Optical Dust Meters May Misestimate Dust Concentrations in Animal Barns

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Dust is a major air quality issue associated with livestock facilities. In an animal barn, dust particles can originate from feeds, feces, and beddings, and can reach a very high concentration when animals are active, ventilation is poor, and/or feeding systems are running. Dust also represents a potential safety and health risk factor for caretakers in barns. Dust particles at high concentrations, especially small particles, are harmful to the humans' respiratory systems. Together with hazardous gases, dust exposure can cause chronic bronchitis, decreased lung functions, aggravated asthma, and other acute and chronic respiratory symptoms. Dust can also carry odorous chemicals and, thus, play a crucial role in transporting and magnifying odor downwind from animal facilities.

Because of its health and environmental implications, dust is regularly monitored in outdoor and indoor environments. The monitoring effort for outdoor environments is exemplified by the state and local air monitoring stations (SLAMS). In South Dakota, there are ten such stations (https://denr.sd.gov/des/aq/monitoring/state-mo.aspx#MapofMonitoringSites) that monitor PM10 (dust particles with diameters smaller than 10 microns) and PM2.5 (dust particles with diameters smaller than 2.5 microns). For its fine size and ability to reach alveoli (tiny air sacs) in the human lung, PM2.5 is of particular health concerns. The monitoring results are then compared with the National Ambient Air Quality Standards to determine whether the local air quality is in compliance with the Environmental Protection Agency (EPA) regulations. For indoor environments, dust is primarily an occupational exposure issue and may be subjected to regulations by the Occupational Safety & Health Administration (OSHA). For livestock facilities, the OSHA standards apply if an operation employs 10 or more employees.

Different instruments are used for outdoor than for indoor dust monitoring. The instruments used by the SLAMS sites are highly sensitive and accurate, but bulky and expensive. Thus, they are unsuitable for dust monitoring in indoor environments, including animal barns. For the indoor dust monitoring, portable samplers or real-time monitors are commonly used. A dust sampler involves the collection of dust particles on a filter and the weighing of the filter before and after dust collection. This method is time consuming and labor intensive. Thus, it has been gradually replaced by real-time dust monitors/meters. These dust meters, however, adopt a different detection principle than those used by the SLAMS.

Nowadays, most portable dust meters rely on the optical detection principle, which measures dust concentrations based on the interaction of light with dust particles. These devices range from inexpensive dust (or PM) sensors to fairly expensive industry-grade meters such as TSI DustTrak, Thermo Scientific DataRam, and MetOne particle counters. In those devices, dust particles illuminated with a light beam cause part of the light to change direction (i.e. scattering) because of the light reflection and refraction by particles, and this scattered light is detected by optical sensors. The dust concentration is translated from the strength and angle of the scattered light. Therefore, those optical dust meters by nature are indirect methods and their measurement involves many assumptions. Most of the assumptions are made for dust particles, including their size, shape, refractive index, density, etc. Those assumptions however may not stand for dust in animal barns or other agricultural settings.

In a previous study, we tested the performance of TSI DustTrak meters, one of the most prevalent portable dust meters in the U.S., in two poultry barns. They were compared against a tapered element oscillating microbalance (TEOM), an EPA-certified instrument for the SLAMS sites. Different from optical meters, TEOM is a direct measurement method. It collects dust particles on a filter mounted on the tip of a cantilever and measures the mass of collected dust based on the vibration frequency of the cantilever. TEOM was used in the study as a reference method because of its great accuracy. Figures 1 shows our test results, with both TEOM and DustTrak units configured for PM10 monitoring. It can be seen that DustTrak meters significantly underestimated the PM10 concentrations in both barns.

We further compared the DustTrak and TEOM data in pairs and did a correlation analysis (Figure 2). DustTrak meters underestimated PM10 concentrations by ~75% in the two barns. The good news was that the DustTrak data correlated well (R^2 = 0.92 and 0.85, respectively) with those from the TEOM, indicating a feasibility to correct for the DustTrak's measurement bias with a simple correction factor (4.117 for the broiler barn and 4.202 for the layer breeding barn in the study). The correction can be done by multiplying the DustTrak raw data by the derived correction factor.

The underestimation of PM10 concentrations is related to the optical detection principle adopted by DustTrak and similar meters. As aforementioned, their measurement involves numerous assumptions about dust particles. For DustTrak meters, they are calibrated by the manufacturer using a standard dust called Arizona road dust, which has significantly different properties than the dust from animal barns (Table 1). We also conducted Mie modeling to simulate the light

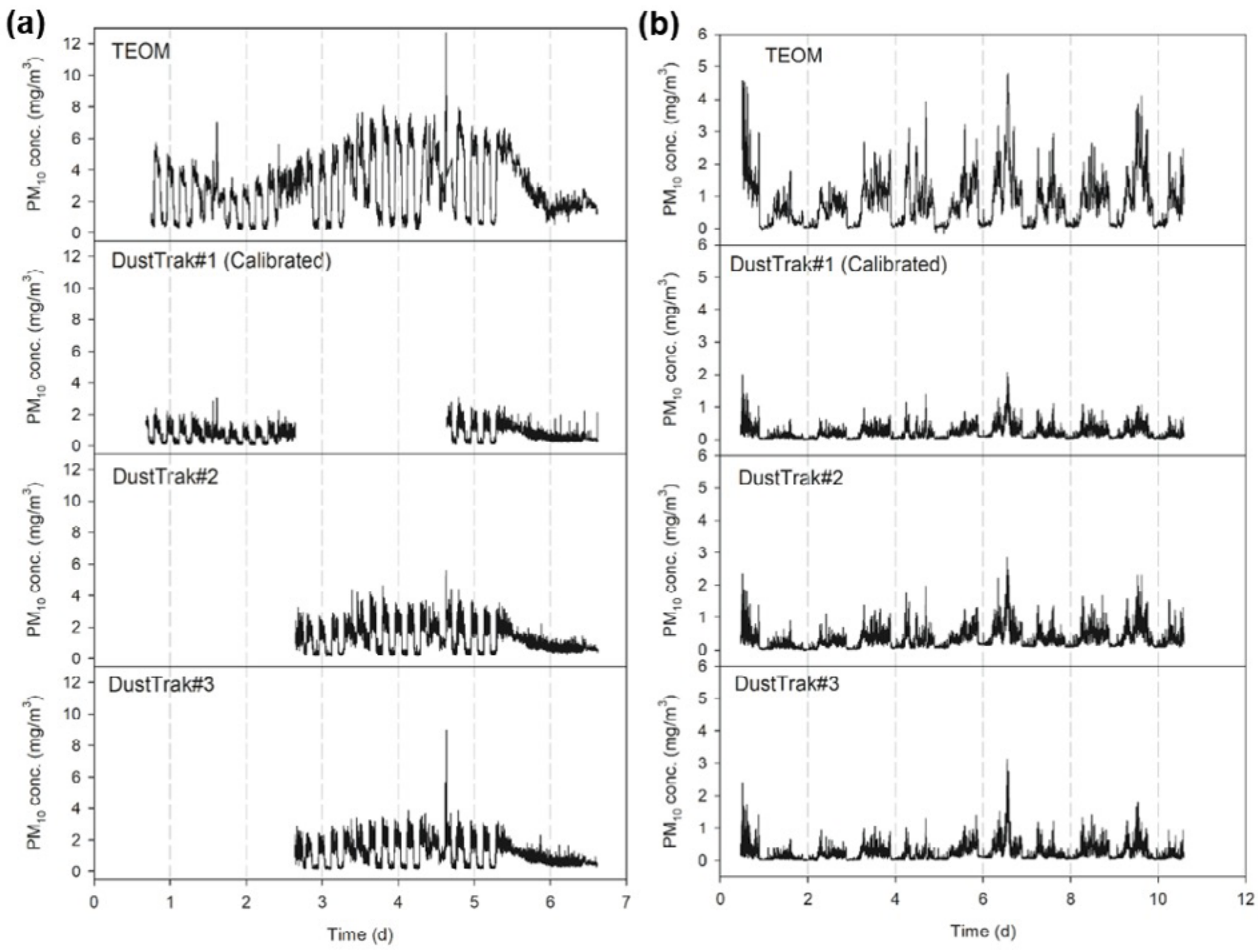

Figure 1. PM10 concentrations measured by TEOM and DustTrak meters in (a) a broiler house and (b) a layer breading house.

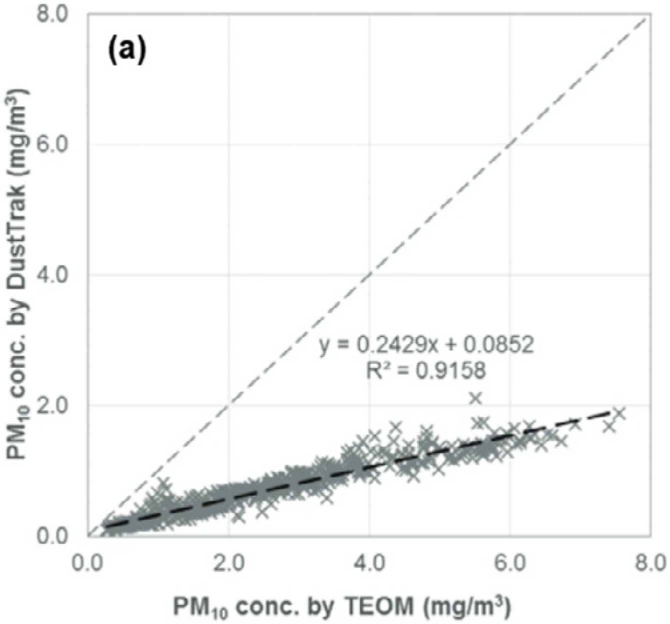

Figure 2. Comparison of TEOM versus DustTrak readings in (a) a broiler house and (b) a layer breeding house.

scattering by dust from poultry barns. A correction factor of 4.90 was estimated from the modeling work. Since the Arizona road dust is extensively used for instrument calibration, we anticipate that other optical dust meters would result in similar underestimation of PM10 from poultry barns.

Table 1. Comparisons of Arizona road dust and the dust from poultry barns.

Properties	Arizona road dust	Poultry barn dust
Particle density	2.65 g/cm^3	1.65 g/cm^3
Refractive index*	1.5 ± 0.0i	1.45 ± 0.0i
Median particle size**	2.5 microns	9.3 microns
Spread of particle size distribution**	2.5	1.4

* Refractive index is a measure of a substance's optical property.
** For PM10 (particles smaller than 10 microns) in poultry barn dust.

It is noteworthy that dust from other animal facilities (e.g. hog barns, dairy barns, and beef barns) may hold different properties than the poultry barn dust in Table 1, especially with regard to particle size. The size of dust particles is influenced by many environmental and operational parameters, such as air velocity, dry or wet feeders, particle size of feed, manure handling, and bedding materials. Therefore, there is no universal correction factor that apply to all animal facilities. A similar study in Europe reported a much smaller correction factor (~1.25) for PM10 in poultry barns, likely because of different barn designs and management practices in Europe. However, based on our field measurement and the literature, dust particles from animal facilities are predominately coarse particles with diameter greater than 5 microns. As a result, underestimating PM10 concentrations in animal barns could be a common issue when optical dust meters are used. For a similar reason, these meters could underestimate PM10 concentrations from other agricultural settings, such as grain bins, elevators, and harvesting, that produce predominately coarse particles.

No experimental efforts have yet been done for PM2.5, inhalable dust, and respirable dust in animal barns. However, based on previous studies on atmospheric PM2.5 (i.e. PM2.5 in outdoor air), optical dust meters could **overestimate** PM2.5 concentrations in animal barns. This is because animal barn PM2.5 has different properties than the dust standards used for instrument calibration. To address the measurement bias issue, a side-by-side comparison with a reference method is often required. Several brands of optical dust meters incorporate this function but many do not. For the latter meters, South Dakota State University has multiple MiniVol samplers and a Grimm Aerosol Spectrometer available for instrument calibration, through the university's extension program.

It is noteworthy that animal barn dust is primarily an indoor air quality issue. Because of the coarse size of these dust particles, they will quickly settle down to the ground and will unlikely transport for a great distance in the outdoor air. Also, one should not exaggerate the level of dust contamination in or from animal barns. For example, the PM10 concentration is typically <2 mg/m^3 in swine barns and <5 mg/m^3 in poultry barns; whereas the PM10 concentration at the exit of a power plant stack could be up to 80-100 mg/m^3, even after a series of dedusters.

Verdict

- Optical dust meters may significantly misestimate the dust concentrations in animal barns because they are calibrated with different dust standards than animal barn dust.
- These meters are known to underestimate the PM10 concentrations in poultry barns. Similar underestimation is anticipated in other animal barns.
- These meters may also result in misestimates of PM2.5, inhalable particle, and inhalable particle concentrations in animal barns. However, the measurement bias has yet to be quantitated.
- South Dakota State University has the equipment and expertise available for the measurement of dust from animal barns and other agricultural settings.

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