AIHA®

Consumer Aerosol Monitors

Fact Sheet

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Developed by the AIHA® Aerosol Technology Committee

1. What is an aerosol?

The term *aerosols* is a general term that refers to a suspension of solids (particulate) and liquids in a gas (typically air). The term originated as the gas-phase analogue to hydrosols (meaning "water particle" in Greek), and it refers to suspension of particles in a liquid.

Other terms for aerosols include: dust (aerosols from the fragmentation of solid matter); suspended particulate matter; smoke (the incomplete combustion of organic materials); fumes (aerosols that are produced by the condensation of metal vapors); clouds, fog, and mists (aerosols from the atomization from of liquids or condensation of vapor), haze (a suspension of extremely small, dry particles in the air (not water droplets) produced by condensation of vapors resulting from photochemical reactions in the atmosphere); and smog (the photochemical aerosol of Los Angeles-type smog). The term *bioaerosols* is also commonly used for aerosols of biological origin—bacteria, viruses, pollens, and so on.

The origins of aerosols in the occupational environment are diverse, but typically an energy-intense process has to be involved. The measurement of aerosols concentration and exposure has been practiced for several decades in industrial hygiene. With the development of sensors, professionals have become more interested in the idea of real-time, time-resolved monitoring of aerosols.

Traditional aerosol monitoring techniques are usually resource and time intensive, requiring at minimum a laboratory equipped with a microbalance or analytical scale, sampling preparation apparatus, and dedicated human resources. Real-time instruments grant a timely and less costly way to get insights on aerosol concentration in a time-series evolution fashion.

2. What is a consumer aerosol monitor?

Consumer aerosol monitors (CAMs) are devices commercially available for monitoring the mass concentration of aerosols in the air. Generally, CAMs are designed and developed for public ambient aerosol and indoor air monitoring. They are not designed primarily for occupational- hygiene and occupational-exposure monitoring. This explains the origin of the term, consumer aerosol monitor, used for these units and that was adopted for this fact sheet.

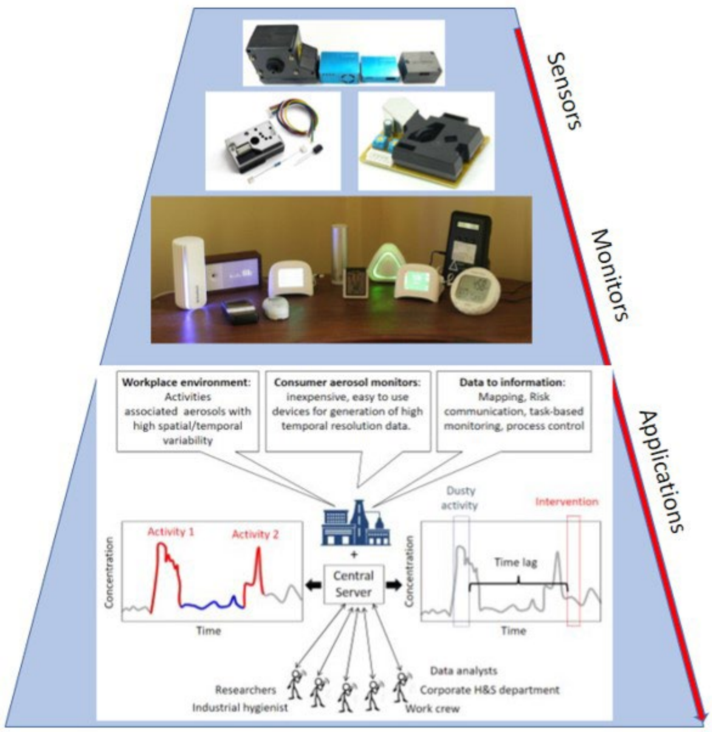
Sometimes CAMs are referred to as low-cost aerosol monitors because the cost for each unit can range from $50 to $500. Some public libraries and community engagement organizations offer the use of these devices for free or for a small fee. In contrast, other direct-reading instrument (DRI) real-time aerosol monitors are traditionally in the range of $2,000 to $15,000.

CAMs are different from these other DRI real-time aerosol monitors (IH-DRI), which are instead being tailored to the needs of industrial hygienists and professionals more generally. The quality of the measurements can be lower for CAMs compared to other IH-DRI, but there is no consistent evidence of this in the scientific literature.

It is also important to note that the documentation that generally accompanies each CAM and the assistance from the manufacturers in terms of technical and scientific aspects are generally not specific to industrial hygiene. In recent years, the difference between CAMs and other IH-DRI has narrowed, which is a positive result of several efforts by universities and companies across the United States to use and create monitors with inexpensive sensors for occupational-aerosol monitoring.

Finally, it is important to make the distinction between an aerosol sensor and an aerosol monitor. The aerosol sensor is the component inside the CAM that allows the real-time detection of aerosol particles in the atmosphere. Each CAM combines an aerosol sensor with other components, such as an electronic board, a display, a power supply, and a case (to name just a few).

Sometimes CAMs are combined with other environmental sensors (gas, temperature, humidity, etc.). Although the sensor is the component that "detects" the aerosol particles, all the components are essential for the generation of data.

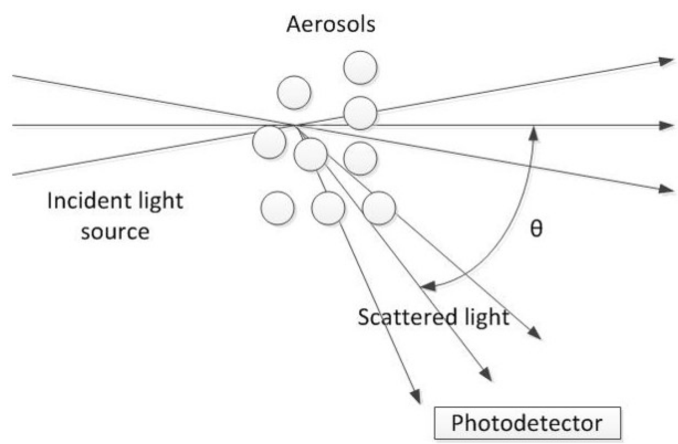


3. How does a CAM work?

It is important to understand the basic operations of a CAM and how a CAM works. Most CAMs include a sensor that detects the presence of a particle in the air by using the interaction between light and the particle. These sensors can be categorized as either photometers or optical particle counters, although the latter is a less common technology for CAMs.

The interaction between light, generated by a specific source in the sensor, and particles has been used for decades by aerosol sensors. When light reaches a particle, the particle can scatter, or block the light beam. All these reactions can be detected and further quantified to correlate that response to the amount of aerosol present. Most common optically based methods are based on light extinction, the cumulative result of light absorption and scattering.

Typical CAMs use the absorption method, whereby a cloud of particles blocking light is being detected. The total light extinction is then converted into a mass concentration using internal calculations that make certain assumptions about particle chemical and physical characteristics. Some CAMs are also able to categorize particles into particle-size fractions (or bins) based on their response.



When scatter is used as a reaction/quantification technique, this is referred to as a photometer or light-scattering aerosol sensor. When instead the blockage of light by the aerosol particle is used, this is the basic principle for an optical particle counter. It is important to note that the sensor in each CAM might have a detection range that is a function of the size of the particles. There might be occupational activities that produce aerosols outside the range of detection of the CAMs—both large and small particles, for different reasons.

A CAM is not only the aerosol sensor. Other components are present that can affect the measurement. The way an aerosol enters the monitor is important as well. The aerosol enters through an inlet that might have been designed to limit the entrance of particles of a certain size. Some CAMs have certain inlet incorporating devices that exclude larger particles (impactor, foam, etc.). The inlet needs to be inspected regularly, and this can be another challenge for measurement by CAMs.

CAMs may use passive or active monitoring. A passive sampler or monitor does not have any component that draws aerosol inside, whereas an active monitor (the more common) instead uses a fan or sampling pump to draw the particles into the monitor to be analyzed. The fan or pump can have a specific flowrate that might need to be calibrated and verified.

Active monitoring enables a CAM to quickly react to changes in aerosol conditions but, on the other hand, entails more issues in terms of maintenance and cleaning of the monitor. After quantification, the particles then need to be captured by a filter or exhausted with the airflow outside the monitor, which is generally the output of a fan or sampling pump.

As in other areas of aerosol sampling, the combination of inlet size and airflow rate are strongly related to the determination of which particle sizes will enter the monitor and be analyzed. As stated above, CAMs generally are not designed for monitoring particles of a specific size range, as is more typically done for occupational aerosol monitoring. For this reason, it is unusual for CAMs to have an inlet/flowrate that provides monitoring of respirable dust or other size-specific of interest in occupational environments. As also mentioned above, some CAMs can estimate particle size once the aerosol enters into the device and responds to the light source.

4. What are the strengths and limitations of using a CAM?

CAMs were developed for communities and users with no experience or skills in ambient aerosol monitoring, and they are extremely easy to set up and use. They can store data on memory cards inside the monitor. More often, however, the data can be sent to a cloud-based server, and the user can download and access the data through smart applications and computer software.

The second advantage of the CAMs is their affordability compared to other IH-DRI for aerosols. The cost of each CAM unit can be a small fraction of a more sophisticated instrument. This is an advantage because it can allow the use of multiple units at the same cost as one IH-DRI. The additional cost for cloud-based server space, however, should also be considered.

Due to these strengths, CAMs can be helpful tools for monitoring novel occupational environments (for example, ride-sharing vehicles) and for the underserved workforce. Finally, most CAMs have a focus on user interface and experience in terms of warning functions, integration with other systems, and power interface.

For the measurement of aerosol concentrations, the main strength of a CAM is its ability to collect temporal data in real time for extended periods of time. In addition, no additional laboratory analysis of a sample is needed when using a CAM, although this is also true for other direct-reading instruments.

It is important to note that CAMs have limitations. The absence of a purposely designed inlet prevents the user from being able to use the CAM for respirable dust monitoring. CAMs can, at best, measure some portion of aerosols, but the size range of particles measured is not controlled by an inlet.

The second limitation of CAMs is the accuracy and precision of the measurement in terms of aerosol mass concentration. The limited accuracy characterizes most aerosol sensors that use interaction with light as a sensing approach. Since mass is not being measured directly, other particle characteristics, such as particle size distribution, density, and shape, can affect the resulting measurements. In addition, the measurement can be affected by temperature, humidity, and other environmental factors (such as the concentration level itself).

Since one of the most attractive advantages of CAMs is the ability to more easily deploy multiple units at the same time, it is important to note that little information is generally provided in terms of inter-unit variability. Generally, the assumption is that different units of the same CAM type will record the same value when exposed to the same concentration of aerosol. However, this assumption is rarely tested by the manufactured and reported.

The limit of quantification (LOQ) or the maximum level detectable by a CAM are generally not known or reported. The LOQ is the lowest level of aerosol mass concentration that the CAM is capable of measuring with confidence. The maximum level is the highest aerosol mass concentration level that a CAM can accurately detect—in other words, the highest level at which the CAM will measure a change in light signal. The maximum level can be seen as a saturation point for the CAM.

Finally, since a CAM might be deployed in an occupational environment for a prolonged period, the user should consider the issue of temporal drift and overall robustness of other CAM components in time.

5. When would traditional filter-based sampling be more appropriate?

Traditional filter-based sampling and analysis is more appropriate than the use of a CAM when a user, for compliance purposes, needs an accurate measurement for the mass concentration of aerosols in a workplace. This is particularly true when specific size fractions, such as respirable aerosols, must be measured. In that case, the user should collect dust samples using validated methods, employing appropriate sampling media and subsequent laboratory analysis.

The ability to conduct further analytical techniques on collected samples is particularly important when the target is a specific compound, such as crystalline silica, metal elements, or diesel particulate matter.

There are several regulations for aerosol concentration in the occupational environment, and, correspondingly, there are several standard methods for industrial hygienists to follow. Most of these methods are gravimetric-based filter measurement. Some examples of those methods include OSHA ID-142 to measure crystalline silica and NIOSH 0600 to measure respirable particles. A size-selector sampler and filters are used in this case.

The concentration of particles can be determined by comparing the filter weight pre- and post-sampling. At this stage, most CAMs can be only complementary tools for gravimetric-based sampling.

6. How can we deploy CAMs in occupational environments?

With a good understanding of the strengths and limitations of this technology, CAMs can be considered a valuable tool for many monitoring applications in occupational environments. Anytime there is a need for a time series of aerosol concentration, CAM systems can be considered—for example, when comparing exposures during a task that is carried out multiple times, when comparing concentrations between different tasks, or when there is a need to investigate how aerosol concentration changes over time.

Mapping is another application for CAMs, where multiple CAM units deployed simultaneously can provide temporal and spatial information about the aerosol concentration in the workplace. Another option is for the user to perform a walk-through of the facility. Finally, CAMs can be used to verify the effectiveness of control technologies such as ventilation systems.

A user needs to remember the issues relative to the accuracy and precision of the data generated by CAMs when applying these technologies to multiple sessions and multiple activities or locations.

CAMs might be considered for personal exposure monitoring in the near future for units that are sufficiently small and ergonomically suitable. CAMs will also need to operate using batteries to be considered for personal monitoring. At that point, CAMs can become another tool for Total Worker Health® and Total Exposure Health activities, whereby the worker can bring them outside the workplace.

Other considerations, such as user interface, privacy issues, and wearability, will need to be addressed for the CAM's prolonged use as a personal monitoring tool. CAMs can be also a complementary tool to be combined with exposure banding. For example, CAMs could be used to explore new similar exposure groups. In general, any task analysis in terms of aerosol concentration or evaluation of the effectiveness of work practices and control technologies can benefit from the use of CAM systems.

Finally, CAMs, like many other IH-DRI, can be an asset for industrial hygienists for improved risk communication with workers. The immediate availability of the data generated by CAMs as well as the possibility to review the evolution of aerosol mass concentration in space and time provide invaluable benefits, such as raising the awareness of workers on the hazards in the workplace and conveying the need to adopt interventions to minimize exposure.

7. How can we evaluate and improve the accuracy of data from CAMs?

The accuracy of the data generated by CAMs is indeed one of the limitations of these technologies. If a user is specifically interested in highly accurate measurements, for example of the time-weighted average (TWA) respirable mass concentration level, they should consider the combined use of a CAM and the collection of a filter-based sample. The analysis of the filter-based sample can provide an accurate measurement of the average mass concentration level of the aerosol, which can then be combined with data from the CAM.

An alternative approach would be to combine the use of the CAM with a more sophisticated IH-DRI for aerosol measurement. In this case, a single field-calibrated IH-DRI can be used to verify the measurement of several CAMs in the workplace.

8. How can I analyze and interpret the data from CAMs?

The specific objective for using CAM system must lead the first step for interpreting data from a CAM. The specific objective can be framed in terms of questions. The questions that need to be answered are: What do I need to know? What kind of information can a CAM system provide me that I do not have in other ways? The second step in the implementation of CAMs in the workplace from an industrial hygiene perspective is to thoroughly understand the strengths and limitations of these units.

Once a data set is generated by a CAM, professional judgment is critical to analyzing the data based on the original objective. The detection of possible outliers or other “nonsense” data is the responsibility of the professional. It is important to note both that high values should not automatically considered outliers and that they can provide valuable information.

Industrial hygienists should be highly capable of interpretation, data analysis, and conversion of data into information—for example for assessing exposure controls or risk communication with the workforce. Analysis of the data might also require specific software, such as for mapping spatial distributions of exposure concentrations. Some CAMs are commercialized with their own specific analysis package.