G. AEROSOL PHOTOMETERS FOR RESPIRABLE DUST MEASUREMENTS

by Paul A. Baron, Ph.D., NIOSH/DPSE

Contents: Page

1. INTRODUCTION

This discussion will cover direct-reading aerosol photometers that are self-contained (battery-operated) and portable (can be used while carried by one person). There is a variety of direct-reading aerosol monitors using light-scattering detectors. These instruments generally have advantages in reduced weight, improved ruggedness, and continuous readout when compared with other direct-reading aerosol monitors. These instruments can be used to provide accurate dust concentration measurements as described below, though in most situations they are most useful for approximate or relative concentration measurements. Their principle advantage is that of providing real time information.

An aerosol is a group of particles suspended in the air. Aerosols can be introduced into the body primarily through the respiratory system. Total dust measurements indicate concentrations that can enter the nose and mouth of a worker as well as that which can settle on the skin while the respirable fraction of dust is that portion which can reach the lower or gas exchange part of the respiratory system.

The respirable fraction of the dust mass has been defined for sampling purposes by the American Conference of Governmental Industrial Hygienists (ACGIH) as that fraction collected by a device with a penetration curve (Figure 1) fitting the following points [1]:

Particle Size, µm *	% Passing Selector
0	100%
1	97
2	91
3	74
4	50
5	30
6	17
7	9
8	5
10	1

*aerodynamic diameter

There are other definitions of respirable dust [2,3,4] as well as empirical data indicating deposition efficiency of dust in the respiratory system. Historically, the most commonly used respirable dust sampling device in the U.S. is the 10-mm nylon cyclone. At a flow rate of 1.7 L/min, the cyclone passes close to 50% of 4-micrometer aerosol particles. However, it has been shown that the 10-mm cyclone has a somewhat sharper cutoff than the ACGIH curve and, with certain size distributions, may introduce a bias with respect to the ACGIH definition [5].

Aerosols are frequently classified according to their physical form and source. Aerosols consisting of solids (e.g., coal, wood, asbestos) are designated dusts. Aerosols consisting of liquid (e.g., oil, water, solvents) droplets are called mists. Submicrometer aerosols that are formed from condensation or combustion processes are generally called fumes or smokes. Some of these aerosols have a significant vapor pressure and will evaporate when aged. The direct-reading photometer may detect these high vapor pressure aerosols while the reference method for respirable dust (Method 0600) will not.

2. PRINCIPLES OF OPERATION

Light-scattering aerosol monitors (also called nephelometers or aerosol photometers) operate by illuminating aerosol passing through a defined volume and detecting the total light scattered by all the particles in that volume (Figure 2). This discussion will not include single-particle counting photometers that are used to measure lower concentrations such as in clean rooms and give information about individual particles. However, there is an instrument listed below (Portable Dust Monitor from A. P. Buck, Inc.) that uses single-particle counting to estimate mass concentration.

The light source of a photometer can be monochromatic such as a light-emitting diode or laser or a broad-wavelength light source such as a tungsten filament lamp. The choice of light source in different instruments has more to do with the ability to control the light output level than with the wavelength of the output. The detector is generally a solid state photodiode but can be a photomultiplier tube. The detection geometry varies from one instrument to another. These instruments generally use a forward-scattering geometry (i.e., less than 90). The angle of scattering (theta) is defined with respect to the beam of light passing through the aerosol in the detection volume. The smaller the value of theta the more the detection is weighted toward larger particles.

The amount of light scattered by a particle into the detector is a complex function of the particle size, shape and refractive index. For spherical particles of known refractive index the instrument response can be calculated. However, in general, calibration must be carried out experimentally. An example of instrument response as a function of particle size for spherical particles of two different refractive indices is shown in Figure 1. It can be seen that there is a peak at approximately 0.6 mm and that there is a drop in instrument response to larger particles. For comparison, the ACGIH definition of respirable dust is superimposed on Figure 1 [6]. It can be seen that the size dependent response of the photometer is somewhat similar to the desired response for a respirable sampler.

For quantitative measurements, it is necessary to calibrate with an aerosol similar in refractive index and particle size to the one being measured. This is because aerosols with different refractive indices can produce photometer responses differing by more than a factor of ten. Since these instruments have specific size-dependent response to particles, the size distribution of dust particles is also important in evaluating the mass response of the instrument for a specific dust.

3. SAMPLING CONSIDERATIONS

a. Safety

Some portable photometers have been designed for intrinsic safety, i.e., for use in potentially explosive atmospheres. This must be checked with the manufacturer to ensure that a specific instrument meets the appropriate intrinsic safety requirements (e.g., Underwriter's Laboratory or Mine Safety and Health Administration).

b. Applications

Photometers generally cannot be used to discriminate between different types of aerosol. The instrument will respond to all types of aerosol present simultaneously in the detection volume. Therefore, measurement of a small amount of a specific aerosol in the presence of a large amount of interfering dust is not feasible with a photometer. For example, if lead fume must be measured in the presence of a large percentage of road dust, the photometer would not be the instrument of choice. However if lead fume were the major aerosol component, use of the photometer would be appropriate for monitoring lead exposure.

At high humidity, water droplets can exist in the air for extended periods of time and be detected by a photometer. These droplets can change size rapidly in response to small changes in humidity. Therefore, care should be taken when measuring aerosols near water sprays and other high humidity locations. It has been found in some cases, such as in cotton mills, that the aerosol produced by dried water sprays can be a significant component of the workplace aerosol.

Aerosol photometers require that the aerosol be carried to the detection volume in some fashion. Because of the inertial and electrical properties of aerosol particles, there may be errors in transporting the aerosol to the detection volume. Most photometers have a sampling pump that draws the aerosol into an inlet, through a length of duct, and to the detector. Some instruments include a preclassifier (cyclone or impactor) to make the overall response more similar to the respirable dust definition. Some photometers rely on air convection or motion of the photometer to bring the aerosol to the detector (passive sampling). In either case, there will generally be some particles that are not detected due to losses in the instrument before they reach the detector. Particles larger than 10 µm are especially likely to be lost. However, these losses will generally be small for smaller particles unless there is high local air velocity or unless the aerosol particles are highly charged.

A list of instruments is provided at the end of this chapter. Other instruments are listed in various references [7,8]. Since instrument development is an active field, it is suggested that current literature sources and the manufacturers be contacted for the latest information.

4. DATA ACQUISITION AND TREATMENT

a. Calibration

Most photometers are factory-calibrated by comparing the instrument response in a well-defined aerosol to measurements by the gravimetric method (e.g. Method 0600). The instrument response at one or more concentrations is compared with the gravimetric method result. In most cases, the photometer response is modified to read directly in mg/m^3. However, it should be remembered that this calibration is only valid for the specific calibration aerosol and may differ by as much as a factor of ten when used with an aerosol from a different source, different composition, or size distribution. The factory calibration of this type is primarily useful to ensure that the instrument is operating properly and responding the same as other similar instruments. It does not ensure that the photometer will respond accurately to another aerosol.

An aerosol photometer measures a single parameter that is dependent on many variables, e.g., particle size distribution, particle agglomeration, particle refractive index, that can and do change in field situations. Therefore, it is necessary that the aerosol photometer be calibrated in conditions closely approximating the aerosol to be monitored. Calibration is carried out by comparing the time-weighted average photometer readings directly with field measurements using Method 0600. Most photometers do not protect the optical surfaces with a clean air sheath and should be checked frequently for zero drift during calibration and routine monitoring.

b. Operation

Data can be collected in either manual or automated mode. Most direct-reading photometers have a digital or analog readout indicating concentration. This allows manual observation of measured concentration. In this mode the instrument is useful for observing relative concentrations between different locations, for detecting leaks in processes, for evaluating work procedures, etc. Some photometers also have an output port that can be connected to a recorder or other data acquisition system. This allows the instrument to operate unattended while it monitors work processes, filter penetration breakthrough, etc. In some cases, the photometer and the data acquisition system together are sufficiently small that they can be worn by a worker. These photometers can be used to provide a time-dependent profile of exposure over a work period as well as an integrated time-weighted average exposure. In addition, the worker can be made aware of aerosol concentrations while carrying out his tasks so that he can modify work practices to reduce exposure.

It should be noted that the concentration of any contaminant in the air can be highly variable. Therefore, a single measurement of concentration, especially with a direct-reading instrument, should only be considered in the context of other measurements and the environmental conditions.

5. INSTRUMENTS

a. MIE, Inc.

Model RAM-1 Features: Active sampling, with 10-mm nylon cyclone, reference scatterer built in, zero air built in, clean air protection for optics, several time constants for output, dehumidifier available, permissible for explosive atmospheres (optional).

Model MINIRAM Features: Passive sampling, with active sampling attachments (optional) that need a separate pump, automatically calculates running and shift average concentrations, permissible for explosive atmospheres, zero air attachment (optional).

b. MST Measurement Systems, Inc.

Model P-5 Features: Active sampling, labyrinth classifier on inlet, integrating or continuous readout, several measurement periods.

Model PCD-1 Features: Active sampling, respirable dust inlet, programmable parameters include sampling period/alarm concentration/calibration factors, data acquisition built in.

Model PDS-1 Features: Passive sampling, allows personal monitoring, requires separate readout unit or data logger.

c. ppm Enterprises

Model HAM Features: Passive sampling, active sampling attachments (optional), zero air attachment, reference scatterer attachment.

Model Personal Aerosol Monitor Features: Passive sampling, zero air attachment, reference scatterer attachment.

d. Sensidyne, Inc.

Model LD-1 Features: Active sampling, laser light source, 10- or 7-micrometer cut impactor classifier built in, analog and digital readout, one-minute or operator-selected measurement period, reference scatterer, zero air attachment.

e. A. P. Buck, Inc.

Portable Dust Monitor Features: Active sampling, laser diode light source, optional cyclone for respirable sampling, pulse height analyzer for particle sizing information, data logger built in, filter for reference mass built in.

6. REFERENCES

[1] Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices for 1993-94, 42-45, ACGIH, Cincinnati, OH (1993).

[2] British Medical Research Council: Recommendations of the MRC Panels Relating to Selective Sampling, Inhaled Particles and Vapours, Pergammon Press, Oxford (1961).

[3] Ad Hoc Working Group Report to Technical Committee 146-Air Quality, International Standards Organization, Recommendations on Size Definitions for Particle Sampling, Am. Ind. Hyg. Assoc. J., 42(5), A-64 (1981).

[4] Air Quality - Particle Size Fraction Definitions for Health Related Sampling, Technical Report ISO/TR 7708-1983(E), International Standards Organization, Geneva, Switzerland (1983).

[5] Bartley, D. L., and Breuer, G. M. Analysis and Optimization of the Performance of the 10-mm Cyclone, Am. Ind. Hyg. Assoc. J. 43, 520 (1982).

[6] Marple, V. A., and Rubow, K. L, Respirable Dust Measurements, Report for U.S. Bureau of Mines Contract No. JO113042 (1984).

[7] Hering, S., Ed., Air Sampling Instruments, 7th ed., ACGIH, Cincinnati, OH (1989).

[8] Willeke, K. and P. A. Baron, Eds., Aerosol Measurement: Principles, Techniques, and Applications, Van Nostrand-Reinhold, New York (1993).

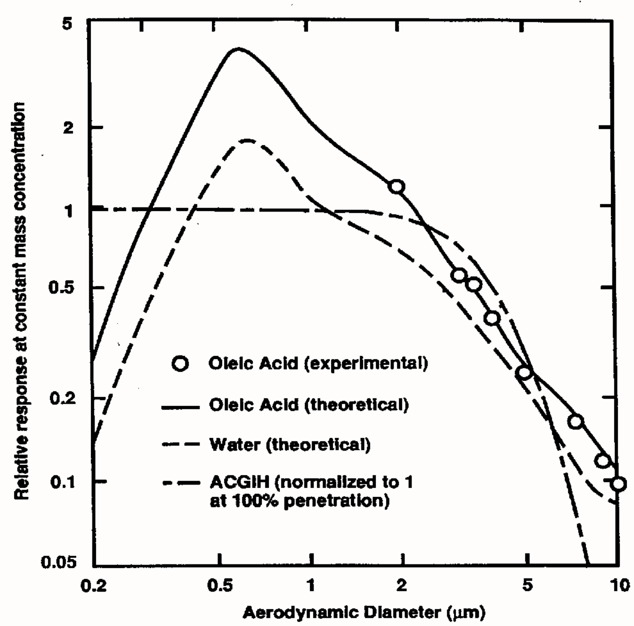

Figure 1. Experimentally determined and theoretically predicted "mass sensitivity" of the GCA RAM-1 to oleic acid and water droplets. Included for comparison is the ACGIH respirable dust penetration curve [1] normalized to one at 100% penetration.

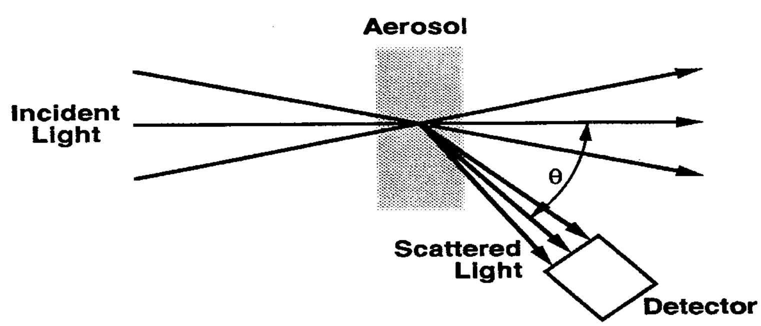

Figure 2. Diagram showing the components of an aerosol photometer.