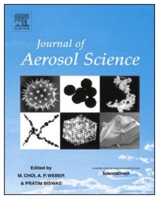
Journal of Aerosol Science 102 (2016) 29–40

Contents lists available at ScienceDirect

Journal of Aerosol Science

journal homepage: www.elsevier.com/locate/jaerosci



Laboratory assessment of low-cost PM monitors

Abhisek Manikonda, Naděžda Zíková, Philip K. Hopke, Andrea R. Ferro *

Center for Air Resources Engineering and Science, Clarkson University, Potsdam, New York, USA

A R T I C L E I N F O

Article history:
Received 5 April 2016
Received in revised form
27 June 2016
Accepted 21 August 2016
Available online 25 August 2016

Keywords:
Low-cost sensors
PM monitoring
Monitor comparison
Exposure assessment

A B S T R A C T

Recently, a number of optical particulate matter (PM) monitors employing low-cost PM sensors have become available on the consumer market. These portable low-cost monitors can be used to characterize PM concentrations with high spatial and temporal resolution. This study evaluates the performance of four low-cost PM monitors (Speck, Dylos, TSI AirAssure, and UB AirSense) against well-characterized reference instruments, and studies their suitability for PM field exposure studies. The low-cost monitors were characterized in a room-sized laboratory chamber with standard relative humidity and temperature conditions, with two PM sources: cigarette smoke and Arizona Test Dust. This study found that any of the monitors tested perform with adequate precision for monitoring air quality in an indoor microenvironment, although the field calibration of the monitor with a standard instrument for specific types of particles would be required. Other factors such as flexibility in data download methods, connectivity, compatibility with environmental conditions, and quality of technical support should also be considered when selecting low-cost PM monitors for human inhalation exposure assessment studies.

1. Introduction

The effects of particulate matter <2.5 μm in diameter ($PM_{2.5}$) on human health, both morbidity and mortality, have been extensively studied over the past 15 years (USEPA, 2009). Particulate matter (PM) is reported to be a serious health hazard, causing cardiovascular and respiratory disease. As a result, many governments around the world have set air standards that define limits for PM concentrations that may not be exceeded (Vahlsing & Smith, 2012) and have established compliance monitoring networks to determine the ambient air quality relative to those standards. Monitoring for particulate matter generally involves the collection of integral filters or using relatively expensive equipment such as beta attenuation monitors (BAM) or tapered element oscillating microbalances (TEOM), which limited the quality of spatial distribution of ambient PM data (Wang et al., 2015). Recently, relatively low-cost ($200–$600), easy-to-use, portable PM monitors, employing available off-the-shelf sensors, have become available on the consumer market.

PM monitors can be categorized into those that measure either mass concentration or number concentration. PM mass can be measured directly by changes in the penetration of electrons through the sample (BAM) (Krost, Sawicki, & Bell, 1977), changes in frequency of an oscillating sensor element (Paprotny, Doering, Solomon, White, & Gundel, 2013; Patashnick & Rupprecht, 1991; Snyder et al., 2013), or indirectly based by light scattering, with the particle diameter estimated by the amount of scattered light (Snyder et al., 2013). Currently, only the light scattering systems can be produced inexpensively.

* Corresponding author.
E-mail address: aferro@clarkson.edu (A.R. Ferro).

http://dx.doi.org/10.1016/j.jaerosci.2016.08.010
0021-8502/

These low-cost monitors have recently gained attention because they can increase our ability to characterize PM concentrations with high spatial and temporal resolution at an acceptable cost since many such devices can be deployed concurrently (Holstius, Pillarisetti, Smith, & Seto, 2014). Commercially available devices include the Speck (Airviz Inc., Pittsburgh, PA) and the Dylos 1100 Pro/Dylos 1700 (Riverside, CA).

Recent studies have characterized the performance of low-cost PM monitors. Williams, Kaufman, Hanley, and Rice (2014) characterized the initial version of the Speck monitor and the Dylos DC1100 monitor. The study showed that Speck did not correlate well with the reference instrument ($R^2 = 10^{-5}$), a Grimm model EDM180 dust monitor (Federal Equivalent Method, FEM), but the Dylos monitor compared well with the Grimm EDM180 ($R^2 = 0.533$). For other studies, comparisons were not made with FEM, but with other research instruments. For example, Wang et al. (2015) characterized three low-cost PM sensors: Shinyei PPD42NS, Samyoung DSM501A, and Sharp GP2Y1010AU0F. They found that all three sensors demonstrated high linearity with a TSI (Shoreview, MN) SidePak AM510 Model AM-510 Personal Aerosol Monitor, and their output was highly dependent on particle size and composition. Dacunto et al. (2015) provided $PM_{2.5}$ calibration curves for the Dylos DC1100 from a set of 64 experiments using common indoor particle sources for which the Dylos DC1100 was collocated with the TSI SidePak and found a wide range of calibration factors based on source type. A validation study of two continuous particle monitors measuring $PM_{2.5}$, including the TSI DustTrak 8520 and a Thermo Scientific (Waltham, MA) personal DataRAM was carried out by Wallace et al. (2010), and demonstrated that the two instruments were in reasonable agreement with gravimetric $PM_{2.5}$ measurements. Sousan et al. (2016) evaluated the performance of the Dylos DC1700 monitor and two Sharp sensors in measuring different aerosols at high concentrations. They demonstrated that all the three sensors had high regression ($R^2 > 0.97$) when the sensor output was compared to the mass concentrations measured with a pDR-1500, and after calibration, all the sensors showed high precision. Budde, Busse, and Beigl (2012) compared different commercial-off-the-shelf PM sensors, including the Sharp GP2Y1010AU0F and Syhitech DSM501A. They report that although there was general correspondence of the sensor responses to reference methods, they were not sufficiently accurate for use as compliance monitors. However, they could be adequate for high spatial/temporal monitoring over extended time intervals where the volume of data produced provides useful information. Thus, the use of these inexpensive air quality monitors to control air quality and characterize the effect of air quality in different microenvironments on personal exposure remains a challenge.

In this study, a series of measurements were made with current low-cost PM monitors to investigate and compare their accuracy and precision for the measurement of particulate matter relative to the well-characterized reference instruments, and their suitability for PM exposure field studies.

2. Methods

Four low-cost PM monitors were obtained and evaluated in this study: Speck (Airviz Inc., Pittsburgh, PA), Dylos 1100 Pro/Dylos 1700 (Riverside, CA), AirAssure $PM_{2.5}$ IAQ Monitor (TSI Inc., Shoreview, MN) and AirSense (Buffalo, NY).

2.1. Study location and parameters

Laboratory experiments were performed in Clarkson University's Indoor Air Quality Chamber with dimensions of 2.24 m wide, 3.91 m long and 2.44 m high. The mixing volume of the chamber is 21.37 m^3. The chamber was built with standard residential materials (wood, drywall). The air flow rate was previously determined to be 0.01 air changes per hour under passive ventilation conditions. The chamber has a HVAC system installed, but the system was switched off during the experiment. The aerosol generator was placed in the corner of the chamber. The test monitors were collocated in the center of the chamber with three well-characterized reference instruments, a Grimm 1.109 (Grimm Technologies), an APS 3321 (TSI Inc.) and an FMPS 3091 (TSI Inc.).

Table 1
Specifications of test monitors according to the manufacturer's data sheets.

Monitor (Sensor)	Measuring principle	Size fraction	Limit of detection	Units of measurement	Power accessory	Data retrieval	Number of units tested
Speck (Syhitech DSM501A)	LED optical sensor	0.5–3 μm	NR	#/L or μg/m³	Mini-USB	USB or WI-FI upload to web-based account	2
Dylos 1100 PRO/Dylos 1700	Laser particle counter	> 0.5 μm > 2.5 μm	NR	#/ft³	AC Adapter	9 pin serial cable	1 each
TSI AirAssure (Sharp GP2Y1010AU0F)	Light scattering photometer	NR	5–300 μg/m³	μg/m³	24 VDC cable	WI-FI	3
UB AirSense (Sharp GP2Y1010AU0F)	IR optical sensor	NR	NR	μg/m³	9 V Battery	SD Card	1

NR: not reported.