GETTING DATA YOU NEED WITH PARTICLE MEASUREMENTS

APPLICATION NOTE PD-001

Particles, large and small, are an important factor in maintaining good indoor air quality. Measurements of these particles need to be done for IAQ investigations, air monitoring applications and for basic aerosol research. For indoor air projects, control measures, such as improved housekeeping, upgraded filters, or proper exhaust design, are usually straightforward actions. However, choosing the proper control depends on having the correct data for decision-making. Many instruments, employing various technologies, are currently available to provide this real time information. The question is “Which technology is right for my application?”

Optical particle counters (OPCs), photometers, Aerodynamic Particle Sizer® (APS™) spectrometers, and condensation particle counters (CPCs) all measure airborne particles in real time. Each technology has a unique sensitivity to specific particle characteristics such as size, mass and refractive index. Table 1 summarizes the basic performance differences. Note in particular the size range and flow rate for each instrument as well as the upper limit of the number concentrations. Table 2 summarizes typical applications for each measurement technology.

TABLE 1. Comparison Chart—Real Time Particle Measurement Technologies

TSI Model	Photometer		Optical Particle Counter					LDSA [5]	APS [6]	CPC [7]
	DustTrak II [1]	DustTrak DRX [2]	Cleanroom Counters			3330 OPS [3]	3340 LAS [4]			
			Portable	Handheld	Intercavity					
Typical Size Fraction	0.1 to 10 µm	0.1 to 10 µm	0.3 to 10 µm	0.3 to 10 µm	0.1 to 10 µm	0.3 to 10 µm	0.09 to 7.5 µm	0.01 to 1.0 µm	0.5 to 20 µm	0.0025 to 2 µm
Flow	3 lpm	3 lpm	28.3 - 100 lpm	2.83 lpm	28.3 lpm	1 lpm	10 - 90 cc/min	2.5 lpm	5 lpm	.3 - 1.5 lpm
Measure Particle Mass	Yes	Yes	No	No	No	No	No	No	No	No
Measure Particle Size	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No
Detects Single Particles	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Typical Mass Concentration Range	0.1 to 400 mg/m^3	0.1 to 150 mg/m^3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Number Concentration Upper Limit (Particles/cm^3)	N/A		14	70	14	3000	1,800 - 18,000	N/A	1,000	10,000 - 10^7

1) TSI DustTrak II is an example of a basic single channel Photometer designed for mass aerosol measurements

2) TSI DustTrak DRX is an example of a combination of photometer and single particle counting designed for simultaneous measurement of multiple mass fractions

3) TSI Model 3330 Optical Particle Sizer is an example of an OPC designed for aerosol measurments

4) TSI Model 3340 Laser Aerosol Spectrometer is an example of an Intercavity OPC designed for aerosol measurments

5) Lung Deposited Surface Area (LDSA) monitors measure the amount of surface area of particles that deposit in the lung

6) Aerodynamic Particle Sizer (APS) spectrometer is an instrument that uses time of flight measurements to determine aerodynamic size

7) Condensation Particle Counter (CPC) instruments use condensation to grow small particles larger so that they can be counted

TABLE 2. Comparison Chart—Applications (Accepted Best Practice)

TSI Model	Photometer		Optical Particle Counter					LDSA	APS	CPC
	DustTrak II	DustTrak DRX	Cleanroom Counters			3330 OPS	3340 LAS			
			Portable	Handheld	Intercavity					
Indoor Air Quality Conventional Testing	Good	Excellent	Poor	Good	N/A	Good	Good	N/A	N/A	Good
Indoor Air Quality - Research Studies	Fair	Fair	N/A	N/A	N/A	Good	Fair	Good	Good	Excellent
Industrial Workplace Monitoring	Excellent	Excellent	N/A	N/A	N/A	Good	Good	Excellent	Good	Excellent
Outdoor Environmental Monitoring	Good	Excellent	N/A	N/A	N/A	Good	Good	Good	Good	Excellent
Emissions Monitoring	Excellent	Excellent	N/A	N/A	N/A	Fair	Fair	Good	Good	Good
Respirator Fit Testing	Good	Good	N/A	N/A	N/A	Poor	Poor	N/A	Poor	Excellent
Filter Testing	Excellent	Excellent	Good	Fair	Good	Excellent	Excellent	Fair	Excellent	Excellent
Clean Room Monitoring	Poor	Poor	Excellent	Fair	Excellent	Good	Good	N/A	Fair	Good
Pharmaceutical	Poor	Poor	Excellent	Excellent	Excellent	Good	Good	N/A	Excellent	Good
Research and Development	Fair	Good	Fair	Fair	Good	Excellent	Excellent	Excellent	Excellent	Excellent
Cost Comparison	$	$$	$$	$	$$	$$	$$$	$$ - $$$	$$$$	$ - $$$

1) Health effects of ultrafine and nanoparticles (below 0.1 µm) are not completely understood, though research suggests that they may cause the greatest harm. There are currently no established exposure limits or government regulations specifically addressing ultrafine and nano-particles.

Optical Particle Counters

Optical particle counters measure particle size and number concentration by detecting the light scattered from individual particles. They were traditionally used for clean room monitoring, but have more recently found application in filter testing, outdoor environmental monitoring, and indoor air quality studies.

Single particles are drawn through a focused laser beam and produce a flash of light, as illustrated in Figure 1. The intensity of the scattered light is a complex function of the diameter, shape and refractive index of the particle as well as light wavelength and geometry of the optical detector. A photodetector measures the amount of light that each particle scatters and records a count for each calibrated size range or bin.

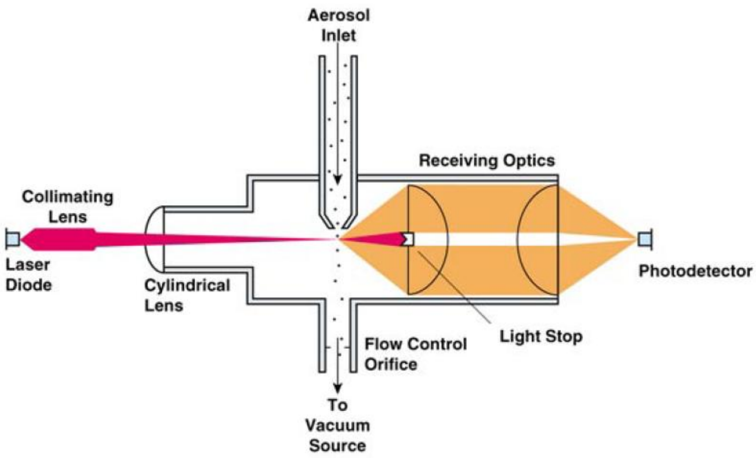

Figure 1
Flow through an Optical Particle Counter

OPCs are calibrated with perfectly uniform, spherical polystyrene latex (PSL) bead particles of known refractive index. The measured size of an unknown particle is therefore the “light-scattering equivalent size” as compared to the known calibration particle. The physical size of real world particles may be quite different from this “calibration” size.

Single particle counting instruments are limited in their maximum concentrations by how many light pulses they can count without coincidence (pulses overlapping so that not all pulses are counted). In general the amount of pulses per time interval is fairly constant. High flow counters have low maximum concentrations and lower flows have higher concentrations.

The size range minimum is typically 0.3 µm diameter due to the strong dependence of light scatter to particle diameter making detection of smaller particles very difficult.

In certifying clean rooms the standards require sampling large volumes of air. To do that, high flow rates are used. At flow rates such as 1 cu ft/min, the maximum concentration is typically 200,000 particles/ft^3 (7 particles/cm^3). For handheld counters used to survey clean rooms (to identify particle sources) flow rates such as 0.1 cu ft/min (2.83 lpm) are often used. In that case maximum number concentrations are often in the range of 2,000,000 particles/ft^3 (70 particles/cm^3). For applications such as measuring indoor air quality, outdoor ambient concentrations and doing filter testing a different category of particle counters capable of higher concentrations are needed. These counters use still lower flow rates and special techniques (such as dead time corrections) and can measure hundreds or thousands of particles/cm^3.

To measure smaller sizes optically the light intensity must be increased dramatically. There is a category of optical particle counters where the particle stream passes through the cavity of a laser where the light intensity is orders of magnitude higher than the output power of the laser. These “intracavity” designs allow the minimum size to drop to 0.1 µm and below. In this category there are also a cleanroom versions (with high flow rate and low maximum concentrations) and research versions (with very low flow rates and maximum concentrations in the thousands of particles/cm^3). The figure below illustrates that technique.

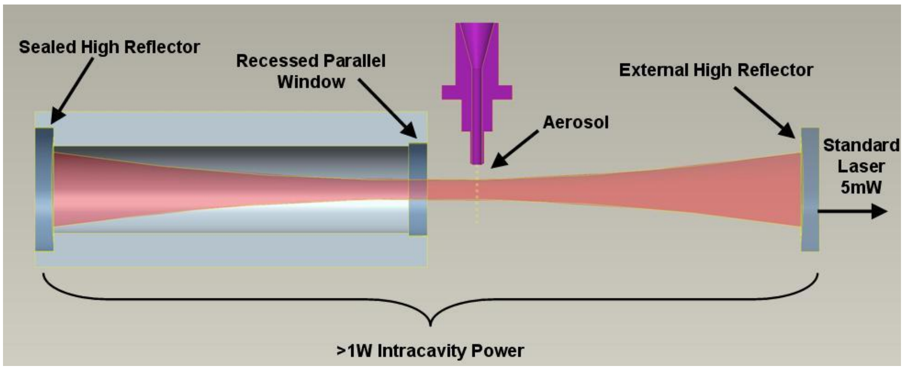

Figure 2
Flow through an Intracavity Particle Counter

Photometers

Often used for industrial workplace studies and emissions monitoring, photometers are well-suited for assessing human exposure to specific size fraction aerosols in real time. They use conventional light-scattering technology to closely estimate particulate mass concentrations.

The operation of a typical photometer is shown in Figure 3. A sample is drawn into the instrument by a continuously running pump. The size fraction of interest can be aerodynamically "cut" from the air stream at the sample inlet using either an impactor or a cyclone. The size fractions of most interest are respirable, thoracic, PM_{10}, $PM_{2.5}$ and $PM_{1.0}$.

The size-classified sample passes through a focusing nozzle and enters the photodetector sensing chamber. A laser diode emits light through a set of focusing optics. As light contacts the sample particles, it is scattered in all directions. A photodetector converts this light into a voltage, which is calibrated against a known aerosol mass concentration (mg/m^3). In some instruments, a portion of the sample is drawn from the main air stream, filtered and re-introduced as sheath air. The sheath air surrounds the particle sample to protect the instrument's optics from fouling.

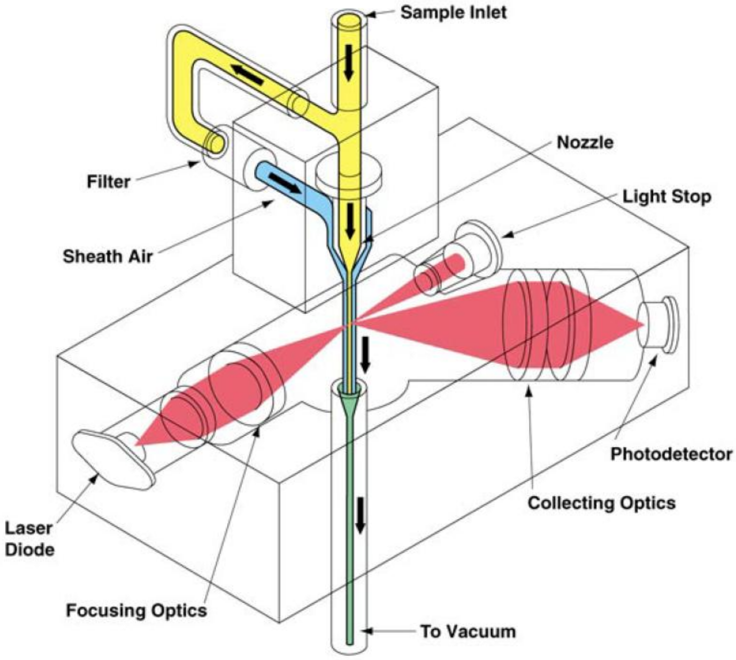

Figure 3
Flow through a Photometer

Photometers typically measure particle size ranges from 0.1 to 10 µm diameter with concentrations ranging from 0.01 to 100 mg/m^3 or more. Photometers cannot "see" particles below 0.1 µm (ultrafine particles) because the particles are too small to scatter detectable quantities of light. Photometers measure the aggregate signal from a "cloud" of particles and are not designed to detect individual particles, even when they are relatively large.

Most photometers are calibrated against a standard test dust, commonly referred to as Arizona Road Dust. This calibration is a good approximation for most ambient aerosols. Because optical measurements are dependent upon particle size and material properties, there may be times in which a custom calibration would improve the accuracy for a specific aerosol.

A new category of photometer (TSI DustTrak™ DRX monitor) combines the functions of a photometer and an optical particle counter. By individually sizing particles with optical size larger than 1 µm diameter and calculating the mass of those particles, multiple mass fractions can be measured simultaneously.

Lung Deposited Surface Area

Current workplace exposure limits are based on particle mass. However, a growing number of experts contend that surface area, a key factor in the toxicity of nanoparticles, rather than mass should be measured. This is particularly true where nanoparticles are concerned since they have far more surface area for the same amount of mass of larger particles. As a result, the need has arisen to assess workplace conditions and personal exposure to engineered nanoparticles based on the measurement of particle surface area. The model 3550 Nanoparticle Surface Area Monitor and the AEROTRAK™ 9000 Nanoparticle Aerosol Monitor are two instruments that make this measurement.

These instruments combine a charger and an electrometer to measure a current proportional to the size distribution, in surface area units, times lung deposition curves for either the tracheobronchial (TB) or the alveolar (A) regions of the lung. This “lung deposited surface area” in units of (μm^2/cc) corresponds to the exposure or dosing of these particles in the lung.

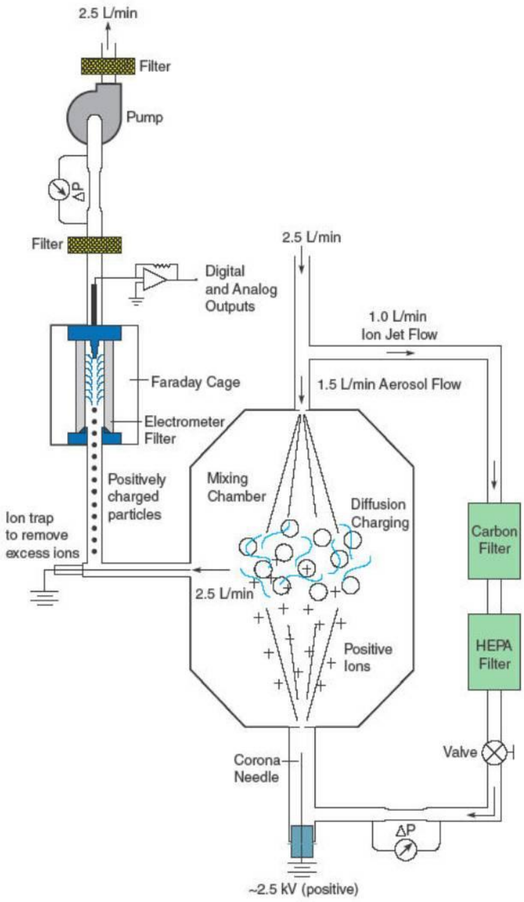

Figure 4
Lung Deposited Surface Area Instruments

Aerodynamic Particle Sizer® Spectrometers

Aerodynamic Particle Sizer spectrometers are specialized instruments that measure how particles behave in air, not by their physical size. Aerodynamic size is defined as, “the physical diameter of a unit density sphere which settles through the air with a velocity equal to the particle in question”. Where optical methods measure light scatter equivalent size, an instrument that measures aerodynamic size provides information about how the particles behave in an air stream. Ambient air regulations specify the size range by aerodynamic size. Deposition in the lung or on filters is based on the aerodynamic size of the particles.

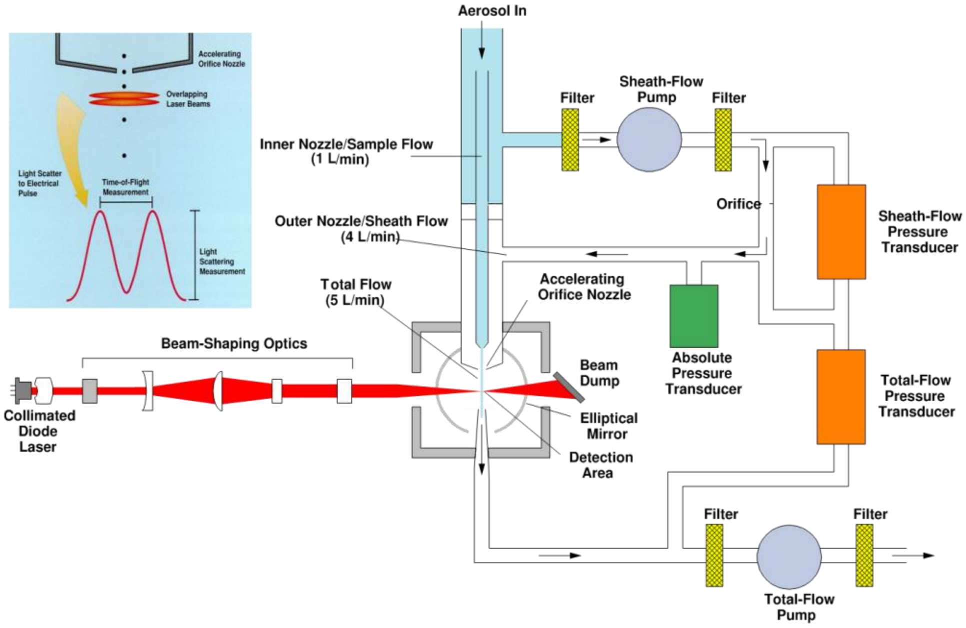

Figure 5
Flow through an Aerodynamic Particle Sizer Spectrometer

An instrument that measures real time aerodynamic particle size is the TSI model 3321 (APS™ spectrometer). It accelerates an aerosol stream through a nozzle and makes a time of flight measurement as the particles cross two closely spaced (partially overlapping) laser beams. How the calibration is done is similar to what is done for optical particle counters, using PSL beads as calibration particles. Unlike optical particle counters that have a calibration curve with poor resolution in the range of 1 µm the calibration curve, due to Mie scattering, an APS spectrometer has a monotonic response over the full size range.

Condensation Particle Counters

Condensation particle counters, sometimes referred to as condensation nuclei counters, are specialized instruments that first enlarge very small particles to an optically detectable size. They excel at counting particles in size ranges that are invisible to OPCs and photometers. CPCs are used for a variety of applications ranging from respirator fit testing to environmental air pollution studies to basic research. They are particularly well-suited for tracking indoor pollutants to their source. With the interest in nanotechnology and the production of nanoparticles the ability to count particles in the nanoparticle size range (< 100 nm) has become increasingly important

As depicted in Figure 6, particles are continuously drawn into the instrument and passed through a warm alcohol vapor. The mixture then flows through a condenser section where the alcohol vapor condenses onto the particles and "grows" them into larger droplets. The individual droplets then pass through the focal point of a laser beam, producing a flash of light. Each light flash is counted as one particle.

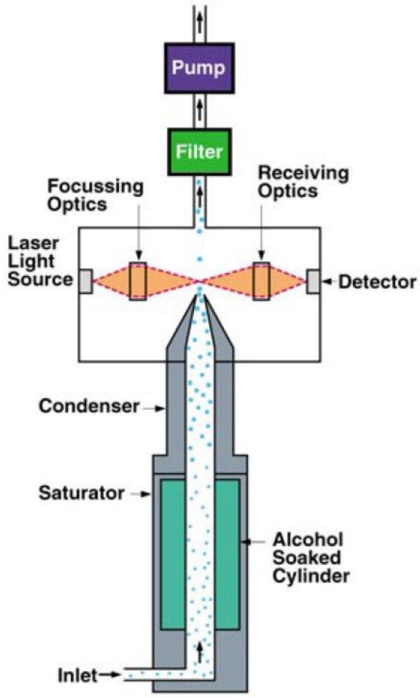

Figure 6
Flow through a CPC

The measured size range is typically from below 0.02 to above 1.0 µm diameter. Number concentration on all CPCs ranges from zero to at least 10,000 particles/cm^3 (280,000,000 particles/ft^3). Some CPCs have a maximum concentration as high as 10,000,000 particles/cm^3. The concentration measurement does not depend on the size or material properties of the particle.

Recent developments have produced a new category of CPCs that use water, instead of an alcohol, as their working fluid. Water behaves very differently than alcohols and requires a different method to grow the particles. In a Water CPC the inlet flow passes through a cool conditioner region where a "wick", saturated with water surrounds the particle stream and maintains a high relative humidity. The air then flows through a growth tube section where the heated wick causes rapid diffusion of water vapor into the particle stream which produces super-saturation. The small water molecules condense onto the cool particles and "grow" them into larger droplets. This technique is somewhat more sensitive to the material in the particles but avoids the need for a flammable working fluid.

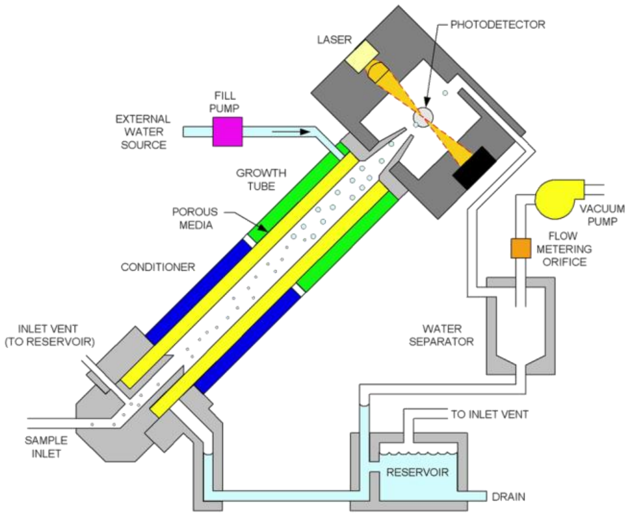

Figure 7
Flow through a Water-based CPC

There are versions of both types of CPCs that can detect particles as small as 0.0025 µm (2.5 nm). Minimum detected particle sizes, maximum concentration range, choice of working fluid are some of the factors that need to be considered when selecting a CPC. Another major use of CPCs is in particle sizing systems. A common sizing system called an SMPS™ (Scanning Mobility Particle Sizer™) spectrometer. This technique combines a size selecting device called a Differential Mobility Analyzer (DMA) with a CPC and scans through a size range to get a high resolution size distribution in the submicrometer size range.

Summary

All of these instruments—optical particle counters, photometers, Aerodynamic Particle Sizer spectrometers, and condensation particle counters—have their place in IAQ investigations, air monitoring, and basic aerosol research. Matching the appropriate technology with your particular application will provide the data you need to understand and improve your measurement quality. Photometers, which measure mass concentration, provide the necessary data to compare against air quality standards and guidelines. OPCs and APS spectrometer's give additional understanding of particle number concentrations and size ranges of the mid-sized particles to help identify the probable source and health impact. Finally, CPCs offer insight into the ultrafine and "nano" particles that are now emerging as an important new metric that may play a significant role in the health and comfort of building occupants.

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