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Evaluation of a Shaker Dust Collector for Use in a Recirculating Ventilation System

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Abstract

General ventilation with recirculated air may be cost-effective to control the concentration of low-toxicity, contaminants in workplaces with diffuse, dusty operations, such as in agriculture. Such systems are, however, rarely adopted with little evidence showing improved air quality and ability to operate under harsh conditions. The goal of this work was to examine the initial and long-term performance of a fabric-filter shaker dust collector (SDC) in laboratory tests and as deployed within a recirculating ventilation system in an agricultural building. In laboratory tests, collection efficiency and pressure drop were tracked over several filter loading cycles, and the recovery of filter capacity (pressure drop) from filter shaking was examined. Collection efficiencies of particles larger than 5 μm was high (>95%) even when the filter was pristine, showing effective collection of large particles that dominate inhalable concentrations typical of agricultural dusts. For respirable-sized particles, collection efficiencies were low when the filter was pristine (e.g., 27% for 1 μm) but much higher when a dust cake developed on the filter (>99% for all size particles), even after shaking (e.g., 90% for 1 μm). The first shake of a filter was observed to recovery a substantial fraction of filter capacity, with subsequent shakes providing little benefit. In field tests, the SDC performed effectively over a period of three months in winter when incorporated in a recirculating ventilation system of a swine farrowing room. Trends in collection efficiency and pressure drop with loading were similar to those observed in the laboratory with overall collection efficiencies high (>80%) when pressure drop exceeded 230 Pa, or 23% of the maximum loading recommended by the manufacturer. This work shows that the SDC can function effectively over the harsh winter in swine rearing operations. Together with findings of improved air quality in the farrowing room reported in a companion manuscript, this article provides evidence that an SDC represents a cost-effective solution to improve air quality in agricultural settings.

Keywords

air cleaner; dust; fabric filter; general ventilation; indoor air quality; inhalable particles

INTRODUCTION

Local exhaust systems remove contaminants where they are generated to reduce worker exposures and maintain low concentrations throughout the work environment.[1] Design

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guidelines for local ventilation are available for many operations, such as enclosing hoods recommended to prevent dust from contaminating a workplace during drum filling. In many environments, however, dust may be generated from multiple sources in a workplace, making local exhaust impractical. In the forest products industry, for example, storage, transport, and processing of wood chips or cellulose fibers release dusts throughout production areas, resulting in high airborne concentrations of wood/cellulose dust.[(2)] This dust can also settle on equipment with subsequent resuspension in the air due to mechanical or other agitation, which represents an explosion and inhalation hazard.[(3)] Similarly in the agricultural sector, particularly in concentrated animal feeding operations, dust from a combination of diffuse sources (feed, dander, feces, mold, pollen grains, insect parts, and mineral ash)[(4,5)] make local exhaust impractical. However, exposure to this dust mixture has been implicated in adverse respiratory health effects among swine CAFO workers[(6,7)] and may also depress the health status of swine,[(8)] indicating that reducing dust concentrations throughout these barns is desirable.

An alternative to local ventilation to reduce dust concentrations, thereby reducing worker exposure and fire risks, is to mechanically exhaust air from points within a dusty room, using clean outdoor air as makeup air.[(1)] This general ventilation option, however, can be expensive when the clean air requires conditioning, either heating in winter or cooling and/or dehumidification in summer. An option to treat exhausted air and recirculate it back into the room may reduce operating costs requires that the air is adequately cleaned prior to being returned.[(9)] Should the control equipment not effectively remove the dust, recirculating the air may increase the dust concentrations over time, resulting in the expense of operating air handlers without the benefit of exposure control, leaving the worker unprotected by the ventilation system.

The American National Standards Institute (ANSI), partnering with the American Industrial Hygiene Association (AIHA), developed a standard (Z9.7-2007) specifying design and operational guidelines for recirculating air exhausted from an industrial process.[(10)] This standard specifies that up to 100% of the exhaust air can be recirculated if concentrations of contaminants in the room are maintained below recommended guidelines, such as the ACGIH Threshold Limit Values (TLVs), and air with only relatively low toxicity compounds be considered for recirculation. A hazard evaluation of the system and strategies to prevent recirculation when the treatment system fails are required prior to installing a recirculating ventilation system.

If properly designed, installed, and operated, recirculation of cleaned air through mechanical ventilation may represent a cost-effective option to improve the air quality in dusty trades with diffuse generation sources, such as agriculture.[(11)] Air cleaners suited to remove dust in a recirculation system include cyclones, electrostatic precipitators, wet scrubbers, and filtration units. Cyclones use centrifugal force to separate large particles (typically >10 μm) from the airstream and may be useful as a pre-cleaner but will likely be ineffective to collect respirable particles. Electrostatic precipitators have collection efficiencies above 95% for particles larger than 0.l μm but have high capital and operating costs. In wet scrubbers, particles larger than 2 μm are removed from an airstream with high efficiency (>95%) when they collide with droplets. Scrubbers, however, require management of the liquid used for collection, which may be difficult when water resources are limited. Filtration is commonly used to collect dry particles from operations such as buffing, grinding, mixing, packaging, polishing, sanding, and sawing. A filtration unit referred to as a shaker dust collector (SDC) relies on standard filtration to remove particles from air and also incorporates a mechanical shaking system that dislodges collected dust and recovers filter capacity (i.e., pressure drop) lost during operation. An SDC air cleaner enables long-term unattended operation without filter handling and requires minimal utility requirements to operate: electrical power to operate the fan and shaker.

Recirculating ventilation systems that incorporate air cleaners, like the SDC, are rarely adopted by many sectors, including agriculture. Possible barriers to the adoption of these systems include a lack of information on whether the system actually improves air quality of the room being serviced, whether the system operates at efficiencies as indicated by the manufacturer in the field, and whether the lifespan and operating costs are sufficient to warrant initial capital costs of the system.

The goals of this article were to examine the initial and long-term performance of an SDC in a recirculating ventilation system under laboratory and field conditions. Performance parameters included collection efficiency and pressure drop, which were tracked over several filter loading cycles. Laboratory experiments with a challenge aerosol in the particle size range typical of agricultural dusts (throughout the inhalable region) were designed to provide information to examine operational costs, lifespan, and operational characteristics, such as cleaning frequency. In subsequent field tests, a swine farrowing room in the upper Midwest of the U.S. was retrofitted with a recirculating ventilation system with an SDC, and performance was monitored over a period of three months in winter. In this article we report on the performance of the SDC during field deployment. A companion manuscript provides information on the effectiveness of the system to improve air quality in the room.[12]

METHODS

Laboratory Evaluation

Experimental Setup—A commercial off-the-shelf 1700 $m^3\ hr^{-1}$ (1000 CFM) SDC (Model 140, United Air Specialists Inc., Cincinnati, OH; dimensions 0.8 m × 0.7 m × 1.2 m) and exhaust ventilation system was assembled, as shown in Figure 1. The duct system was assembled of 254-mm (10-in) diameter, circular, galvanized steel ducting with clamp-together connections (NORDFAB USA, Thomasville, NC). Airflow through the system was provided by a radial flow fan integral to the exhaust-side of the SDC and controlled with a blast gate at the entrance of a 3-m long (longitudinal distance of 12 duct diameters) inlet duct. Airflow entering the SDC, traveled around a baffle plate that separates very large particles (>100 μm) from the airstream. Airflow and suspended particulate matter then passed through a pocket fabric filter designed for the SDC (14-pocket, polyester sateen filter, SDC-140, 9-oz cloth with 13-m^2 surface area). Filtered air passed through the fan at the top of the unit and exhausted through ductwork. The SDC unit included an integrated reciprocating arm mechanism that, when activated at the control panel, dislodged dust cake from the filter media by shaking the pocket filter assembly. The dust shaken from the filter accumulated in a sealed storage drum beneath the unit.

As an indicator of airflow, velocity pressure was measured with a Pitot tube positioned in the center of the exhaust duct and 8 duct diameters downstream of the SDC outlet. The Pitot tube ports were connected to a pressure transmitter (Model 616-2, Dwyer Instruments, Michigan City, IN) with plastic tubing. A second pressure transmitter (Model 616-2, Dwyer Instruments, Michigan City, IN) was used to measure the pressure drop across the SDC filter. Pressure transmitter signals were recorded using a custom electronic data logger (Arduino, Adafruit Industries, New York, NY) set to log once every second. All tests were conducted indoors where room temperatures ranged from 22–26°C, relative humidity ranged from 45–62%, and atmospheric pressure ranged from 737–745mm Hg.

Loading—The performance of the SDC was tested through three loading cycles of dust, taking the system to the maximum pressure drop recommended by the manufacture (of 1000 +/− 50 Pa). At the end of each cycle, the pocket filtration assembly was mechanically shaken to remove the dust cake on the filter and reduce the pressure drop across the system. A commercially available standardized test dust with particles in the respirable and inhalable size range (Arizona road dust, ARD, d_p < 1–200 μm, A4 Coarse Test Dust, Powder Technology Inc., Burnsville, MN) was used to simulate dust typically found in CAFOs and other agricultural settings. The ARD was dispensed at a target rate of 0.6 g min^{-1} using an auger-type dry material feeder (Model 53190, Accurate, Whitewater, WI), positioned one-half duct diameters downstream from the ventilation system inlet. The ARD became entrained in the high velocity airflow as it entered the inlet duct. This feed rate resulted in a nominal dust concentration in the ventilation duct of 21 mg m^{-3} at an airflow rate of 1700 m^3 hr^{-1} (1000 CFM). Although high compared to that typical of indoor concentrations (e.g., swine facilities 0.8–15 mg m^{-3}[(13)]), this dust concentration allowed us to conduct loading tests over an accelerated time period.

A loading test was stopped when the filter pressure drop reached the manufacturer's recommended maximum (1000 +/− 50 Pa). The actual quantity of dust fed into the hopper of the material feeder during a loading test was determined gravimetrically with a scale (4010G, Pelouze Products, Richardson, TX). The first loading test was started with a pristine filter. The same filter was used continuously throughout the study and was cleaned by shaking after each loading test. For each test, a relationship between the airflow (calculated from exhaust velocity pressure) and the pressure drop across the filter was examined, calculating the coefficient of determination (R^2) (Microsoft Excel, Version 14, Microsoft Corp., Redmond, WA).

Collection Efficiency and Quality Factor—Collection efficiency of the SDC, by particle aerodynamic diameter, was measured four times during the loading tests: with a pristine filter before the first loading; after the first loading; before the second loading; and after the second loading. Polydisperse solid glass microspheres (3.3 μm count median diameter, 1.7 geometric standard deviation; 5000A, Potters Industries, Valley Forge, PA) were fed with an auger-type dry material feeder (Model 53190, Accurate, Whitewater, WI) to a Venturi nozzle (Model JD-90M, Vaccon, Medway, MA), which aerosolized the microspheres. The nozzle was oriented so that the microspheres entered the inlet duct. Glass microspheres were selected for these tests because their known density (2,500 kg m^{-3}) and spherical shape allows for accurate measurement of particle aerodynamic diameter, thereby improving the generalizability of results.

An aerodynamic particle sizer (APS, Model 3321, TSI, Shoreview, MN) fitted with a gooseneck nozzle (Model 401SS, Clean Air Engineering, Palatine, IL) was used to isokinetically sample the test aerosol from the duct. Clean air was supplied to the sheath airflow of the APS to reduce the sample airflow from the default 5 L min^{-1} to 4.4 L min^{-1} in the duct to meet isokinetic requirements. The APS was used to measure particle number concentration by size for 60 sec alternately at locations one duct diameter upstream (without filtration, WO) and 5 duct diameters downstream (with filtration, W) of the SDC in the following sequence: WO_1-W_1-WO_2-W_2-WO_3-W_3-WO_4. Particle density of the glass beads and Stokes correction were applied in the APS software (AIM, Version 7, TSI, Shoreview, MN) to convert measured diameters to aerodynamic diameter. For each aerodynamic diameter, the collection efficiency (CE) for each of three repetitions, *i*, was calculated as:

$$CE_i = \left(1 - \frac{W_i}{\frac{WO_i + WO_{i+1}}{2}}\right) \times 100\%. \quad (1)$$

The overall collection efficiency ($CE_{overall}$) was calculated as the arithmetic mean of collection efficiencies over all particle sizes up to 20 μm in aerodynamic diameter.

Quality factor (q_F) is a parameter that combines both collection efficiency and pressure drop (Δp) across the device, useful to rank control devices by both efficiency and operating costs. The quality factor was assessed at startup of the first loading, end of first loading, startup of second loading, and end of second loading. The quality factor was calculated as:

$$q_F = \left(\frac{-\ln(1 - CE_{overall})}{\Delta p}\right). \quad (2)$$

Filter Pressure Drop Recovery by Shaking—Following each loading test, the SDC filter was shaken for 35 sec (manufacturer's default setting) three times using the reciprocating shaker arm mechanism. The pressure drop across the filter was measured before and after each of the shaking events. The pressure drop recovered by each shaking was calculated as the pressure drop measured before shaking minus that measured after shaking. A one-way analysis of variance (ANOVA) was used to test the hypothesis that the mean of the recovery in pressure drop with sequential shaking cycles were equal. Post hoc Tukey tests were conducted to compare mean recoveries; significant differences in mean recoveries were reported using ANOVA at a significance level of 0.05. Statistical analyses were performed in Minitab (Version 17.1, Minitab, Inc., State College PA).

Field Tests—A recirculating ventilation system incorporating the same SDC from laboratory tests was installed at the large swine farrowing room of the Mansfield Swine Education Center at Kirkwood Community College (Cedar Rapids, IA) over winter from December 13, 2014 to February 27, 2014. A full description of this system is provided by Anthony et al.[12] and briefly described here. The room (9.2 m wide × 14 m long × 2.4 m height) contained 4 rows of animal crates with a total capacity of 19 sow. Sows were moved into their crates prior to delivering piglets, which remained in the room for 21 days before being moved to a separate nursery room. At one point in this study, all sows and piglets were relocated into a smaller farrowing room, and sampling occurred on one of these days (December 31–January 1). Positioned outside of the building, the SDC pulled air from the farrowing room through a 14-pocket standard polyester sateen filter and then pushed filtered air back into the room. The system was set up to process 0.47 $m^3\ s^{-1}$ (1000 CFM) at start up with a pristine filter installed. Inside the center of the room, the flow was split to deliver half of the return air to each of two 10-in (0.254 m) diameter fabric air diffusers (Softflow Diffusers, Air Distribution Concepts, Delvan, WI) suspended above the aisles between crates.

The pressure drop across the SDC was logged every minute to track filter loading. Overall collection efficiency of the SDC was periodically assessed throughout the study. The protocol for measuring collection efficiency was modified from that used in the laboratory evaluation because of practical concerns for using the APS under field conditions. Dust mass concentrations in the supply (with, W, the SDC) and return (without, WO, the SDC) air ducts were measured with a DustTrak (Model 8534, TSI, Shoreview MN) in the following pattern: WO_1-W_1-WO_2-W_2-WO_3-W_3-WO_4, and the overall collection efficiency for each of three repetitions using Equation (1).

RESULTS

Laboratory Evaluation

Loading—The pressure drop and flow rate by mass delivered to the SDC system are summarized in Figure 2. These data are presented as the combination of mass concentration times time (C × t), which was calculated as the mass of ARD dispensed divided by the airflow rate. The total mass of ARD dispensed and time to reach the manufacturer's recommended maximum pressure drop (1000 +/− 50 Pa) for subsequent loadings were: Loading 1, 5.6 kg over 7.1 days; Loading 2, 4.5 kg over 5.6 days; and Loading 3, 4.0 kg over 5.0 days. The initial loading test duration was longer than subsequent tests because the pristine filter was not pre-loaded with dust. A total of 14.1 kg of ARD was dispensed over the cumulative 17.7-day accelerated laboratory test. The mean airflow over this period was 1450 $m^3\ hr^{-1}$, resulting in a mean dust concentration challenging the filter of 22.9 mg m^{-3}.

The filter pressure drop increased from 120 Pa when pristine to 950 Pa at the conclusion of the first loading (C × t = 163 mg m^{-3} day). Cleaning reduced the filter pressure drop to 350 Pa. The filter pressure drop reached 970 Pa over the course of the second loading (128 mg m^{-3} day), and cleaning reduced the pressure drop back to 370 Pa, slightly higher than what the initial loading cleaning had achieved. The pressure drop reached 1000 Pa during the third loading with less challenge dust (C × t = 115 mg m^{-3} day).

At the start of each of the loading tests, the system airflow was approximately 1700 $m^3\ hr^{-1}$. As particles deposited on the filter media, this flowrate decreased linearly and the pressure drop increased (Figure 3). A change in airflow explained 99% of the variability in filter pressure drop ($R^2 = 0.99$). After loading to the target filter pressure, the system airflow rate was reduced to approximately 1200 $m^3\ hr^{-1}$, or 30% lower than at startup.

Collection Efficiency and Quality Factor—Filter collection efficiency by aerodynamic particle diameter measured four times during loading tests are shown in Figure 4. Overall collection efficiencies and quality factors are summarized in Table I. Collection efficiencies were high for particles larger than 5-µm particles (>95%) at all time points. For particles smaller than 5 µm, collection efficiencies were low for the pristine filter (e.g., 27% for 1-µm particles; Figure 4a), resulting in a low overall collection efficiency ($CE_{overall}$) of 44%. At the end of the first loading cycle, the collection efficiencies were substantially higher (Figure 4b, 98% at 1 µm increasing to 99% for >5 µm; $CE_{overall}$ = 99%). Before the startup of the second loading cycle, after the shaker was used to dislodge dust loaded on the filter, the collection efficiency remained substantially higher than the pristine filter (Figure 4c, 90% for 1-µm particles increasing to 99% for >5 µm; $CE_{overall}$ = 91%). At the conclusion of the second loading, collection efficiency for particle sizes between 1–10 µm was 99% (Figure 4d) with $CE_{overall}$ = 99%. The SDC quality factors ranged from 0.005–0.007 Pa^{-1}.

Filter Pressure Drop Recovery by Shaking—The results of sequential shaking to clean the SDC filter, measured as the recovery of filter pressure drop, are summarized in Table II. The means of filter capacity (pressure drop) recovered with sequential shakings were not equal ($p<0.001$). The mean recovery in pressure drop for the first shake cycle (mean = 550 Pa) was substantially and statistically greater than that for the second (25 Pa) and third shake (5.0 Pa), as determined by Tukey pairwise comparisons. All other comparisons were not significant.

Field Tests

Figure 5 summarizes the results of field testing the same SDC that was incorporated into a recirculating ventilation system of a swine farrowing room in the Midwest U.S. over winter. As shown in Figure 5a, the pressure drop of a new pristine filter at startup was approximately 150 Pa, steadily increasing to 255 Pa in a manner consistent with the development of a dust cake on the fabric filter. The pressure drop was reduced to 235 Pa on 1/9, presumably from inadvertent jostling of the SDC, which knocked off some of the dust cake. The pressure drop then rose steadily back to 250 Pa again consistent with an increasing thickness of the dust cake. The ventilation system was shut off on 1/22, and the SDC filter was shaken as part of the field study protocol. On 1/27, when the system was turned back on, the pressure drop was 185 Pa, indicating that the shaking process was effective in recovering filter pressure drop. The pressure drop then increased until the end of the study.

As shown in Figure 5b, the overall collection efficiency of the filter was ~60% for the pristine filter and steadily rose to near 100% before the filter was turned off and shaken on 1/22. The collection efficiency was substantially reduced after shaking to 70% but then again steadily increased to higher than 90% with continued dust loading.

DISCUSSION

This article shows that the SDC can function effectively as an air cleaner in a recirculating ventilation system for dusty operations. Accelerated loading tests performed in the laboratory provide insight on performance of the SDC and anticipated cleaning frequency with long-term use. The SDC was identified as providing a reasonably high efficiency, indicating it may be suitable for use in recirculating ventilation systems for dusts with low toxicity. The finding of high collection efficiencies (>95%) for particles larger than 5 μm, even when the filter was pristine, provides evidence that the SDC should be effective for particles that dominate the inhalable mass concentrations typical of agricultural dusts.

A dust cake on the filter is needed to achieve high collection efficiencies reported by the manufacturer (>99%) for all particle sizes but in particular for the particles <5 μm. For particles between 1 μm and 5 μm, the collection efficiency of the filter was low when pristine (Figure 4a; 28% at 1 μm and 95% at 5 μm) but much higher after the filter had developed the dust cake (Figures 4b and 4d; >99% for all size particles). Although the overall collection efficiency was low for the pristine filter (44%), it increased to 99% after the first loading. Even after shaking of the filter, the overall collection efficiency was still high (90%) again increasing to greater than 99% after the second loading.

These results can be attributed to increased impaction with the additional dust layer on the filter: the Stokes number of a particle passing through cloth fibers in a pristine filter is low compared to that of a particle passing through the same cloth fibers with a dust cake. Even after subsequent cleaning of the filter, by using the manufacturer's shaking mechanism, a sufficient residual dust cake remained to provide collection efficiencies ranging from 88% for 1 μm to >99% for 5 μm particles. When pristine, some particles were able to pass unimpeded through the open spaces between fibers, resulting in a lowered collection efficiency for particles larger than 5 μm (Figure 4a; 95%) compared to that when the dust cake was present (Figures 4b, 4c, and 4d; >99%). These observations are consistent with Dennis and Wilder,[14] who demonstrated the importance of the dust cake in collecting fly ash with cotton fabric filters.

The collection efficiencies observed in laboratory tests were also consistent with the findings of others when pressure drop and airflow rate are taken into account. After the dust cake developed, collection efficiency was greater than 90% with a normalized filter pressure drop of 9800 Pa m s^{-1} (0.2 in. w.g. ft^{-1} min^{-1} at 7 ft min^{-1}). Similarly, Dennis[15] observed greater than 85% collection efficiency with a normalized pressure drop of 9800 Pa m s^{-1} (0.2 in. w.g. ft^{-1} min^{-1} at 3 ft min^{-1}) for fly ash collected with a fabric-filter system. Billings et al.[16] reported that preloaded fabric dust collectors typically collect greater than 99% of dust particles for particles <1–50 μm and the pressure drop ranges from 250–2500 Pa (1–10 in. w.g.). The quality factors for this unit (0.005–0.007 Pa^{-1}) were slightly lower than literature values. In a collection of studies by Dennis and Wilder[14] a quality factor of 0.01 Pa^{-1} was typical for cotton fabric bags filtering fly ash.

Laboratory tests also provide guidance on how to minimize mechanical damage to fabric polyester filters from shaking. A single, standard, 35-sec shaking cycle was found sufficient to recover most of the filter pressure drop developed by loading of the dust cake. The first shaking cycle recovered 550 Pa, whereas the second and third shakings recovered less than 25 Pa. These results are consistent with those of Walsh et al.[17] and Dennis and Wilder[14] who observed dramatically diminishing recovery of filter pressure drop after the first shaking. Minimizing the number and frequency of cleanings will reduce stress and strain to the filter media and the shaker's mechanical components. Consequently, a single cleaning is recommended for field use. While concentrations used to load the filter in laboratory tests were on the order of four or more times the dust concentrations seen in manufacturing / agricultural environments, the trends of system performance by mass rate of dust applied to the system can be used to extrapolate to actual field exposures. Table III was compiled to provide estimated time to operate the SDC when treating exhausted room air at more realistic indoor air dust concentrations, indicating the time to require until the pressure drop of the filter would indicate that shaking is needed. For example, we estimate 160 days to the first shake and 130 days for the second shake if inlet concentrations are 1 mg m^{-3}.

In field tests, the SDC performed effectively throughout the harsh Midwest U.S. winter when incorporated in a recirculating ventilation system for a swine farrowing room. Initial concerns that the outdoor temperatures or difference in the agricultural dusts compared to the laboratory ARD may change the results of the field performance. However, the trends in collection efficiency and pressure drop with dust loading observed in field tests were similar to those observed in laboratory tests. Overall collection efficiency and pressure drop were low for the pristine filter but increased with time as the dust cake became established on the surface of the filter. Shaking of the filter effectively dislodged the dust cake and recovered a substantial portion of pressure drop built up from loading of dust on its surface. The highest filter pressure drop (255 Pa) observed in the field, however, was substantially lower than manufacturers recommendations for this filter type (1000 +/− 50 Pa) and that tested under laboratory conditions. Thus, the filter has capacity to either service more airflow or operate in substantially dustier environments than the swine farrowing room that was the subject of this study. Despite not being loaded to capacity, efficiencies were higher than 80% when pressure drop exceeded 230 Pa.

Importantly, the field tests demonstrate feasibility for SDCs use in agricultural environments. The dust in a swine barn is substantially more complex than the ARD tested in the laboratory with substantial components of biological materials, such as animal feed, feces, hair, and dander.[5] The environmental conditions in a swine barn, often including high relative humidity, ammonia, and other caustic gases, were much harsher than laboratory conditions. Moreover, emission sources, size distribution, organic content, temperature, and relative humidity were uncontrolled and may have varied throughout the course of the study. The finding that the SDC performed effectively for an entire winter despite the complex aerosol and environmental conditions provides substantial evidence that this technology can be used to clean the air in an agricultural setting.

A major limitation of the shaker dust collector is its specificity to dust collection. Other control technologies may be required within the recirculating ventilation system to ensure that hazardous gaseous components do not build up. In agriculture, for example, ammonia and hydrogen sulfide may build up with a recirculating ventilation system that incorporates a control device only removing particulate. In a companion article,[(12)] we demonstrate that this specific issue was not problematical for the swine farrowing room studied in the current work. This study investigated one type of filter fabric that was supplied by default with the air cleaner. Other commercially available filters should be evaluated and filter quality should be used as a benchmark to quantitatively compare media performance. Laboratory tests did not measure the particle collection efficiency after the “pristine” filter tests until the pressure drop reached the recommended change period, at which time collection efficiencies were well above 95% for all particle sizes. Consequently, the results of laboratory testing are not able to inform how much initial loading (or total concentration × time) is needed to pretreat the filter to achieve these efficiencies. Field tests do, however, provide insight that collection efficiencies greater than 80% can be achieved with fairly light dust loadings.

CONCLUSIONS

A fabric-filter air cleaner (i.e., a shaker dust collector, SDC) was evaluated under laboratory and field conditions for potential use in a ventilation system with recirculation to control dust concentrations while conserving energy to condition makeup air. In laboratory tests, the finding of high collection efficiencies (>95%) for particles larger than 5 μm even when the filter was pristine provides evidence that the SDC should be effective for particles that dominate the inhalable mass concentrations typical agricultural dusts. For respirable-sized particles, collection efficiencies were low when the filter was pristine (e.g., 27% for 1 μm) but were much higher when a dust cake was present on the filter (>99% for all size particles), even after shaking (e.g., 90% for 1 μm). Loading tests provided qualitative data to estimate the cleaning frequency required to maintain filter pressure drop below manufacturer's recommendations and shaking tests showed that a single shake is sufficient to dislodge the dust cake and recover pressure drop.

Field tests were conducted over a complete winter season to assess the performance of the SDC as part of a recirculating ventilation system for a swine farrowing room. The SDC performed effectively throughout the winter with trends in collection efficiency and pressure drop with dust loading being similar to those observed in the laboratory. Overall collection efficiencies were higher than 80% when pressure drop exceeded 230 Pa, or 23% of the maximum loading recommended by the manufacturer. These laboratory and field tests provide evidence that an SDC can function as an air cleaner in a recirculating ventilation system, effectively removing particles of concern without excessive maintenance. Our work specifically targeted swine farrowing operations but the findings are relevant to many dusty industries.

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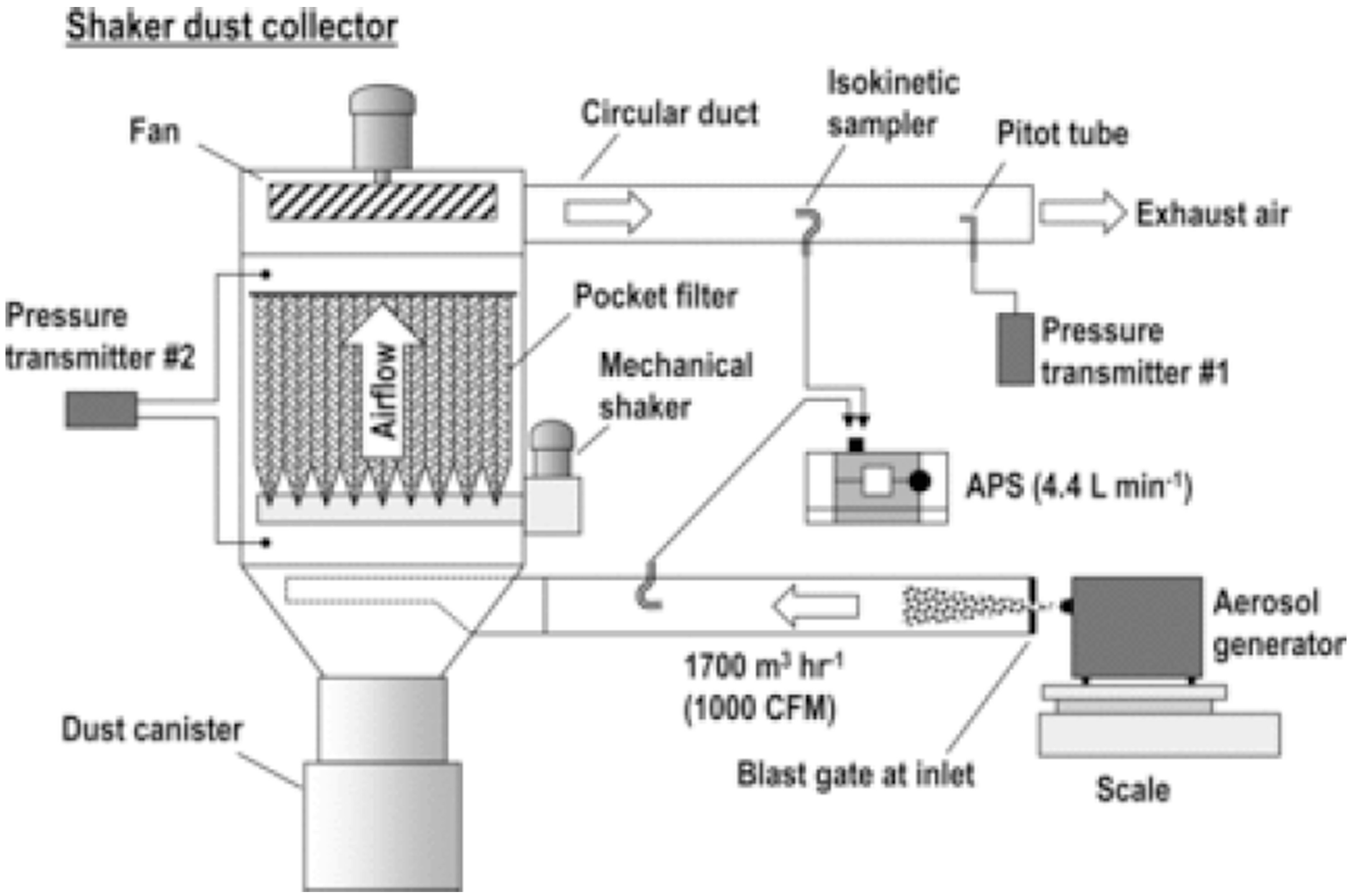

Figure 1.
Schematic of shaker dust collector (SDC) and experimental setup

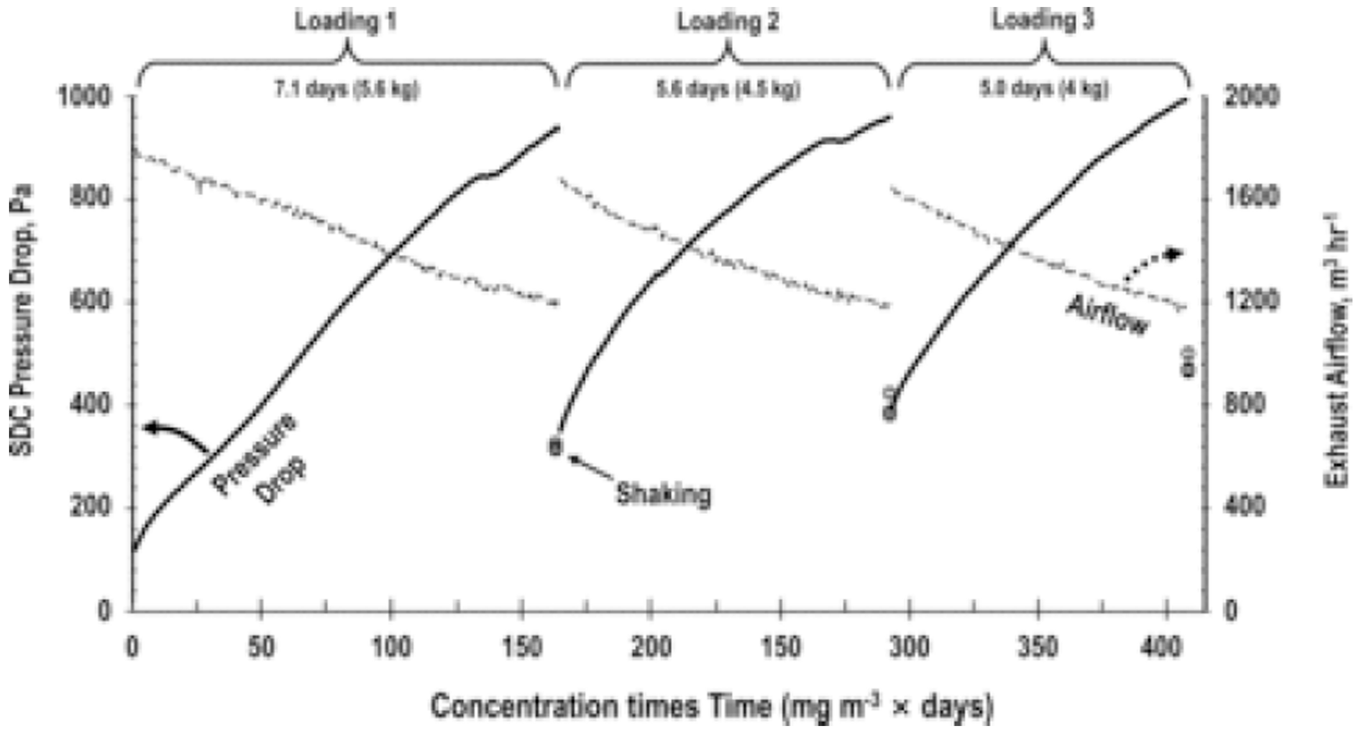

Figure 2.

Filter pressure drop and exhaust air flow observed during loading in laboratory tests

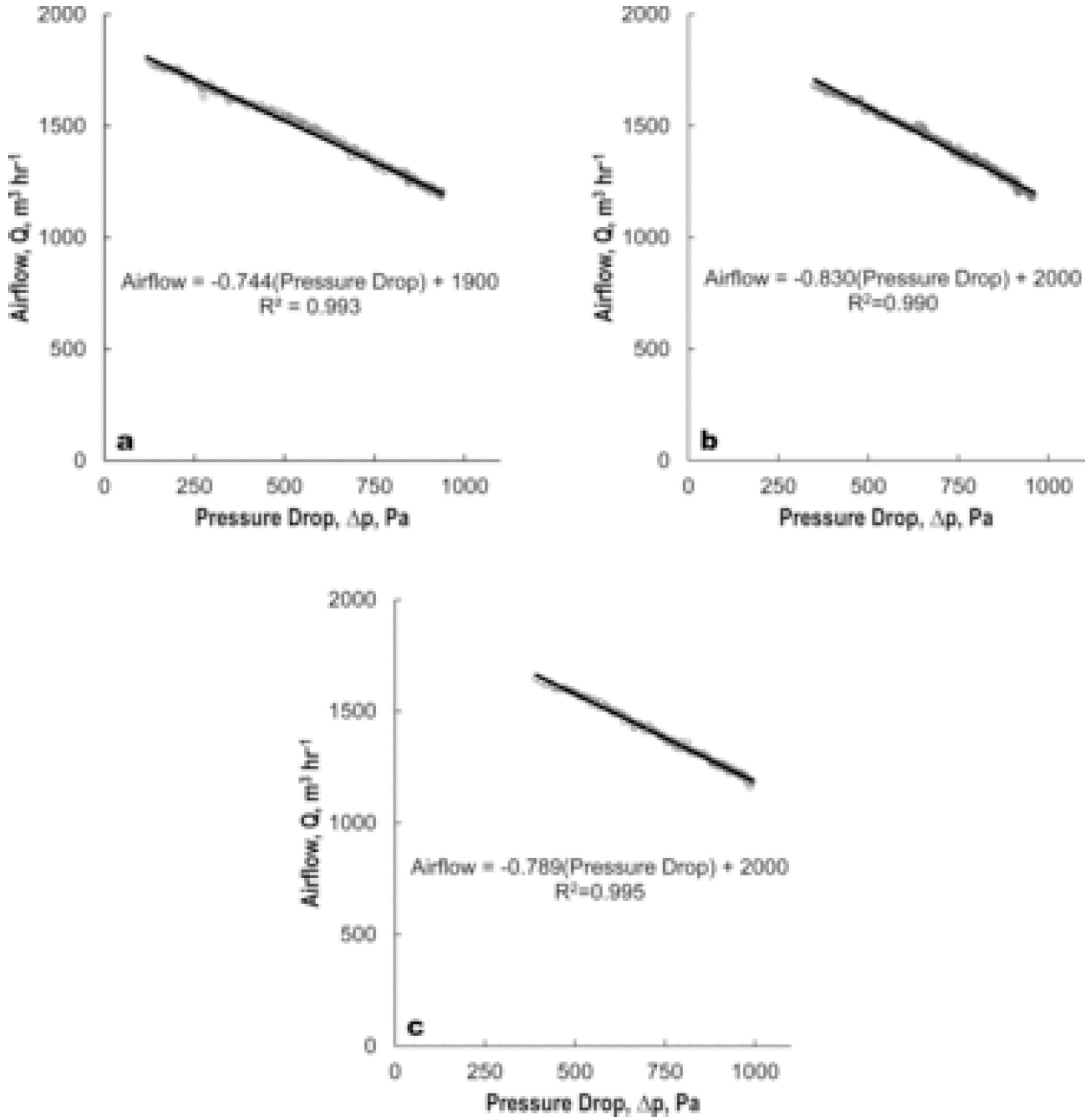

Figure 3.

Linear regression of airflow vs. pressure drop observed in laboratory tests for: (a) first loading, (b) second loading, and (c) and third loading

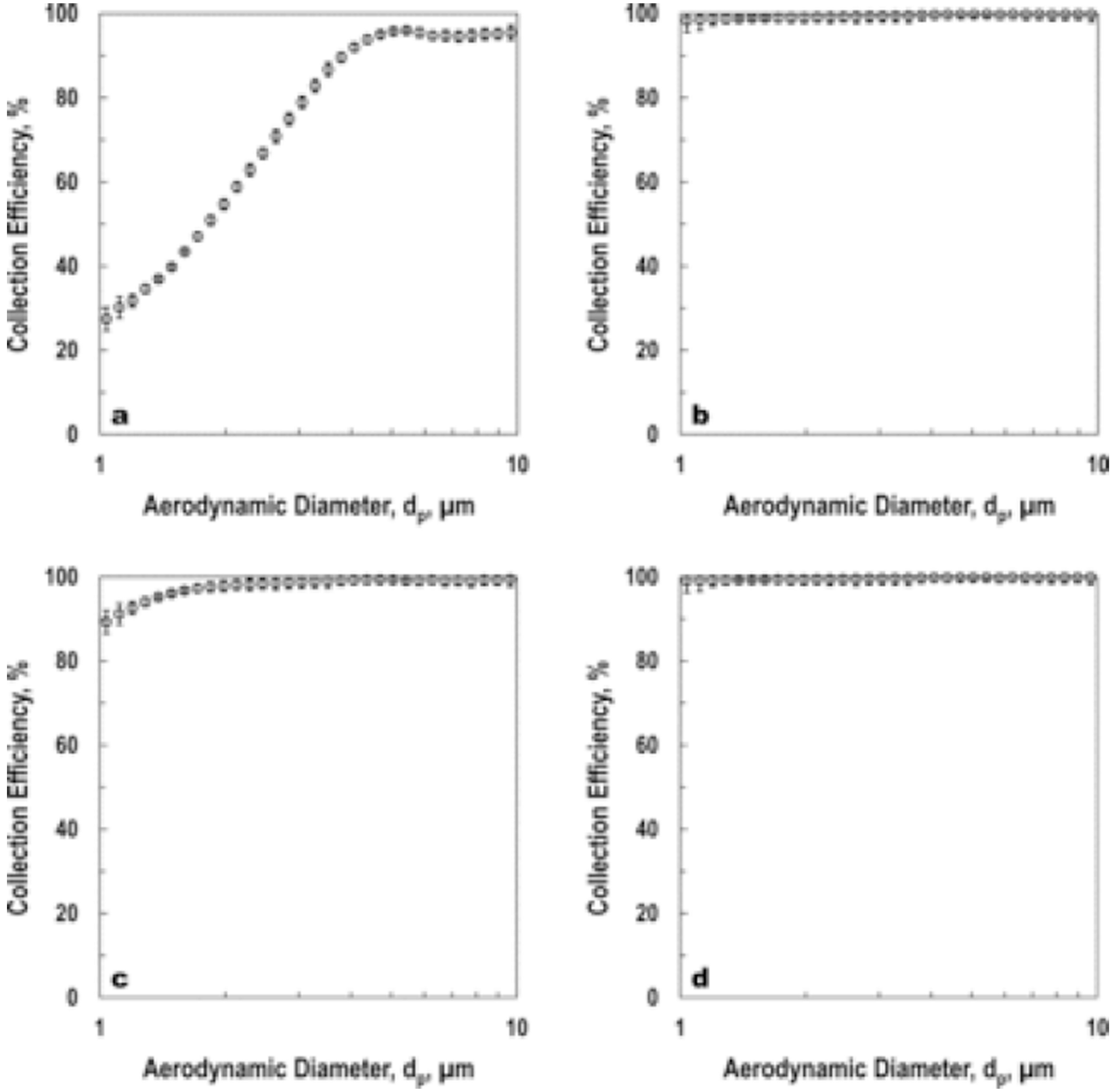

Figure 4.
Collection efficiency by particle aerodynamic diameter before the first loading (a), at the end of the first loading (b), at the startup of the second loading (c), and at the end of the second loading (d)

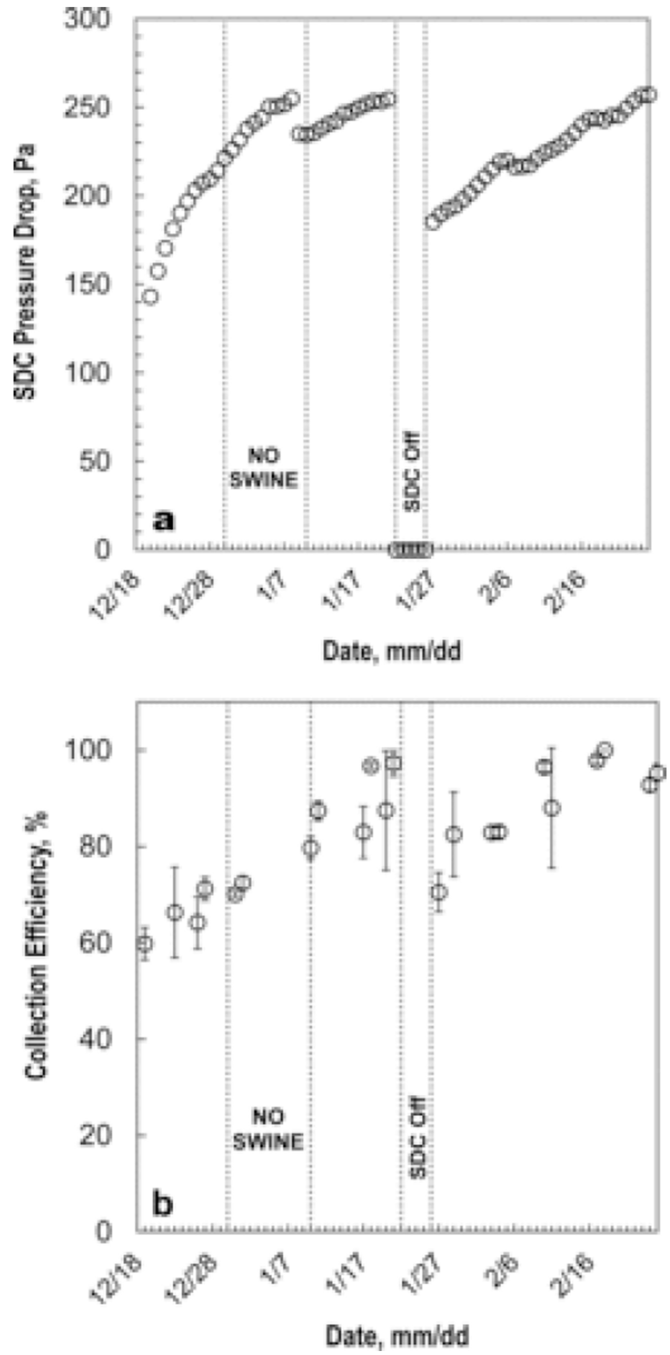

Figure 5.

Pressure drop (a) and collection efficiency (b) of the SDC observed in the winter field study

Table 1

Summary of Collection Efficiency and Quality Factor

Test Condition	Collection Efficiency for d_p 1–10 μm %	Overall Collection Efficiency%	Pressure Drop Across Filter Pa	Quality Factor Pa^{-1}
Startup of 1st Loading	27–96	44	120	0.005
End of 1st Loading	98–99	99	950	0.005
Startup of 2nd Loading	90–99	91	350	0.007
End of 2nd Loading	99	99	970	0.005

Table 2

Recovery in Filter Pressure Drop for Multiple Cleanings

	Recovery in Pressure Drop, Pa		
Loading Cycle	**Shake 1**	**Shake 2**	**Shake 3**
1	615	10	2.5
2	540	35	7.5
3	496	30	5.0
Mean	550 (A)	25 (B)	5.0 (B)
St Dev	60	13	2.5

The letter in parentheses after the mean indicates the grouping from Tukey pairwise comparisons.

Table 3

Estimated Operation Time before Shaking is Required for an SDC (1000 CFM unit) With Polyester Sateen Filter Given Various Inlet Concentrations

Concentration Estimate, mg m^{-3}	Anticipated Time to 1st Shaking, days	Anticipated Time to 2nd Shaking, days
22.9^{A}	7.1^{A}	5.6^{A}
10	16	13
5	32	26
1	160	130
0.5	330	260

[A] Indicates Values Observed in the Laboratory.