Application Note ITI-058

# Measuring Total Suspended Particulates (TSP) with Aerosol Photometers

The term “TSP” refers to “total suspended particulates” (re-defined by American Conference for Governmental Industrial Hygienists - ACGIH as “total” dust). An aerosol instrument that claims to measure TSP implies that it is able to measure all particles that are suspended in air. Any such claim is far from the truth. TSP is a measure of what the instrument can “see”, not 100 percent of what is in the air. Even the best sampling instruments measure only a fraction of the particles in the air due to inherent limitations in the collection and measurement technique.

In practice, an aerosol-measuring instrument can only measure particles that actually enter the device and are also in the size range that the detector can “see”. These are two important elements that affect the range and accuracy of aerosol instruments. Claiming the ability to measure TSP simply means that the aerosol instrument has no controlled size-selective sampling inlet. In other words, the sampling efficiency for particles is unknown.

First, let's look at the inlet efficiency. Particles in the atmosphere range in the size from less than 0.1 micrometer micron to 100 microns or more. The fraction of particles that actually enter the sampling inlet and get transported to the detector is a complex function of the particle size, the ratio of the ambient air velocity to the sampling inlet air velocity, air turbulence, and the shape, size and orientation of the sampling inlet. The most important factor in sampling efficiency is the particle size. In general, large particles are sampled less efficiently due to inertial losses and gravitational settling. Above 10 microns, sampling efficiency drops off very rapidly. For example consider the sampling efficiency of a typical instrument sampling at a flow rate of 1.7 lpm across a 12-inch long horizontal tube (inside diameter of 0.25 inch) with a 90° bend. Table 1

| PARTICLE SIZE, microns | PENETRATION | TOTAL SYSTEM LOSS (1 - PENETRATION) |
|---|---|---|
| 0.1 | 100% | 0% |
| 1 | 100% | 0% |
| 5 | 93% | 7% |
| 10 | 75% | 25% |
| 20 | 25% | 75% |
| 25 | 6% | 94% |
| 35 | 1% | 99% |
| 50 | 0% | 100% |

*Table 1 Sampling loss for different particle sizes for simple system with one 90° bend.*

It is evident from Table 1 that it is nearly impossible to sample particles larger than 20 microns without taking extreme precaution to not bend the sample tube or mis-orient the sampling inlet. Table 1 clearly indicates that it is impossible to have a sampling instrument that measures all the suspended particles in the air (includes particles greater than 100 microns). Without a controlled size-selective inlet, the measuring range is ill-defined and will vary greatly from instrument to instrument. It is desirable to know the exact measurement range so that data from instrument to instrument can be compared. For example, the TSI DUSTTRAK Aerosol Monitor Model 8520 is designed to have an upper limit of 10 microns to match the requirements of health-based aerosol sampling.

The second issue to consider is the sensitivity of the detector. A general rule of thumb is that a light-scattering aerosol instrument can effectively measure over a particle size range of not more than 1½ to 2 orders of magnitude. Thus the largest measurable particle size is about 50 to 100 times larger than the smallest detectable size. For example, the particle size range of the DUSTTRAK monitor is 0.1 to 10.0 microns.

Aerosol photometers (sometimes called nephelometers) detect particles by measuring the total amount of light they scatter. The intensity of light scattered by a particle is a function of the particle size, shape and index of refraction. Particles in the size range of 0.1 to 10 microns scatter much more light for a given particulate volume (or mass) than do particles that are much smaller or much larger. Figure 1 illustrates the scattered light intensity in the DUSTTRAK monitor for different aerosol compositions. The response is a function of particle size for unit mass concentration. In addition to the variations due to material composition, one thing is very consistent: the scattering intensity drops off rapidly below 0.1 micron and above 10 microns. Therefore, light-scattering instruments like aerosol photometers are usually limited to measuring particle sizes in the range from 0.1 to 10 microns.

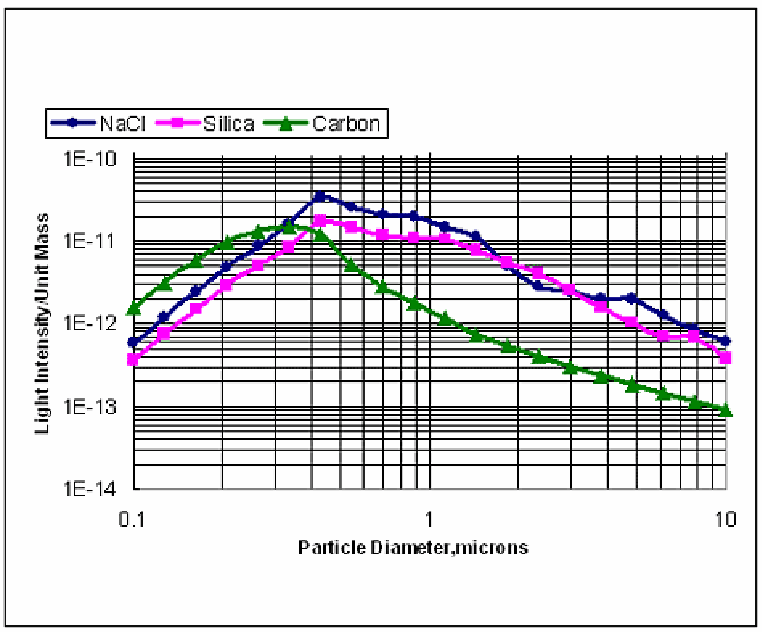


*Figure 1. Comparative response of various materials as a function of particle size for a constant mass concentration (TSI DUSTTRAK Aerosol Monitor Model 8520).*

Figure 1 illustrates that the response function depends on the material composition (index of refraction). Figure 1 also illustrates that fine aerosol (less than 1 micron) scatters more light per unit mass than particles greater than 1 micron. Consequently, a special case of photometric measurement is the measurement of fumes, haze and combustion aerosol like cigarette smoke or diesel exhaust. Due to the shape of the curve in Figure 1, these aerosols can scatter as much as 2 to 5 times more light per unit mass than the ISO fine dust with which most photometers, including the DUSTTRAK monitor are calibrated. Consequently, a 1 microgram/$m^3$ fine aerosol will scatter as much light as that scattered by 2 to 5 micrograms/m3 of ISO fine dust. Therefore, the indicated concentration will also be 2 to 5 times more than the actual concentration. Fortunately, for respirable dust particles, the effect of overestimation due to presence of fine particles and the underestimation due to coarse particles tend to be fairly well offset, leading to a flat response by the photometer for a wide range of industrial aerosols. Therefore, photometers are well suited for measuring respirable aerosols.

For most accurate calibration, it is best to calibrate the instrument with the aerosol in the environment being monitored. The DUSTTRAK monitor may be calibrated in the field for specific aerosols such as wood dust, silica, coal dust or cigarette smoke.

Figure 1 also illustrates that the light scattering intensity from particles greater than 10 microns drops to almost zero. To measure particles greater than 10 microns using light scattering photometry, you need to isolate the large particles from the rest of the sample and apply a calibration factor just for the large particles. If the large particles remain mixed with the smaller particles, the signal from the small particles will dominate. Hence, if the aerosol is monodisperse or coarse, small changes in particle size distribution will cause a large bias in measurements.

Any aerosol photometer that claims to measure TSP (implying all particles in the air) provides misleading information at best. Ask the following questions:

- What is the actual sampling efficiency of the inlet of the instrument in terms of particle diameter?
- Can it really sample 100 percent of the particles in the air?
- What is the particle size range of the instrument detector?
- If 100 percent of the particles in the air were to actually reach the detector, would the instrument "see" them?
- Is there a provision for physically separating the large particles from the small particles with a separate calibration factor for each size range?
    - If not, then the particles in the range of 0.1 to 10 microns will dominate the signal.
    - Without size segregation, it is impossible to accurately measure the mass of large particles above 10 microns using light-scattering methods.

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