphere Packaging, oxygen detection

1. INTRODUCTION

In food packaging industry the use of gases other than air in the process of manufacturing and sealing of food items for distribution to the consumer chain (supermarkets, retail points, etc.) has progressively grown [1]. Presently, Modified Atmosphere Packaging (MAP) is extensively used to improve shelf life and freshness of the products. It follows that the precise measurement and control of the internal atmosphere is a requirement for the food and packaging industries in order to fulfill safety/quality issues. The most common gases to be sensed are oxygen and carbon dioxide, as filling gas mixtures are usually carbon dioxide and nitrogen while oxygen is a residual gas. Oxygen is known to promote bacterial and mold growth, while carbon dioxide is used to slow down decaying processes.

No techniques are presently available for in-line measurements on 100% of the MAP production. Current testing procedures include periodic sampling on the production line to check for

package tightness and filling gas composition in a destructive way. The sensors used for this task include in the majority of cases electrochemical cells [2].

We propose to use Tunable Diode Laser Absorption Spectroscopy (TDLAS) [3] as an optical technique to be used for in-line contactless inspection on sealed containers. TDLAS is used for oxygen detection at 760 nm wavelength while carbon dioxide is sensed using near-infrared wavelengths at around 1.6 μm or 2 μm . The control can be made in-line after closure or later to monitor the integrity of the seal and its evolution in time. TDLAS can be operated on partially transparent containers, such as food trays, bags, bottles, etc., as well in almost non-transparent containers.

We will discuss here the results obtained in the framework of the SAFETYPACK EU-FP7 project, “Innovative non-intrusive laser gas sensors on food production for real time quality/safety in line control of food packaging and bottling systems”. The aim of the project is to demonstrate the applicability of the TDLAS sensing procedure to the monitoring of MAP. The sensors will be demonstrated and validated with two real time in line pilot installations regarding bread, tortilla and cheese production.

In particular, we will describe the sensors that has been developed for in-line application to mozzarella-cheese bags for one of the end-users, Latteria di Soligo, Treviso, Italy. The aim of the measurement is to check the percentage of oxygen inside sealed bags, that is expected to be below 5%. Two devices have been realized in the framework of SAFETYPACK: a benchtop version where samples are manually placed and an device for in-line applications where samples are fed by a conveyor.

In this paper a brief description of the system is given along with an analysis on the different mechanical settings that could affect the measurement. The calibration and validation of the device are finally included

2. DEVICES AND PERFORMANCE

The principle of TDLAS is shown in Figure 1. A laser diode is emitting light that is tuned to scan through an absorption line of the gas to be analyzed. Knowing the length of the optical path, the gas concentration is measured through the light absorption. In the case of oxygen, the only absorption lines are in the 760-nm band. However, these lines are very weak resulting in a very low absorbance for the normal percentage concentration in MAPs when detected using direct absorption spectroscopy.

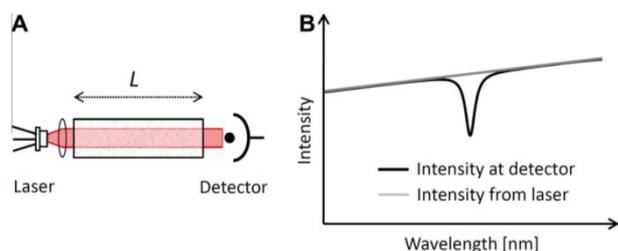


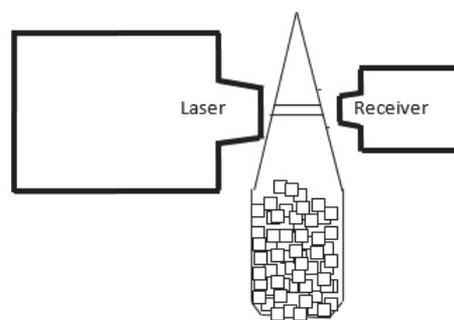
Fig. 1. Principle of diode laser absorption spectroscopy. A) Experimental setup. From left to right: emitting tunable laser diode, medium to be analysed (L is the length of the optical path), photodiode detector. B) Detected signal.

A method to increase the sensitivity of the measurement is the Wavelength Modulation Spectroscopy (WMS) [4]. The laser is modulated by a ramp current and a much higher frequency sine wave. Harmonic components are selected for the measurement by using a lock-in amplifier. Second-harmonic detection is generally used [5]. The gas concentration is retrieved from the WMS signal by using a calibration process. The signal is collected for different values of known concentration, e.g., filling the cell with pre-calibrated mixtures of the gas.

The gas sensor used by this measurement system is based on a DFB laser source scanned at 760 nm working with fast WMS. Two versions have been realized: 1) a laboratory-based sensor where the samples are manually measured with a typical integration time of few seconds; 2) a sensor realized for in-line applications, where the total transit time of each sample in the optical path depends on the conveyor speed. For the in-line application at the actual line productivity of Latteria di Soligo the maximum integration time is 600ms.

A picture of the laboratory-based version is shown in Figure 2 [6]. The instrument is based on

760nm 15-mW DFB laser source modulated with WMS technique. The laser power is high enough to perform measurements with satisfactory performance even in strongly diffusive plastic packages. The laser and its collimating optics are housed in an oxygen-free case, that is visible as the yellow case in the right part of Figure 2(b), in order to cancel the strong background signal from atmospheric oxygen. The laser light is detected by a Si photodiode. To have a zero-path of oxygen outside the package we have adopted the approach of getting both laser and photodiode heads in gentle contact with the package, by using two suction cups one at the end of the nose of the laser head and the other near the photodiode [6]. An example of the experimental data and the fitted ones is shown in Figure 3.



a)



b)

Figure 2. The laboratory prototype developed within the SAFETYPACK project to measure oxygen inside sealed food packaging: a) measurement principle; b) picture of the device with typical samples where measurements have to be performed.

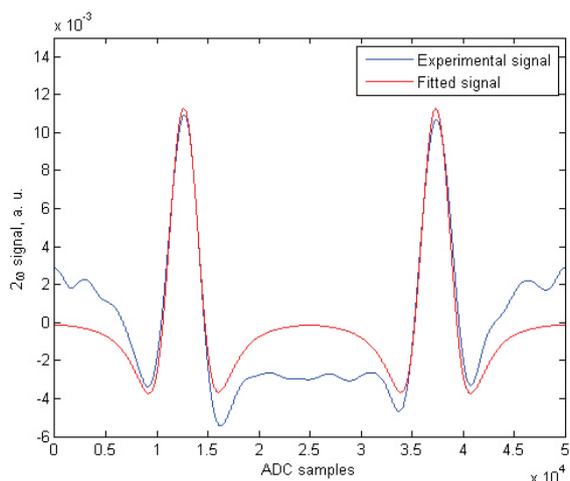


Figure 3. Experimental and fitting absorption line. The data refer to a measure on a mozzarella bag with almost 3% O₂ in a path length of about 50 mm.

Validation of the instrument was done on samples from the end user as well as other kind of samples such as trays and cups. An accuracy in the 0.1% oxygen range (as standard deviation from reference measurement done with invasive technique) was found on the full 0 to 20% oxygen concentration scale, as shown in Figure 4.

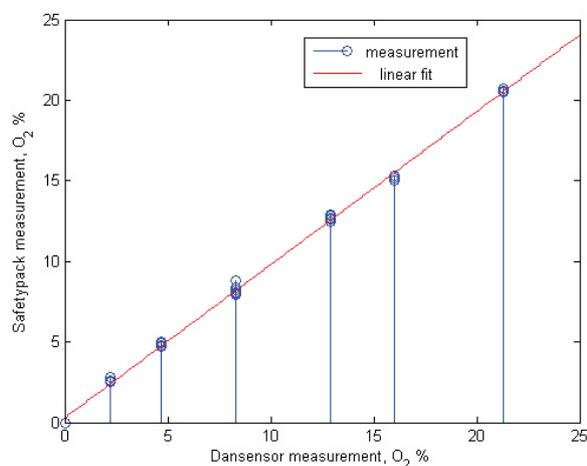
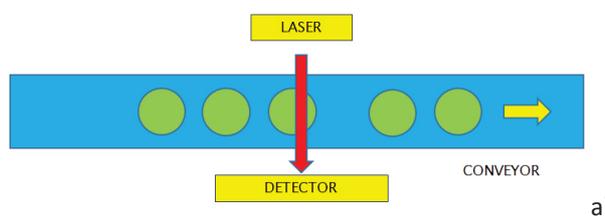


Figure 4. Measurements on a mozzarella bag filled at different O₂ concentrations performed with the SAFETYPACK lab-based device and an intrusive Check Point Dan Sensor device.

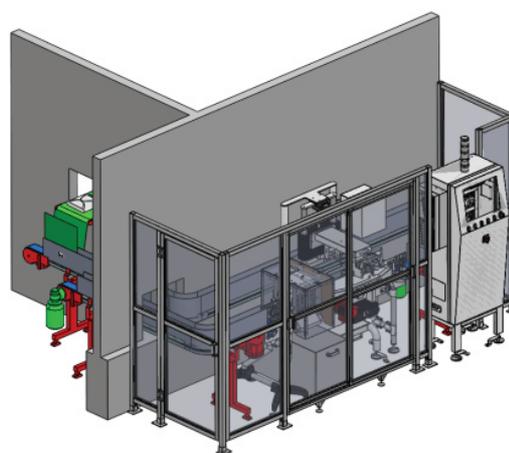
The in-line gas sensing machine consists on a conveyor belt that carries the samples through the measurement region, as schematically shown in Figure 5. The optical scheme is similar with the exception of some hardware improvements to allow operation at shorter integration times and to achieve lower thermal drifts over the wider

temperature range typically found on an industrial installation. The coupling between sensor and sample has been simplified in order to avoid any moving part, differently from the benchtop device. The mozzarella bags are sliding between two guides where the laser head and the detector are hosted. In addition a nitrogen purging is applied to reduce the influence from residual atmospheric oxygen. Furthermore, the machine is designed to support different bag formats.

After a first mechanical optimization phase, validation tests of the in-line measurement have been done showing performances comparable to the bench-top instrument. In particular, preliminary measurements made with the SAFETYPACK sensor on actual samples with oxygen concentration in the 3-8% range have been shown to be fully correlated with intrusive measurements.



a)



b)

Figure 5. a) Schematic of the in-line operation. The samples are moving on the conveyor belt and the measurement is performed on 100% of the sample; b) 3D schematic view of the machine as realized by FT System, Italy, partner of the SAFETYPACK project.

4. CONCLUSIONS

To our knowledge, the SAFETYPACK project is the first attempt to apply the TDLAS technique to the in-line analysis of food packages. Two pilot installations are being realized within the project framework. Here we have described the device

realized for the in-line monitoring in cheese production chain. The preliminary calibration and validation results show a strong correlation with standard invasive techniques well accepted in packaging lines.

ACKNOWLEDGMENTS

The authors acknowledge the financial support of the FP-7 project SAFETYPACK, "Innovative non-intrusive laser sensors on food production for real time quality/safety in line control of food packaging and bottling systems", Grant Agreement 613795.

The authors acknowledge: 1) the designer and provider of the mechanical part of the SAFETYPACK machine, FT System (<http://www.ftsystem.com>) and all the design team of FT led by M.Sc. G. Frazzi; 2) the end-user of the SAFETYPACK sensor here described, Latteria di Soligo, Italy (<http://www.latteriasoligo.it>); 3) the SAFETYPACK partner responsible of the final validation of the system, Danish Technological Institute (<http://www.dti.dk/>) and all the validation team led by Dr. A. Bardenstein.

REFERENCES

- [1] G.L. Robertson, *Food Packaging: Principles and Practice*, CRC Press, London (UK), 2013.
- [2] M. Willet, "Oxygen Sensing for Industrial Safety — Evolution and New Approaches", *Sensors*, Vol. 14, pp. 6084-6103, 2014
- [3] P. Werle, F. D'Amato, S. Viciani, "Tuneable diode laser spectroscopy: principles, performance and perspectives", in *Laser in Chemistry*, S. Lackner editor, Wiley, New York (USA), 2008
- [4] L. Mei and S. Svanberg, "Wavelength modulation spectroscopy—digital detection of gas absorption harmonics based on Fourier analysis", *Appl. Opt.*, Vol. 54, pp. 2234-2243, 2015
- [5] L. Cocola, M. Fedel, L. Poletto and G. Tondello, "Laser spectroscopy for totally non-intrusive detection of oxygen in modified atmosphere food packages", *Appl. Phys. B*, Vol. 119, pp. 37-44, 2015
- [6] S. Søndersby, L. Cocola, H. Allermann, M. Fedel, J.P. Schreiber, G. Tondello, A. Bardenstein and L. Poletto, "Laboratory validation of new non-intrusive laser optical sensor of oxygen for in-line monitoring of food packaging headspace", *Proceedings of 27th IAPRI Symposium on Packaging*, pp. 85-93, Valencia, Spain, June 2015