DOI 10.5162/EUROSENSORS2025/M1.1.3

Active Colorimetric Sensor for Real-Time Detection of Gas Mask Filter Saturation

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Summary:
The respiratory filter cartridge ensures the wearer's safety in toxic environments, provided the cartridge remains unsaturated. To address the challenge of monitoring this saturation to alert the wearer, we present an active colorimetric detection system, which is evaluated with ammonia using a sensitive chromogenic dye. The influence of humidity is also investigated.

Keywords: Chemical warfare agents, toxic industrial chemicals, end-of-service life indicator, colorimetric sensors

Background, Motivation and Objective

Terrorist attacks or industrial disasters can release toxic gases, creating an invisible and often lethal threat to affected areas. In these situations, rescue teams must be deployed to locate and assist victims, requiring them to use personal protective equipment such as gas masks with filter cartridges to mitigate the risk of inhaling harmful substances. However, the efficiency of these filters is influenced by factors including the type of gas, its concentration, and environmental variables such as temperature and humidity. The lifespan of the filter is typically limited by the saturation of its active materials, which decreases its ability to adsorb harmful gases. Therefore, a system capable of detecting filter saturation is crucial to ensure the safety and effectiveness of rescue operations [1,2].

In this study, we present a novel approach for detecting filter saturation using an active colorimetric system, which enables real-time monitoring of filter saturation. The study focuses on the system and a specific chromophore dye, chosen for its sensitivity to both organosphosphorus compounds and ammonia.

Description of the New Method or System

The filter cartridge saturation detection device consists of a sensor module array connected to an electronic board interface via flexible data cables. Each sensor module (see Fig. 1), measuring 12 mm x 10 mm, includes a colorimetric sensor and a commercial air quality gas sensor, the BEM680 from Bosch. The colorimetric sensor is made up of two white LEDs (L130-4070002011001 from LUMILEDS) and a photodetector (VEML3328SL from VISHAY) providing a R, G, B ,C (Red, Green Blue and Clear without filter) optical signals. It operates based on reflection detection. Colorimetric sensor is designed to detect only one specific chemical compound. Therefore, the use of an array of sensors is more effective for detecting saturation caused by a wider range of toxic molecules, and could also be used to provide redundancy and thus improve reliability. The BEM680 sensor measures ambient temperature, barometric pressure, and relative humidity (RH), while also detecting a broad range of gases such as volatile organic compounds (VOC). Subsequently the BEM680 will be able to compensate from drifts in the ambient environment and to take into account saturation due to gases not detected by the colorimetric sensors.

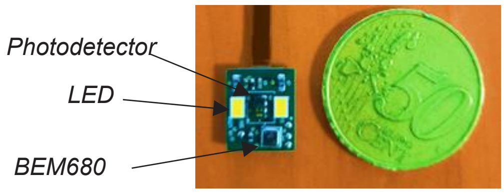

Fig. 1. Module sensor composed of colorimetric sensor and the Bosch BEM680 sensor.

An experimental dedicated filter cartridge integrates 8 sensor modules to be tested on gas test bench (see Fig. 2), this cartridge is the same size as commercial one but it includes flanges for connecting to the gas test bench. A USB wire connection between the electronic board and the computer allows power-up and real-time data acquisition. During experimental evaluation, activated charcoal is replaced by some piece of PTFE to avoid adsorption. The sensor array is integrated into the cartridge between two layers of PTFE chunks. In line with the direction of air flow, the first layer serves as the primary filtration, while the second layer is designed to provide enough time to replace the cartridge after the saturation alarm is triggered by the sensors.

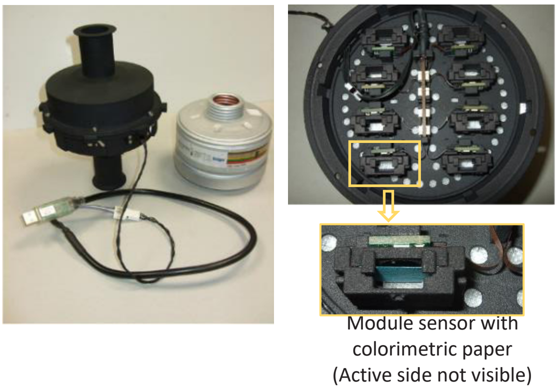

Fig. 2. On the left, the dedicated instrumented filter cartridge is compared to a commercial filter. On the right, the module sensor array inside the dedicated cartridge.

Results

The colorimetric sensor performances were evaluated with gas test bench on ammonia. The gas bench test provides a flow rate range from 6 l/min to 85 l/min, closely matching dynamic respiration range. The carrier gas is synthetic air with RH ranging from 0% to 75%. Ammonia is supplied from a diluted gas bottle with a concentration of 15 ppm. The colorimetric substrate consists of a rectangular piece of paper with a circular area, 8 mm diameter, containing chromogenic dye diluted in dimethyl sulfoxide (DMSO) at a concentration of 10 mM. The remaining area of the paper is black to minimize optical noise.

Experiments were conducted at flow rates of 6 l/min, 33 l/min and 85 l/min with RH set at 0%, 25%, 50%, and 75%, all at room temperature. The system was initially flushed with synthetic air at the desired RH and flow rate. The cartridge was then isolated by closing the valves before and after it. During this isolation, synthetic air mixed with ammonia, maintained at the same RH and flow rate, was stabilized on an independent line until equilibrium was reached. Once stabilized was achieved, the ammonia mixture was switched onto the cartridge. Throughout this entire procedure, measurements were continuously taken for the all eight module sensors. To clarify further, the Figure 3 presents the results of an experiment for only one module sensor, at a flow rate of 85 L/min and 25% RH. The other module sensors showed a similar response. The Green colorimetric signal is not shown due to its high correlation (approximately 0.99) with the Red signal.

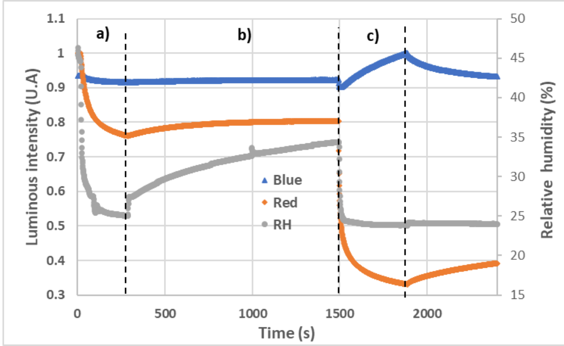

Fig. 3. RH and optical signal responses (Red and Blue signals) under different conditions. a) flow rate of 85 l/min with 25% RH, b) isolation (no flow), c) flow rate of 85 l/min with ammonia and 25% RH.

The results reveal that the colorimetric sensor is able to detect a concentration of 15 ppm ammonia; however; relative humidity interferes with the optical signal. Variations in humidity and ammonia reduce the light intensity of the Red and Green responses, while the Blue response appears less affected by relative humidity, showing an inverse variation with ammonia. As the humidity increases, the magnitude of the variation with NH_3 become more pronounced. For this chromophore, the Blue signal is a key factor to consider when accounting for variations in humidity. However, further investigation and a more in-depth analysis of all the signals are needed to identify the most relevant approach to compensate for humidity.

All the results will be synthesized and presented at the conference related to the final application.

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Acknowledgements

The authors thank the French trans-governmental CBRN-E R&D program for its financial support.