

Precision in Gas Sensing: A Quantitative and Qualitative Analysis of Comparative Bias in Reported Metrics

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Summary:

Gas-sensing performance is commonly assessed through metrics such as sensitivity and response time, often compared across studies without considering experimental variability. Here, we demonstrate that experimental variables significantly influence these metrics. By systematically isolating these parameters, we show that apparent performance differences may arise from measurement artifacts rather than intrinsic material properties. These findings highlight a critical limitation in cross-study comparisons and emphasize the need for standardized reporting and experimental transparency in gas-sensing research.

Keywords: gas sensors, reproducibility, chamber dynamics, flow rate, pre-conditioning

Background, Motivation and Objective

Gas-sensing research relies strongly on performance indicators such as sensitivity, response time, and recovery time to evaluate and compare sensing materials [1]. However, these comparisons typically assume equivalent experimental conditions across different studies. In practice, variations in chamber design, gas delivery systems, and sensor conditioning protocols introduce uncontrolled variables that may significantly bias reported results [2]. Although the influence of these parameters is acknowledged within the community, they are often not explicitly accounted for in comparative analyses, leading to quantitative comparisons that may overlook the qualitative differences among experimental setups. In this sense, this study aims to quantify how chamber volume, flow rate, and pre-conditioning influence the measured sensing performance, highlighting the risk of comparing data from non-equivalent systems.

Description of the New Method or System

A modular gas-sensing chamber with adjustable volume was developed to allow a controlled variation of the parameters under investigation to minimize the influence of other variables. The stackable ring architecture of the chamber allowed changing the chamber volume (550 and 860 cm³) while maintaining identical sensor positioning and electronic interfaces. Different flow rates (100–1000 sccm) were also used, and their

influence in response and time parameters were investigated. Sensor temperature and gas-flow were varied pre-measurement to assess their impact on subsequent transient responses. A first-order mass transport model was employed to describe gas concentration dynamics and correlate them with experimentally observed sensing responses.

Results

The experiments were conducted on two different sensors, based on ZnO (S1) and STN (S2), operating at their optimal operating temperature. The sensors' response profile showed a significant change when the chamber volume increased from 550 cm³ (V₁) to 860 cm³ (V₂) (see Fig. 1). For a 20 ppm CO exposure at 500 sccm, the response magnitude varied up to ~50% in the larger volume. The volume increase was more critical to the time parameters. The response and recovery times increased by about 75% and 85%, respectively. These variations were attributed to the increased dilution time of the target gas, which delayed the attainment of the steady-state concentration.

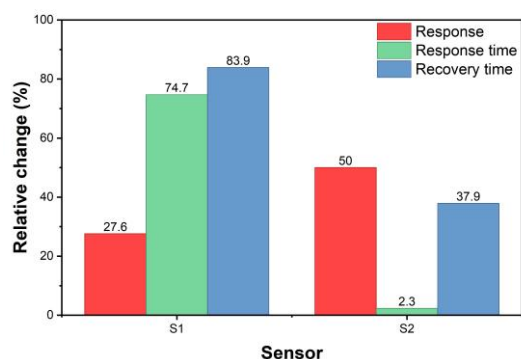


Fig. 1. Relative change of response, response time, and recovery time to 20 ppm of CO when increasing the volume of the chamber from 550 cm³ to 860 cm³.

By varying the flow rate from 100 to 1000 sccm, we observed that the kinetics of the sensing process are dominated by the gas delivery system rather than the adsorption/desorption rates associated with the sensing material. At 100 sccm, the response takes a long time to achieve the steady-state (22 min and 19.8 min for S1 and S2, respectively), while at 1000 sccm, the same sensors present response times of 1 min (S1) and 3.6 min (S2, see Fig. 2). Interestingly, the response magnitude was not significantly influenced by the flow-rate, indicating that the steady-state response is intrinsic to the sensing material.

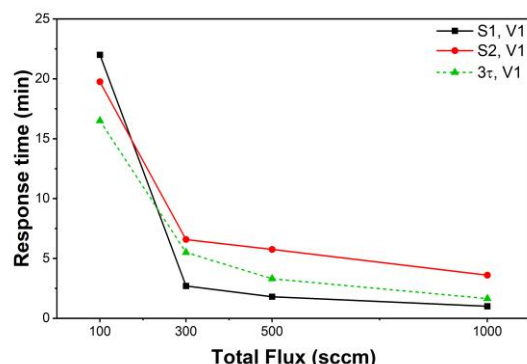


Fig. 2. Variation of response times to 20 ppm of carbon monoxide for different applied flow rates and comparison with the theoretical 3τ curve (95% chamber filling of V1; green dashed line).

Finally, another influencing factor in performance indicators is the sensing history of the sensors. After being exposed to a flow-rate higher than that used during the sensing experiments (1000 and 500 sccm, respectively), S2 exhibited an increased response to CO, whereas no changes were observed for S1. These results indicate that applying a high flow-rate promotes the regeneration of active surface sites and baseline recovery. The fact that S2 remained unchanged may instead be attributed to its higher operating temperature, which already induces a continuous desorption of surface adsorbates

and surface regeneration. Thermal pre-conditioning at 500°C was found to induce increased transient responses that lasted for several measuring cycles (see Fig. 3). Initial exposures following high-temperature cleaning showed response magnitudes up to 30% higher than the stabilized baseline. These effects may be less apparent in single-cycle measurements and can therefore be easily overlooked, as the full transition to steady-state operation is not always captured.

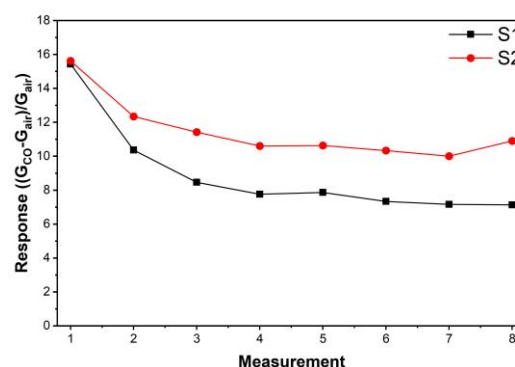


Fig. 3. Stability of the sensors over consecutive sensing measurements after being heated at 500°C for 10 min.

Conclusions

Experiments using two chemoresistive sensors exposed to carbon monoxide (20 ppm) reveal that chamber volume alone can alter response magnitude by up to 50%, and response/recovery times by ~75% and ~85%, respectively. Flow rate strongly influenced time metrics, with response times varying from ~1 min to ~20 min, in agreement with theoretical predictions. Additionally, both flow-induced and thermal pre-conditioning significantly altered sensor responses. These results demonstrate that commonly reported sensing metrics are highly sensitive to experimental conditions, which should be disclosed in detail in sensing studies.

Acknowledgements

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