proceedings

Abstract

Atmospheric Particulate Matter Sensing with Commercial Quartz Crystal Microbalance: A Feature Extraction and Evaluation Study †

Ettore Massera *, Brigida Alfano, Tiziana Polichetti and Maria Lucia Miglietta

TERIN-FSD-DIN, R.C. ENEA Portici (Napoli), 80055 Portici, Italy; brigida.alfano@enea.it (B.A.); tiziana.polichetti@enea.it (T.P.); mara.miglietta@enea.it (M.L.M.)
* Correspondence: ettore.massera@enea.it; Tel.: +39-349-7783456
† Presented at the XXXV EUROSENSORS Conference, Lecce, Italy, 10–13 September 2023.

Abstract: This article presents the results of a study of the ability of the vibrating membranes, such as quartz crystal microbalances, to measure particulate matter. This study builds on the feasibility study previously presented using a low-cost commercial product suitable for research and development purposes. This work shows the results of the treatment of the vibrating surfaces of the membranes, which significantly amplifies their sensitivity. The study provides an analysis of the impedance spectra of the membranes during their exposure to known concentrations of particulate matter. The results of the study show electronic features highly correlated with the concentration of particulate matter in the air.

Keywords: QCM; PMS; PM sensors; particulate matter; aerosol; dust sensor

Citation: Massera, E.; Alfano, B.; Polichetti, T.; Miglietta, M.L. Atmospheric Particulate Matter Sensing with Commercial Quartz Crystal Microbalance: A Feature Extraction and Evaluation Study. *Proceedings* **2024**, *97*, 18. https://doi.org/10.3390/proceedings2024097018

Academic Editors: Pietro Siciliano and Luca Francioso

Published: 14 March 2024

1. Introduction

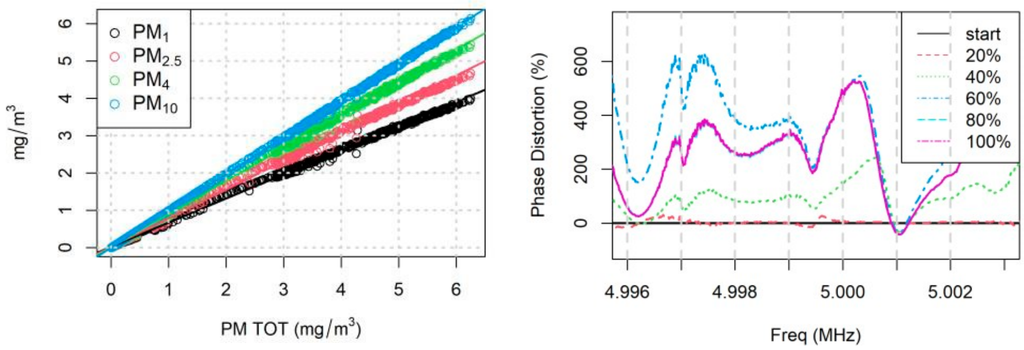
Particulate matter (PM) is a major environmental pollutant that poses significant health risks, particularly in urban areas with high traffic volumes and industrial activities. PM sensors are essential for monitoring air quality and supplying prompt alerts to protect public health. However, traditional PM sensors can be expensive and bulky and require skilled operators for accurate measurements. As a result, there is a growing need for low-cost and compact PM sensors that can accurately detect and measure PM concentrations in real time. Recent studies have shown the potential of several types of low-cost sensors to measure particulate matter [1]. A study conducted by Lu et al. [2] showed the effectiveness of a low-cost, portable, and sensitive vibrating membrane sensor for PM2.5 monitoring. Similarly, a study conducted by Lee et al. [3] proposed a novel design for a portable system, adopting an optical particle counter and quartz crystal microbalance (QCM) for PM10 detection, which showed excellent sensitivity and selectivity. QCM acoustic wave devices are largely studied for their intrinsic excellent mass sensitivity [4], and our previous work [5] demonstrated the possibility of using a stand-alone QCM for PM evaluation.

2. Materials and Methods

The experimental setup for the characterization of devices in a controlled environment was previously described in [5]. In brief, the injector was a TOPAS SAG-410 Dresden, GERMANY, the reference instrument used for PM detection was a TSI DustTrak 8533 Shoreview, Minnesota 55,126 USA, and the reference material used as PM was ISO 12103-1 Arizona test dust [6]. Herein, the active surface of the QCM was spread with a few nanograms of silicon oil until a thin, homogeneous layer covered the device. Data acquisition and management software allowed for recording up to 5 impedance spectra per second.

3. Discussion

The idea was to use quartz crystal resonators' unique sensitivity and speed to weigh the total mass deposited on the surface. The surface coating with silicone oil investigated herein maximized the efficiency of dust capture in the air. In fact, the sensitivity of the QCM to dust appeared to have increased by a factor of more than 10 compared to untreated membranes. To move from the gravimetric measurement of particulate matter accumulated on a membrane to the estimation of the concentration of airborne dust (total PM), it was necessary to temporally differentiate the gravimetric measurement. According to the reference instrument for PM measurement, the concentrations of distinct size fractions of PM and the total PM of injected dust during the tests were strongly correlated, as highlighted in Figure 1a. Each size fraction showed a different correlation coefficient. Thus, as shown in [5], typical parameters, such as resonance frequency shift and dissipation coefficient, used for gravimetric measurement, could be well correlated to PM fractions. However, temperature and humidity could heavily interfere, and sufficient precision and speed of measurement were necessary to reach an accurate estimation of the PM fraction. This work aimed to analyze the impedance spectra variations around the resonance frequency to evaluate if there were useful characteristics that could make QCM capable of estimating the different PM fractions with sufficient accuracy. As an example, Figure 1b shows how the phase spectrum around the resonance frequency becomes distorted as the dust accumulates.



(**a**) (**b**)

Figure 1. (**a**) PM categories are linked to the intensity of total PM during injection in a controlled environment; (**b**) spectral phase percentage distortion around the resonant frequency during dust injection as the powder accumulates on the membrane surface.

Author Contributions: Conceptualization, E.M., M.L.M. and B.A.; methodology, T.P.; software, E.M.; validation, B.A., M.L.M. and T.P.; formal analysis, T.P.; investigation, E.M.; resources, E.M.; data curation, M.L.M.; writing—original draft preparation, E.M.; writing—review and editing, M.L.M.; visualization, B.A.; supervision, T.P.; project administration, E.M.; funding acquisition, E.M. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by the National Programs (PON) of the Italian Ministry of Economic Development (MISE), S.A.L.V.O. Project—grant number B48I20000050005 (Prog n. F/190012/01/X44).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data sharing is not applicable.

Conflicts of Interest: The authors declare no conflicts of interest.

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