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Impact of dust loading on long term portable air cleaner performance

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ABSTRACT

Although there has been many studies conducted on the initial performance of portable air cleaners (PACs), there is little research on the evaluation of their long term performance. This paper quantifies the effects of particle loading on PAC particle removal, airflow rate, power consumption and ozone emissions for a HEPA- and electrostatic precipitator (ESP) - based PAC. Ozone emission rates decreased in a linear fashion for the ESP-based PAC suggesting dust masking on the unit's discharge electrode. Performance in terms of particle clean air delivery rates (CADR), airflow rates and power consumption reduced for both units as dust was loaded up to the filter's half-life. For the HEPA based PAC, particle CADR reductions are due to reduced airflow rates. As a consequence, the particle single pass efficiencies (SPEs) grew indicating dust accumulation on the filter. This phenomenon is not observed on the ESP-based PAC where both particle CADR as well as SPE reduced upon dust loading. This study demonstrates the importance of regular filter maintenance for PAC to ensure optimal performance.

1. Introduction

Airborne particles exposure has been established to have a significant effect on human health [21,29]. As we spend a large fraction of our time in buildings [13], it is therefore important to reduce their concentrations indoors [16]. Portable air cleaners (PACs) have been recommended to reduce particle exposure indoors [5,18,23,26]. This is because they are easy to be positioned in different parts of a building to be used where air cleaning is needed [18] and can be effective when concentrations of particles are high [5]. However, despite the plethora of studies documenting initial performance of PACs (for e.g. Refs. [23,26], there are very few research presented on performance of PACs over a long period in laboratory and residential settings [6,23]. Batterman et al. [6] reported a study documenting reduction in airflow rates and pressure drop as the PAC of the filters were blocked (to simulate dust accumulation) by 0, 25, 50, 75, and 100% filter area. Shaughnessy et al. [23] reported that the clean air delivery rates (CADR) for a HEPA PAC installed in a residential bedroom decreased by 25% after intermittent operation for 800 h. For PAC with electrostatically charged filters, filtration efficiency and CADR decreased as dust loading increased. Shaughnessy et al. [23] also noted that dirt on electrostatic precipitator PACs has been observed to reduce removal efficiency.

Unfortunately, research on long term performance of PACs to remove particles has been conducted in non-controlled field studies. Under this situation, particle loading on the PACs *and* other environmental parameters (air exchange rates, relative humidity (RH) and temperature) are not regulated which could lead to confounding in the results [6]. In addition, simulation of filter loadings by blocking the filter using a solid material (Batterman et al., 2005) is not comparable to actual dust loading. Indeed, there is a lack of measured data and analysis for the evaluation of long term performance of PACs in a controlled laboratory setting that mimic actual residential use. This paucity of information is noteworthy considering that building occupants require information when to change non-performing used filters or service dirty PACs. In addition, maintaining performance of PACs over the long term is important when the intent is to manage symptoms associated with high particle exposures for sensitive and health compromised occupants. In order to better understand the efficacy of PACs in improving indoor air quality impacted by their long term usage, a study to quantify the effects of dust loading on PAC particle removal, airflow rate, power consumption and ozone emissions is conducted through a controlled laboratory testing. The long term performances for a HEPA based PAC and that of an electrostatic precipitator based PAC were also compared.

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2. Materials and methods

2.1. Dust loading chamber (DLC) and dust loading procedures

A specially-designed, electro-polished stainless steel chamber was fabricated to load dust onto the PAC. The DLC used is a cylindrical chamber of radius 0.60 m and height 1.77 m (internal volume: 2.0 m^3) (Fig. 1) capable of accommodating PAC of various sizes and airflow configurations. It is airtight (air leakage is less than 0.5% of the chamber volume per minute at an overpressure of 1000 Pa) and operated slightly above atmospheric pressure to avoid influence from the laboratory atmosphere. The control of temperature in the DLC is achieved by maintaining the temperature of the supply air and controlling the temperature of the laboratory area. To generate humidified air, dry filtered air is passed through a set of 20 L vessels containing deionized water. Differential pressure, temperature and RH in the DLC are continuously monitored using a data acquisition system (DAS). A fan consisting of 4 stainless steel blades (AC motor and variable frequency drive is located outside of the DLC) is mounted on the ceiling of the DLC to aid dust mixing in the chamber during the loading process. Air mixing, as measured via ventilation measurements, is greater than 80%. Deposition of loading dust on the DLC floor surfaces is reduced using a “dust resuspension system” to increase loading dust resuspension into the air. The system is comprised of two ¼” stainless steel tube rings that run the circumference of the chamber floor containing holes that are offset by 3.8 cm from each other. The rings are supplied with filtered air independently and operated using a custom designed air control system. The air control system allows the user to set the timing and the length of the burst of air used. Lastly, the exhaust outlet of the chamber is located on the DLC top which is connected to a filter housing. A clean particle filter is added to the housing to capture any loading dust that may enter the exhaust stream. The filter housing outlet is connected to a 6″ duct where the air is exhausted out of the lab.

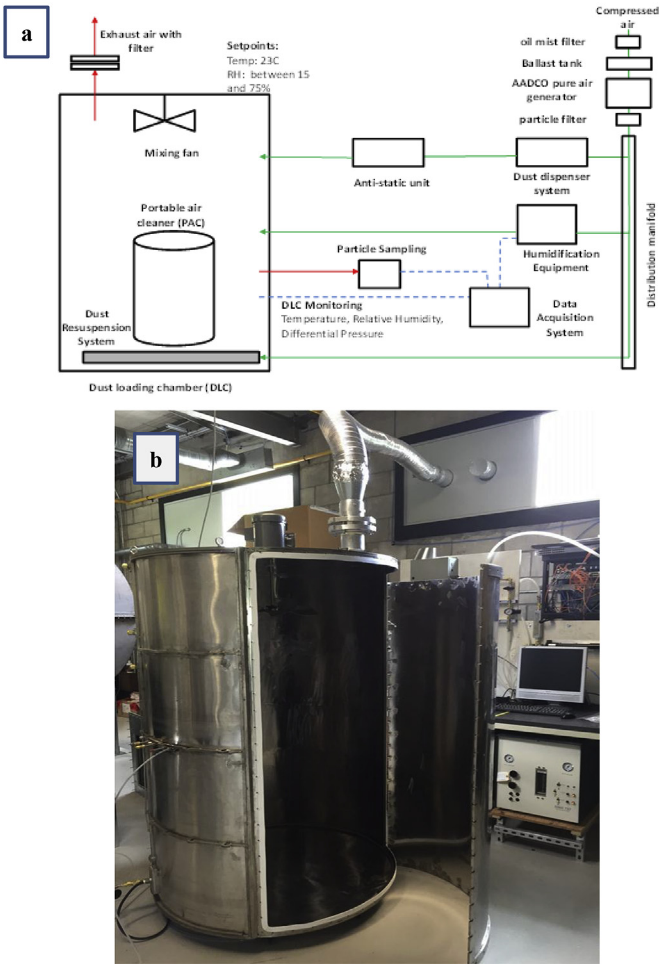

Fig. 1. (a) Schematic and (b) photo of the DLC.

Before each dust loading test, the internal chamber surfaces were cleaned with water, and wiped with Kimwipes to remove adhered dusts. A pre-weighed clean filter was installed on the exhaust of the DLC. The loading dust used was ISO 12103-1 A1 ultrafine test dust (Table 1). An ASHRAE compliant dust loading system ASHRAE [4] was used to provide delivery of the loading dust into the DLC. A Kr85 beta radiation source applies a Boltzmann equilibrium to the dust injected. A custom nozzle is used to disperse the dust in the chamber. Before and during the loading process, the DustTrak™ DRX Aerosol Monitor 8533 was used to measure airborne dust concentration in 2 particulate matter (PM) indices, total suspended particles (TSP) and $PM_{2.5}$. The total dust mass to be loaded onto the PACs was calculated to be at least equal to 30 $\mu g/m^3$ multiplied the airflow rate of the PAC multiplied the simulated duration of the test. 30 $\mu g/m^3$ was used as it was the average indoor concentration of airborne dust typically encountered by a PAC in a Canadian residence [28]. In this test, the hours of operation for the PAC used to calculate the total dust mass to be loaded was 24 h per day. Simulated number days used was the air cleaning technology half-life which is the time required for the expected life of the PAC media to fall to half its initial value. Typically, this is described as half the time when the PAC media is expected to be changed according to the PAC manufacturer's claim. It can also be described as half the time required for electronic air cleaning technology to be maintained or serviced as recommended by the manufacturer. The calculation for the total dust mass is given in the equation below:

$$\text{Total Dust Mass} = 30\ \mu g/m^3 \times \text{airflow rate} \times 1440\ \text{min/day} \times \text{days} \tag{1}$$

Dust injected into the DLC that was not collected by the PAC was accounted for and weighed. Dust deposited on the internal surfaces was first collected using a custom built vacuum system with a dust collection device comprising of a dust glass collector and a filter

Table 1
Particle size distribution by volume and chemical makeup of ISO 12013-1 ultrafine test dust.

Particle size distribution by volume %		
Size (μm)	% less than	
0.97	3.0–5.0	
1.38	7.0–10.0	
2.75	23.0–27.0	
5.50	65.0–69.0	
11.00	95.5–97.5	
22.0	100.0	
Chemical makeup		
Chemical	CAS number	% of weight
$Si0_2$	14808-60-7	68–76
Al_20_3	1344-28-1	10–15
Fe_20_3	1309-37-1	2–5
Na_20	1313-59-3	2–4
CaO	1305-78-8	2–5
MgO	1309-48-4	1–2
TiO_2	13463-67-7	0.5–1.0
K_20	12136-45-7	2–5