



Comparison of Particle Sizing Methods

This document is a slightly irreverent, but honest, comparison of several different particle sizing methods. It is by no means an attempt at an exhaustive survey of the particle sizing field, since such a survey would require a good size text book or two. Our primary objectives are:

- To help potential buyers of particle sizing instruments (especially those without a lot of particle sizing experience) sort through the often exaggerated claims of instrument performance.
- To help them appreciate that all particle sizing methods have both advantages and limitations. These advantages and limitations should be understood and weighted before choosing a particle sizing instrument.

We urge potential customers to be very cautious about accepting the performance claims of any instrument manufacturer, including CPS Instruments, and to be cautious about accepting at face value the results of any particle sizing instrument. The truth is that while a certain particle sizing application may be dominated by one sizing method, other applications are dominated by other methods. The most sophisticated particle sizing customers often use completely different sizing methods for different applications, and even use two different methods for the same application; these customers understand that the best choice of sizing method depends upon both the nature of the sample and what characteristics of the size distribution are most important. One method can never suit all samples. If you read this document and find what you believe to be a substantial error of fact, please contact CPS Instruments via e-mail and tell us what you think is wrong.

Particle sizing methods can be separated into three basic classes:

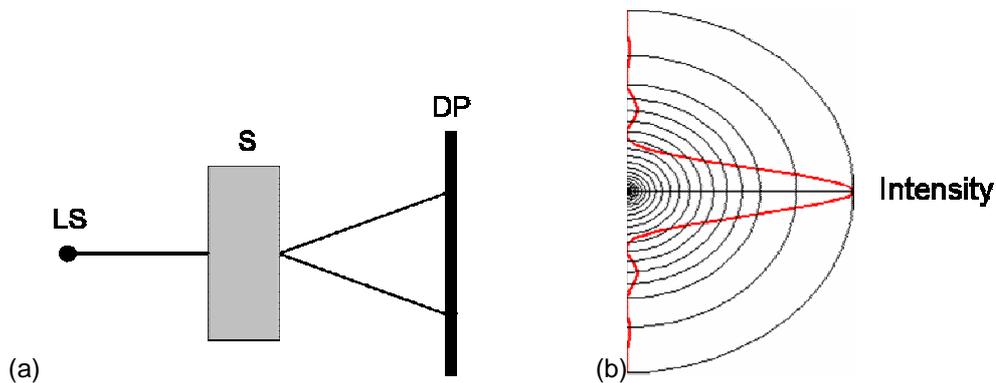
- Ensemble Methods: all particles in a sample are measured at the same time. Size distribution data is “extracted” from a combined signal for all particles.
- Counting Methods: individual particles are measured and counts of similar size particles are placed into “size bins” to construct a distribution.
- Separation Methods: an outside force/process is used to separate particles according to size. The quantities of the separated different sizes are determined.

Each of these classes is covered in a separate section below.

1. Ensemble Methods: Low Angle Laser Light Scattering (LALLS – Laser Diffraction)

This method uses a laser beam passing through a sample of particles in suspension (in liquid or air for instance), and collects light intensity data at different (low) scattering angles away from the axis of the laser beam. Intensity data is collected at many different angles (32 or more in most instruments). Mie light scattering theory calculations and standard mathematical methods for solving the inverse problem are applied to the intensity data to generate a distribution of particle sizes that is consistent with the observed light intensities at the observed angles.

LALLS is applied to relatively low concentration samples, so that there is a minimum of multiple scattering (where light scattered from one particle is scattered by a second particle before reaching the detectors), since multiple scattering makes it difficult to generate an accurate size distribution based on scattering angles.



Schematic representation of the Low Angle Laser Light Scattering technique: (a) experimental set-up (LS: laser source; S: particle suspension; DP: diffraction pattern) and (b) scattered light intensity as measured by circular light detector at the detection plane.

Advantages

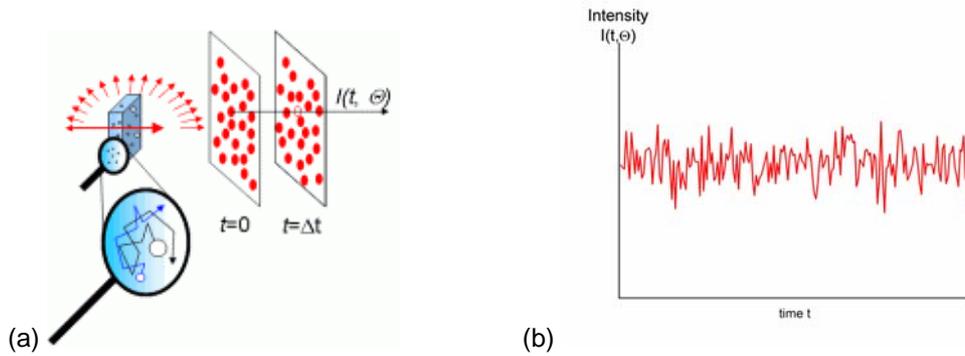
- Simple and fast data collection.
- Very broad dynamic range (claimed from < 0.1 μm up to millimeter sizes).
- Can measure both powders (with suitable sampling equipment) and fluid suspensions.
- Testing is non-destructive, so samples can be recovered if necessary.
- The method is widely used; many people are familiar with the method.

Disadvantages

- Low resolving power. Narrow, side-by-side particle size peaks must be at least 15% - 20% different in size to be resolved. The entire distribution is represented by a limited set of data points (usually 128 or less; a number of data points equal to the number of independently measured angular intensities) over the entire size range, so truly high resolution measurement is not possible.
- Accuracy depends on the accuracy of the optical parameters (refractive index, light absorption) available for the particles, as well as the accuracy of information about particle shape. Light absorption characteristics are often unknown and must be “estimated”. Non-homogeneous and/or non-spherical particles can give terribly incorrect results.
- Mixtures of particles with different optical properties cannot normally be measured.
- Strongly absorbing particles can present problems because they may not produce a usable scattering signal.

2. Ensemble Methods: Dynamic Light Scattering (DLS)

In Dynamic Light Scattering (DLS), also known as quasi-elastic light scattering (QELS), the Brownian motion (movement in random direction) of sub-micron particles is measured as a function of time. A laser beam is scattered by particles in suspension. The diffusion of particles causes rapid fluctuations in scattering intensity around a mean value at a certain angle (varying from 10° to 150°, but most commonly measured at 90°).



Schematic representation of the Dynamic Light Scattering technique: (a) particle Brownian motion and scattered light, (b) scattered light intensity as a function of time.

From the scattered light intensity signal, two techniques are used to retrieve information about the Brownian motion of the particles and subsequently their size: the Photon Correlation Spectroscopy (PCS) and the Frequency Power Spectrum (FPS).

The Photon Correlation Spectroscopy is based on the analysis of the autocorrelation function $G(\tau)$ calculated from the light intensity fluctuations and given by:

$$G(\tau) = \langle I(t + \tau).I(t) \rangle \tag{1}$$

where $I(t)$ is the scattered intensity light at time t and the symbol $\langle \dots \rangle$ represents the average over time.

For a monodisperse particle suspension, it has been well established that the autocorrelation function is given by a decaying function as:

$$G(\tau) = \exp(-\Gamma \tau) \tag{2}$$

with Γ , the decay rate given by:

$$\Gamma = Dq^2 \tag{3}$$

where q is the scattering vector and D is the translational diffusion coefficient.

Then, by using the Stokes-Einstein relationship, the particle size d can be calculated as:

$$d = \frac{kT}{3\pi\eta D} \tag{4}$$

where k is the Boltzmann's constant, T is the absolute temperature and η is the viscosity of the solvent. Therefore, by fitting the autocorrelation function, one can obtain the decay rate Γ and

from Eq. 3 and 4 deduce the particle size d . But this is only valid for very narrow particle size distributions.

In the case of polydisperse particle suspensions, a more complex data evaluation is needed to extract the particle size distribution from the raw data. For a polydisperse particle distribution, Eq. 2 can be rewritten as a Laplace transform:

$$G(\tau) = \int_0^{+\infty} C(\Gamma) \exp(-\Gamma \tau) d\Gamma \quad (5)$$

where $C(\Gamma)$ represents the distribution of decay rates due to the particle size distribution. Several methods have been developed to solve the inverse problem of Eq. 5. The earliest methods (as the “2nd cumulant” method) gave only a mean particle size and a polydispersity index (related to the distribution width of a polydisperse distribution). Due to the increasing computing resources the latest methods allow the evaluation of multimodal distributions. The most widespread method nowadays is based on the fitting of the autocorrelation function by the Non Negative Least Squares technique.

While the Photon Correlation Spectroscopy considers basically the number of photons scattered by the particles, the Frequency Power spectrum technique considers the light as a travelling wave and uses the analysis of the scattered light in frequency ω . In order to calculate the power spectrum function $S(\omega)$, the Fourier transform $F(\omega)$ of the scattered light intensity $I(t)$ must be firstly calculated:

$$F(\omega) = \int_{-\infty}^{+\infty} I(t) e^{i\omega t} dt \quad (6)$$

and, the power spectrum function $S(\omega)$ is given by:

$$S(\omega) = \lim_{T \rightarrow +\infty} \frac{1}{2T} |F^2(\omega)| \quad (7)$$

It is then shown that:

$$S(\omega) = \langle I_s \rangle^2 \frac{2\Gamma}{(2\Gamma)^2 + \omega^2} \quad (8)$$

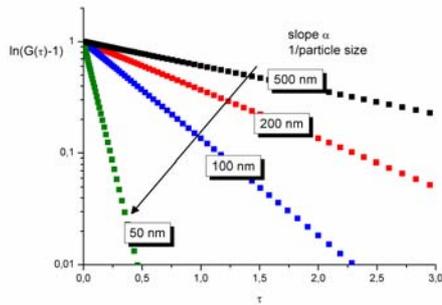
where $\langle I_s \rangle^2$ is the square of the scattered light intensity and Γ is defined by Eq. 3. Then, similarly to Eq. 5, the particle size distribution of a population of particles can be deduced by solving the following equation:

$$S(\omega) = \int_0^{+\infty} C(\Gamma) \frac{2\Gamma}{(2\Gamma)^2 + \omega^2} d\Gamma \quad (9)$$

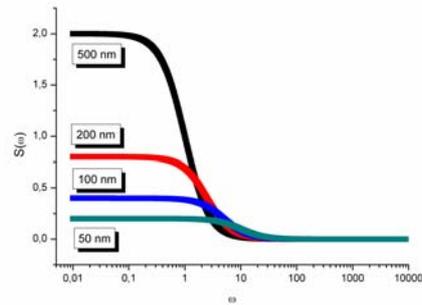
where $C(\Gamma)$ represents the distribution of decay rates due to the particle size distribution.

Both techniques are connected since the autocorrelation function $G(\tau)$ and the power spectrum function $S(\omega)$ form a Fourier transform pair, i.e.:

$$S(\omega) = \int_{-\infty}^{+\infty} G(\tau) e^{i\omega \tau} d\tau \quad (10)$$



(a)



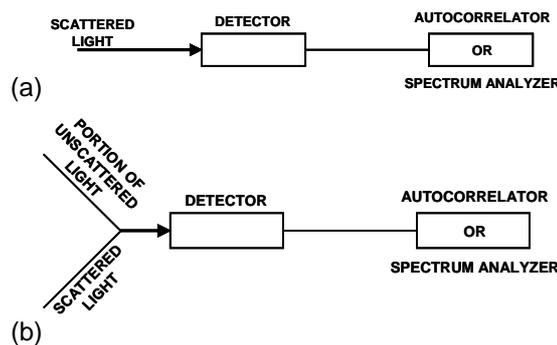
(b)

Schematic representation for different particle sizes of the: (a) autocorrelation function and (b) the power spectrum function as used respectively by Photon Correlation Spectroscopy and Frequency Power Spectrum.

This graph shows how the auto-correlation function changes with correlation time for several very narrow distribution samples. Broad distributions and/or multi-modal distributions yield non-linear auto-correlation curves, and it is difficult to extract accurate size distributions from the more complex non-linear auto-correlation curves.

The mathematical treatment of the signal for both techniques is valid only for diluted suspensions for which only single scattering occurs. Nevertheless, new instrumentation configurations have been developed in the last decades to overcome this limitation. The combination of focusing optics and the collection of backscattered light has allowed the measurement of particle size distribution in turbid suspensions.

There are two standard methods of optical detection in a dynamic light scattering experiment: homodyne and heterodyne. In the homodyne method, scattered light emanating only from the particles impinges upon the detector whereas in the heterodyne method, light from the source is mixed at the detector with scattered light from the sample. It is not clear from the literature which one of these set-ups gives the best results. Indeed, the interferential comparison of the scattered and incident lights as used by heterodyne set-up is expected to eliminate more efficiently disturbances from external sources but inversely gives a lower light intensity than homodyne set-up.



Schematic representation for the optical detection in a Dynamic Light Scattering experiment: (a) homodyne and (b) heterodyne.

Alternatively, a new technique based on PCS has been developed. This technique is called Photon Cross Correlation Spectroscopy (PCCS). Indeed, the correlation function is calculated from two light signals with the same scattering vector q and probing the same scattering volume. Thus, multiple scattering is eliminated by comparing both signals.

Advantages

- A minimum amount of information about the sample is needed to run an analysis.
- Even mixtures of different materials can be accurately measured; only the viscosity of the medium must be known accurately.
- Very small minimum measurable particle size.
- Only a tiny sample is needed.
- The analysis is fast and simple.
- Testing is non-destructive, so samples can be recovered if needed.

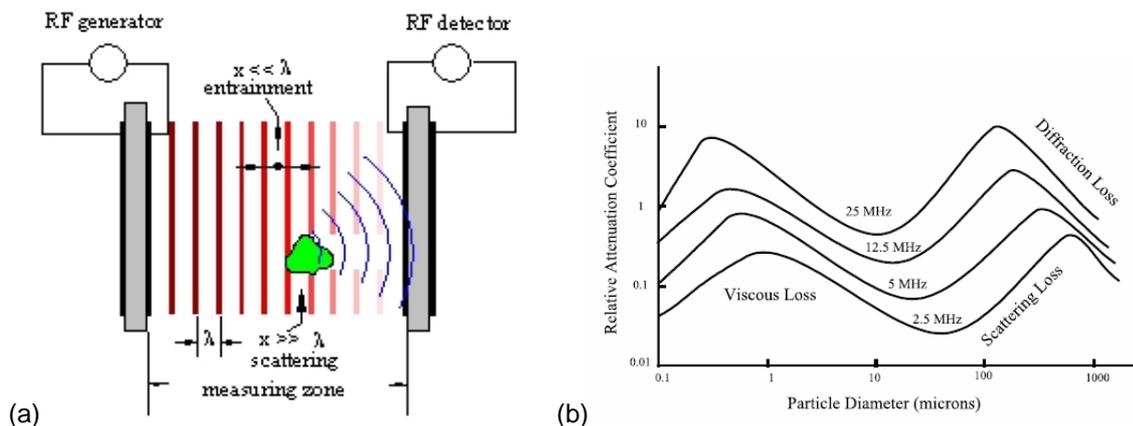
Disadvantages

- Extremely low resolution; particles must usually differ in size by 50% or more for DLS to reliably detect two peaks. The method does not really provide much size distribution data but rather a mean size and estimate of the polydispersity of the suspension.
- A small quantity of small size particles can easily be “hidden” in a much larger quantity of large size particles.

3. Ensemble Methods: Ultrasonic Attenuation Spectroscopy (UAS)

The principle of this technique is that plane sound waves moving through a particle suspension are attenuated in a predictable manner according to the size and concentration of the particles in the suspension, the spacing of the transmitter and receiver and other physical parameters.

Attenuation of an ultrasonic wave passing through a suspension may be modelled given a set of mechanical, thermodynamic and transport properties describing both the continuous and particulate media. The relationship between spectral data and particle size is illustrated by considering attenuation curves which are typical of solid, rigid, high density contrast particles suspended in water. Each curve shows the attenuation of sound waves of a particular frequency as a function of the size of a monosize population of fixed volume concentration. From these curves, it is clear that if the attenuation of sound was measured accurately at a single frequency, only four potential monosize distributions could have produced that measured attenuation. Accurate measurements at more than two frequencies would eliminate all but one of the potential sizes in principle. However, measurement noise along with modelling errors leads to instabilities of the data inversion procedure, so that usually a greater number of frequencies are needed for a reliable analysis.



Schematic representation of the ultrasonic attenuation spectroscopy technique and (b) typical variation of ultrasonic attenuation with particle size at different frequencies.

Advantages

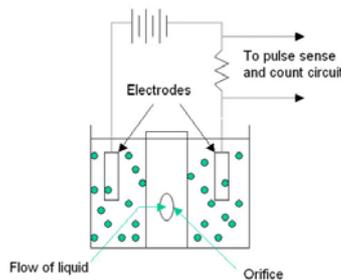
- Able to measure turbid suspensions.
- Technique relatively easy to implement

Disadvantages

- Extremely low resolution.
- Needs intense data evaluation based on mathematical modelling.
- Most instruments on the market are dedicated to industrial on-line applications.

4. Counting Methods: Electrozone Counter

The electrozone counter was pioneered by the Coulter Company many years ago for blood cell counts in hospitals, where it is still widely used. Particles are suspended in an electrically conductive fluid (usually saline water with emulsifier) and forced to flow through a small orifice. Conductors are placed in the fluid on either side of the orifice, and the electrical resistivity of the orifice is monitored as particles pass. Each particle produces a sharp “spike” in electrical resistivity as it passes the orifice, and the total area (time × height) under the spike is approximately proportional to the volume of the particle. Each of the spikes is classified according to total area, and a particle count is placed in a bin that corresponds to the appropriate particle size. After several thousands of particles have passed the orifice, the bin counts are converted to a particle size distribution, and the distribution is finally adjusted to account for the statistically finite probability of “co-incident” counts.



Schematic representation of the Electrozone Counter.

Advantages

- Suitable for a relatively broad range of sizes (0.5 micron to >300 microns, using different orifice sizes).
- Simple in concept, and easy to calibrate with known size standards.
- Quick analysis time.
- Gives repeatable results with many kinds of samples, including many non-spherical particles.
- Resolution comparable to LALLS; adjacent narrow peaks that differ by about 15% can be resolved.

Disadvantages

- Dynamic size range is limited to about 30 in a single run (from about 2% of the orifice size to about 60% of the orifice size). Analysis of broader distributions requires pre-separation of samples according to size.
- Samples must be suspended in a conductive fluid; saline water may not be convenient for many kinds of samples.
- The particles must normally be electrical insulators.
- While the minimum size for the method is about 0.5 micron, experience has shown that measurements below 1-2 microns are often very difficult due to stray oversize particles that get trapped in the orifice.
- Particles below 0.5 micron can't be measured by this technique under any circumstances.
- Resolution near the lower limit of the instrument is often not as good as in the middle of the measurable range.

5. Counting Methods: Microscopy Counting

The microscopy counting technique consists in imaging a large population of and using image processing and analysing software in order to convert the images into a particle size distribution. The choice between scanning and transmission modes when using the electron microscope will depend on the size and physical properties of the particles. This technique requires that the dimensional calibration of the microscope is accurate.

Moreover, it has been shown for particles made of material sensitive to vacuum conditions and electron bombarding that the scanning probe microscope used in non-contact mode gives better results. Nevertheless, in the case of particles imaged by scanning probe microscopy, it is well established that the contact mode is more reliable for particle sizing. But it necessitates preparing the particles in a way that they will be fixed on their substrate.

Advantages

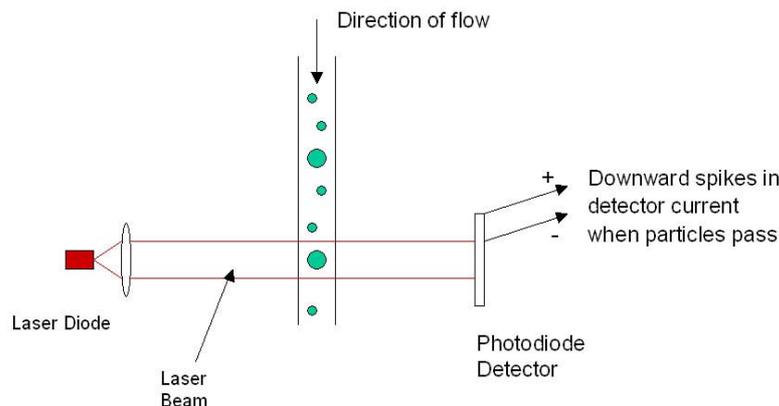
- Microscopic evaluation allows you to “really” see the particles and evaluate their range of shapes and sizes. The method inspires great confidence in the results.
- A quick look with a microscope often gives a great deal of information that other methods are unable to give.

Disadvantages

- The method inspires too much confidence in some cases. It may be difficult to collect enough data to give a reliable result.
- Analysis time can be very long, especially for electron microscopy counting.
- The number of particles measured is usually small compared to other particle sizing methods, so representative sampling becomes critical.
- It is normally not possible to determine if two or more particles are just “touching” or if they are permanently stuck together and must be considered as one bigger particle. This can lead to significant errors in reported size distribution.
- Sample preparation for electron microscopes is slow, expensive, and requires considerable technical expertise.

6. Counting Methods: Optical Counter

The light counter is very much the optical equivalent of the electrozone counter. Particles are forced through a counting chamber, where a focused laser beam is partially blocked as the particle passes. The reduction in light intensity reaching a detector is related to the optical cross section of the particle, and this is converted to a size distribution.



Schematic representation of the Optical Counter.

Advantages

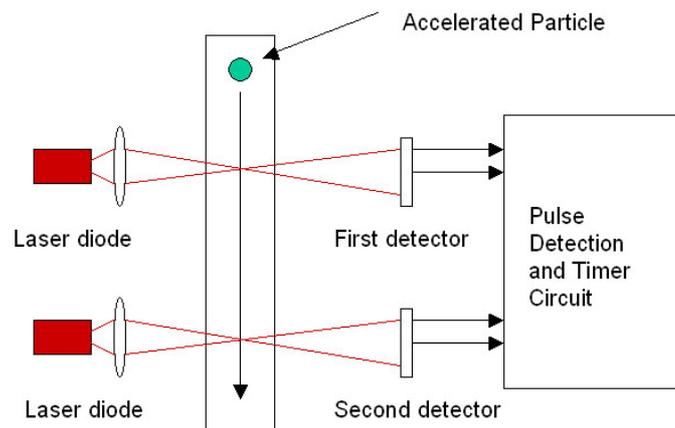
- Suitable for a relatively broad range of sizes (0.5 micron to >300 microns, using different orifice sizes).
- Simple in concept, and easy to calibrate with known size standards.
- Quick analysis time.
- Gives repeatable results with many kinds of samples, including many non-spherical particles.
- Resolution comparable to LALLS; adjacent narrow peaks that differ by about 15% can be resolved.

Disadvantages

- Dynamic size range is limited to about 30 in a single run (from about 2% of the orifice size to about 60% of the orifice size). Analysis of broader distributions requires pre-separation of samples according to size.
- Samples must be suspended in a conductive fluid; saline water may not be convenient for many kinds of samples.
- The particles must normally be electrical insulators.
- While the minimum size for the method is about 0.5 micron, experience has shown that measurements below 1-2 microns are often very difficult due to stray oversize particles that get trapped in the orifice.
- Particles below 0.5 micron can't be measured by this technique under any circumstances.
- Resolution near the lower limit of the instrument is often not as good as in the middle of the measurable range.

7. Counting Methods: Time-of-flight Counter

This technique is targeted for dry powders, although very dilute particulate suspensions in water can be “nebulized” and the particles measured after the water has evaporated. Sizes are measured as follows: an air stream containing particles is drawn through a fine nozzle into a partial vacuum, producing a supersonic “barrel shock envelope” of air. Particles accelerate in the air flow according to size, with smaller particles accelerating more rapidly than larger particles. The particles then pass two focused laser beams. The first laser beam detects each particle and starts a time-of-flight clock, while arrival at the second laser beam stops the clock.



Schematic representation of the Time-of-flight Counter.

Advantages

- Works with dry powders.
- Can be easily calibrated with known size standards.
- Broad total measurement range, ~0.2 to 700 microns.
- Fast analysis time, normally about 1 minute.
- Resolution comparable to LALLS, at least for particles above 0.5 micron, where narrow adjacent peaks that differ by ~20% can be resolved.

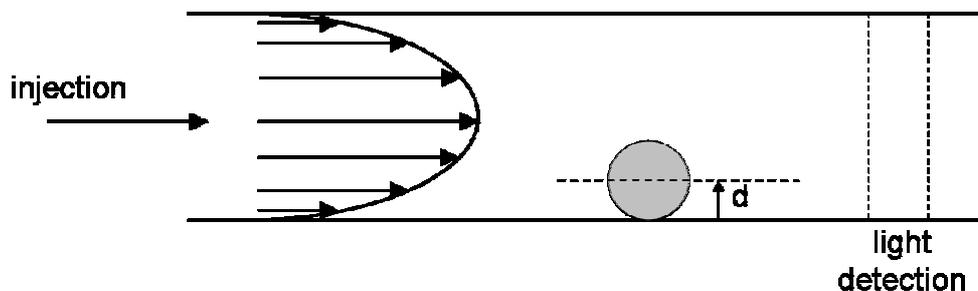
Disadvantages

- Liquid suspensions of particles may be difficult or impossible to measure.
- Particles less than 0.2 micron can't be measured; measurements below 0.5 micron will likely be lower resolution.
- Non-spherical particles will be reported as smaller than correct, but the magnitude of the error is not known.
- High resolution analysis is not possible due to physical limitations of the method.

8. Separation Methods: Capillary Hydrodynamic Fractionation (CHDF)

A very fine capillary tube (a few μm inside diameter) carries a flow of emulsifier in water. At the start of an analysis, a very dilute suspension of particles is added to the flow just upstream of the capillary. As the particles move down the capillary they diffuse across the capillary bore, due to Brownian motion. Over time, each of the particles resides at all possible distances from the center of the capillary, thus experiencing all possible velocities. The flow velocity profile within the capillary tube is approximately parabolic, with the highest velocity at the center.

At any instant, a particle moves at a speed close to the speed of the fluid at that particle's center. The center of a particle of diameter d can only approach the capillary wall to a distance of $d/2$; each particle is excluded from residing closer to the wall than half its diameter. On average, large particles have a higher velocity down the capillary than small particles, because large particles never experience the lowest flow velocities that are near the capillary wall. Large particles reach the end of the capillary first, very small particles reach the end last. A detector (optical, ultra-violet, or other) at the end of the capillary measures the concentration of particles as they exit the capillary in order to deduce the particle size distribution.



Schematic representation of the Capillary Hydrodynamic Fractionation technique. Horizontal arrows represent the velocity parabolic profile.

Advantages

- Relatively fast analysis time; ~ 7 to 10 minutes in all cases.
- Minimum of information needed about optical characteristics.
- Performance can be verified with calibration standards.

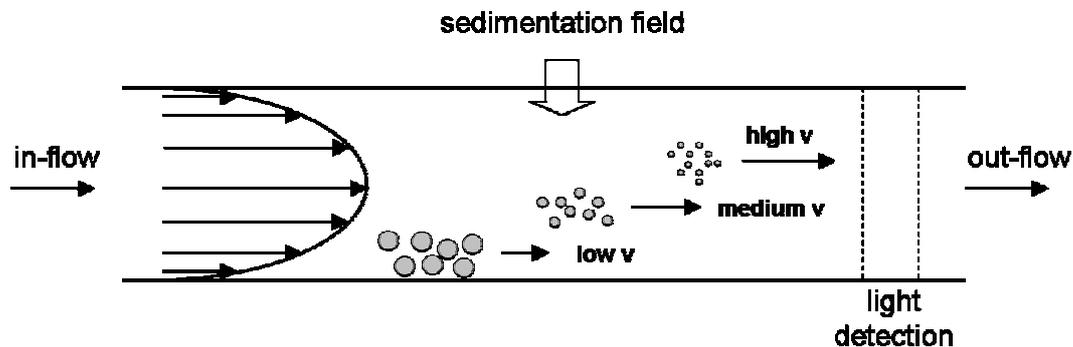
Disadvantages

- Aqueous emulsifier medium only.
- Very poor resolution; narrow families must differ in diameter by >40 % to be physically separated in the capillary (mathematical enhancement of the original distribution improves resolution to ~10%-15%, but adds uncertainty to the results - artefact peaks generated by the enhancement process are sometimes a problem).
- Capillary plugging is a common problem.
- Non-spherical particles may not be correctly measured.

9. Separation Methods: Sedimentation Field Flow Fractionation (SF³)

An SF³ instrument consists of a rotating disc that has a closed flow chamber located near the outside edge of the disc. This flow chamber has a cross section of ~1 - 3 mm × several mm, resembling a hollow belt strapped around the rotating disc. Fluid is continuously pumped through the flow chamber while the disc is spinning at up to several thousand RPM.

A sample run begins with the disc spinning at the highest speed. The rotational rate is gradually reduced during the run. At the start of a run, a suspension of particles is injected into the fluid stream by means of a syringe. The particles are driven by g-force toward the outside edge of the flow chamber (if higher in density than the fluid), or toward the inside edge of the chamber (if lower in density than the fluid). Large particles are effectively “pinned” against the chamber wall by g-force, and initially make little or no progress along the length of the chamber. Small particles (with greater Brownian motion) form a “cloud” of particles that hovers above the chamber wall. The smaller the particles, the higher the Brownian cloud. The liquid velocity profile inside the chamber is parabolic (just as in CHDF), so smaller particles spend more time in the higher velocity portions of the flow, and make faster progress (on average) along the length of chamber, exiting the chamber first (just the opposite of CHDF). As the speed of rotation falls, the g-forces fall as well, allowing larger and larger particles to spend time away from the chamber wall, and thus moving along the length of the chamber. There is a “transition” point where the g-forces become low enough that large particles (those too big to have significant Brownian motion) essentially “roll” or “slide” down the length of the chamber due to the lateral hydraulic force applied by the fluid flow. After this transition point is passed, larger particles move faster than smaller particles, because their centers are located at higher flow velocity than smaller particles (the same as CHDF). Particles are detected in the liquid flow leaving the chamber with a light, ultraviolet, or other detector.



Schematic representation of the Sedimentation Field Flow Fractionation technique. Horizontal arrows represent the velocity parabolic profile.

Advantages

- Broad dynamic range (especially if both “Brownian” and “rolling” modes are included).
- Very good resolution with small (< 3-5 μm) particles; narrow peaks as little as 5-6% different in size can be resolved.
- Performance easily verified with calibration standards.
- Only moderately dependent on particle geometry in “Brownian” mode.

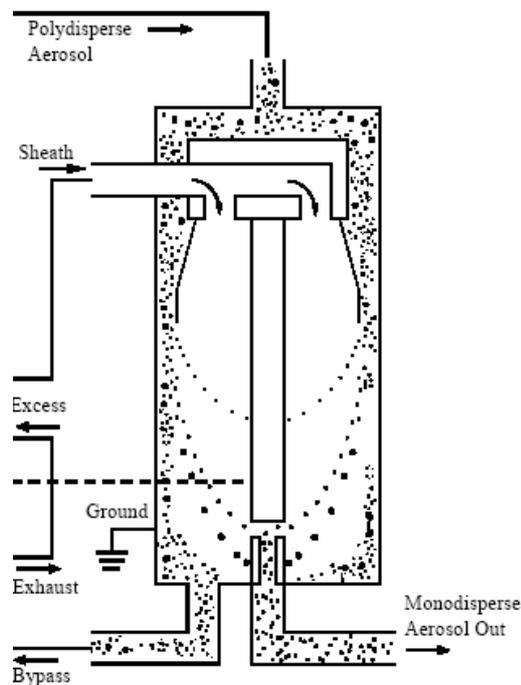
Disadvantages

- Extremely complicated algorithm for size separation, very difficult for many people to understand clearly; reduces confidence in the results.
- Complicated mechanical construction with critical high speed rotating seals; has a history of mechanical/maintenance problems.
- Relatively long run times, normally >1 hour.
- Separation in the “rolling/sliding” mode would appear to be a very complicated function of both size and shape.

10. Separation Methods: Scanning Mobility Particle Analyzer (SMPS)

The Scanning Mobility Particle Sizer is based on the principle of mobility of a charged particle in an electric field. Particles entering the system are neutralized (using a radioactive source) such that they have a Fuchs equilibrium charge distribution (all particles are singly charged with an equal number of positively and negatively charged particles).

They enter then a Differential Mobility Analyser (DMA) where the aerosol is classified according to electrical mobility, with only particles of a narrow range of mobility exiting through the output slit. This monodisperse distribution then goes to a Condensation Particle Counter which determines the particle concentration at that size. The DMA consists of a cylinder, with a negatively charged rod at the center, the main flow through the DMA is particle free 'sheath' air. It is important that this flow is laminar. The particle flow is injected at the outside edge of the DMA, particles with a positive charge move across the sheath flow towards the central rod, at a rate determined by their electrical mobility. Particles of a given mobility exit through the sample slit at the top of the DMA, while all other particles exit with the exhaust flow. The size of particles exiting through the slit is determined by the particle concentration, charge, central rod voltage, and flow within the DMA. In the case of a scanning instrument, the voltage on the central rod is exponentially varied and a full particle size distribution is built up.



Schematic representation of the Scanning Mobility Particle Sizer.

Advantages

- This is the most widely used technique to measure particle size distribution of aerosols.
- The system integration enables users to measure particle size on-site, which is very interesting for aerosol characterization related to environmental issues.

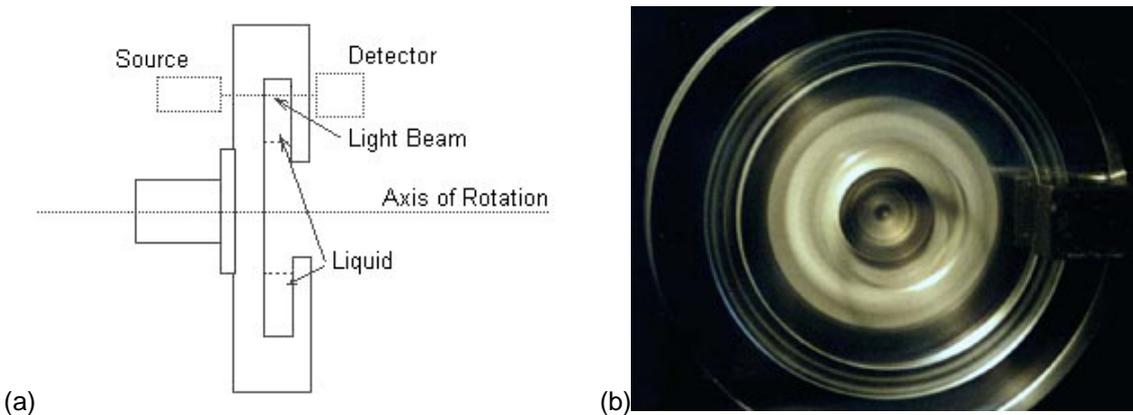
Disadvantages

- Can measure only aerosol sample usually from 2.5 to 1000 nm in size.

11. Separation Methods: Differential Sedimentation (Disc Centrifuge)

The disc centrifuge is a hollow, optically clear disc with a central opening on one side. The opposite side of the disc is centrally mounted on a drive shaft that rotates at a known speed, from ~600 - 900 RPM up to ~24,000 RPM. The empty spinning disc chamber is partly filled with liquid that is held against the outside edge of the chamber by centrifugal force, forming a ring inside the chamber. The liquid ring has a slight density gradient: the liquid at the outside edge of the ring is slightly denser than that near the inside edge.

A dilute sample (normally <1% solid content) is injected into the center of the disc at the start of analysis. The time for particles to reach the detector beam versus beam intensity is converted to a size distribution using both Stokes' Law (modified slightly for use in a centrifuge) and Mie theory light scattering calculations.



(a) Schematic representation of a disc centrifuge particle size analyzer and (b) photograph of running centrifuge test where the visible rings correspond to different particle size.

When centrifuge sedimentation is used Stokes' law must be modified to account for the variation in gravitational force with the distance from the center of rotation:

$$d = \sqrt{\frac{18\eta \ln(R_f / R_i)}{(\rho_p - \rho_f)\omega^2 t}} \tag{11}$$

where d is the diameter of the particle, η is the viscosity of the solvent, R_i and R_f are respectively the starting and ending radii of rotation, ρ_p and ρ_f are respectively the particle and fluid density, ω is the rotational speed and t is the arrival time for the particle from R_i to R_f .

It is important to note that when a sample of particles which are denser than the fluid in the column is placed on top of the column, the particles might not settle individually according to Stokes' Law. Instead, the entire sample suspension rapidly settles as a bulk fluid through the liquid column, in exactly the same way as a homogeneous liquid of higher density (like 10% sodium chloride in water) would settle through a column of another liquid of lower density (like water). The bulk settling of a sample in disc centrifuge sedimentation is commonly called "streaming" or "sedimentation instability". To avoid "streaming", a slight concentration gradient is created in the rotating disc usually by using sucrose solution (in water suspensions). Density gradients of less than 0.01 g/mL per centimeter of fluid height are normally sufficient to insure complete stability.



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Advantages

- Extremely high resolution; narrow particle families < 5% different in diameter can be completely resolved, 2 % different partly resolved.
- Dynamic range up to 1000 or more with disc speed ramping during analysis.
- Size results can be corrected when the particle shape differs from a sphere.
- Easy to verify accuracy using calibration standards.
- Recently extended to allow measurement of low density particles.

Disadvantages

- Maximum dynamic range of ~75 when disc speed is fixed (not ramped during the analysis).
- Non-spherical particles are reported as smaller than correct unless the operating software accounts for particle shape; for example, rods three times as long as wide are reported ~8 % smaller than correct.
- Analysis times are long for very small particles (< 50 nm) with density close to the liquid density.
- Absolute weight accuracy of the distribution depends on knowing both optical properties and particle shape.