Partector Application: Fast wide range particle sizing

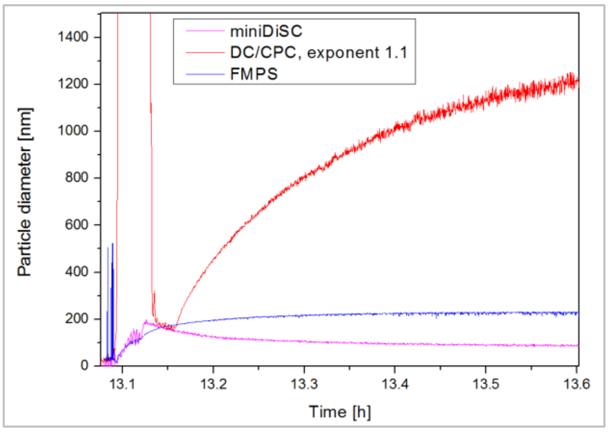
Summary: Size particles between 10nm and one micron by combining a partector with a CPC.

In aerosol science, typical particle sizes range from a few nm up to 10 micrometers, spanning over 3 orders of magnitude in size. This poses a lot of problems for aerosol detectors, as they should work over such a large size range – and in fact, most aerosol detectors only work in a limited size range. As a rule of thumb, optical particle counters can detect (and size and count) particles larger than about 300nm, but cannot see smaller particles; whereas electrical techniques can size and thus also "count" particles smaller than around a few hundred nm, where the upper limit depends on the technology used. For combinations of unipolar charging and mobility sizing, it is in the range of 200-300nm (e.g. the TSI FMPS, TSI nanoScan, Testo DiSCmini); the standard SMPS is limited by uncertainties due to multiple charging to particles smaller than about 1 micron.

The only instrument that can do fast wide range particle sizing is the Dekati ELPI, however, this is a large, complex instrument with a corresponding price tag.

A simple way of measuring average particle size is by combining a diffusion charger, such as the partector, with a CPC. The diffusion charger measures a signal that is approximately proportional to the particle diameter, or weighted with d^1. The CPC measures particle number, or a signal weighted with d^0. A simple division of the two signals therefore gives an approximate average particle size. Since both instruments are fast (second-by-second data), the sizing with this method is also fast. The method is limited to particles between about 10nm (where the sensitivity of the partector and the CPC drop rapidly) and about 10 micrometers (where particles are lost due to impaction at the inlet of the instruments).

The following figure shows an own experiment, where huge amounts of Cerium oxide particles were generated via flame spray pyrolysis in a fume hood, and then they grew rapidly by coagulation. Instruments used to measure the particles included the miniDiSC (Matter / Testo), the FMPS (TSI), a CPC (TSI). Looking at the particle diameter reported by the miniDiSC, it actually decreases over time, because larger particles are misclassified. The FMPS is doing slightly better, with particle diameter growing to 200nm and then stopping. The DC/CPC measurement reveals that the particles actually grow larger than 1 micron, and that the miniDiSC and FMPS misclassify the size massively. If you are wondering about the start: the CPC was unable to measure the extremely high concentrations, and before about 13.15h on the x-axis, it was in saturation, so no reliable diameter could be measured. Nevertheless, the DC/CPC method clearly outperforms traditional instruments if the particles to be measured transition from nm to µm.



Reference: Bukowiecki et al, J. Aerosol Sci, 33, 1139-1154 (2002).
http://dx.doi.org/10.1016/S0021-8502(02)00063-0

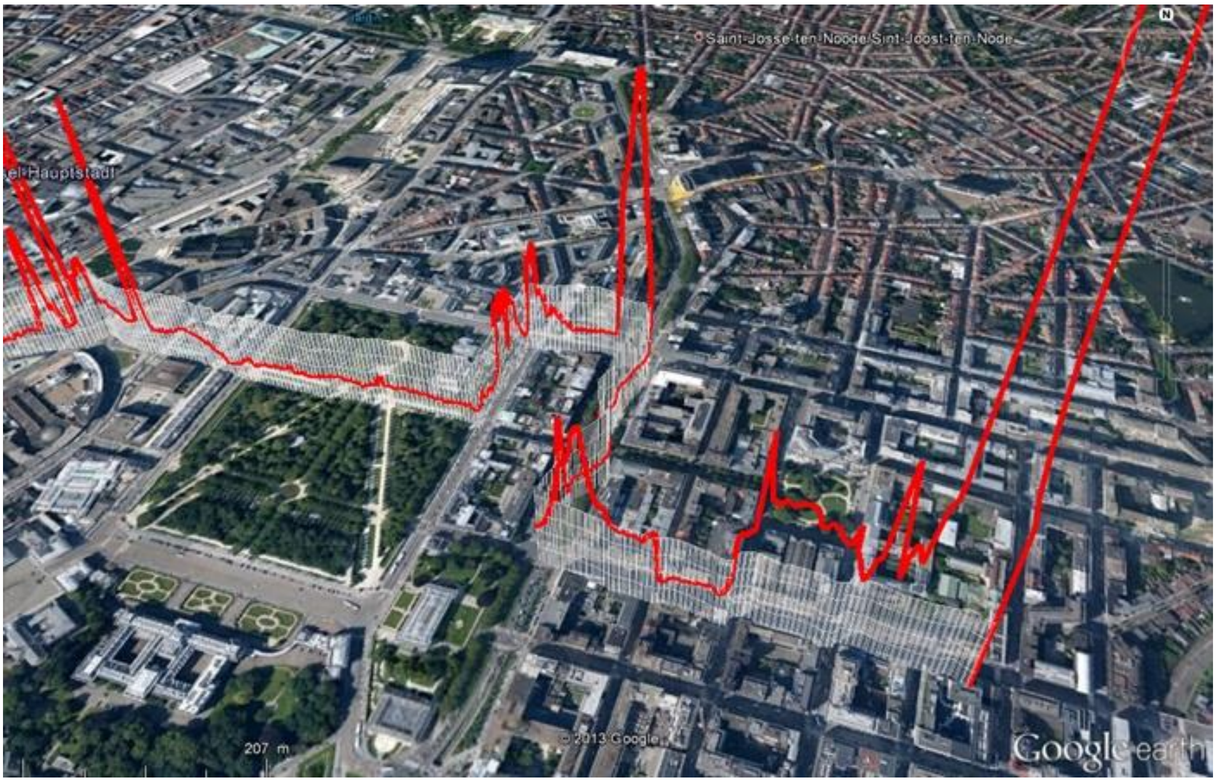
Partector Application: Monitoring personal exposure with GPS

Summary: Easily create maps with location and pollution data.

Due to its small size, low weight and long battery lifetime, the partector is well suited for mobile applications. One example is the monitoring of personal exposure. Traditionally, this is often done with filter-based samplers, where only a time-weighted average over e.g. a work shift or a couple of hours can be calculated in the end. The time and location of the exposure remains unknown. The partector on the other hand is a fast instrument (second-by-second data) that can be used to measure a time-resolved exposure. The bundled software makes it extremely easy to combine GPS data with the air pollution data:

1. Carry a GPS with you while measuring with the partector
2. Stop the GPS recording at the same time as the partector
3. Export the GPS data in the standard file format .gpx
4. Load both partector and GPS data in the java-based partector data analysis tool
5. Click “export KMZ file…” in the menu. The program will save the data file in Google Earth format and automatically open Google Earth for viewing it.

The image below is from a walk in Brussels. Note the high pollution levels along streets, and the much lower pollution level in the park.



Partector Application: mobile monitoring Network

Summary: Use multiple partectors on mobile platforms to create city-wide air pollution maps.

Traditionally, air pollution is measured at a few centralized stations containing a lot of very expensive equipment. This allows a very accurate determination of air pollution levels, but the pollution level is only known exactly at the station itself. Different pollutants have very different spatial variability – for example, PM10 (the mass of particles smaller than 10 micrometers) is usually fairly constant throughout a city. Therefore, a single point measurement gives a good estimate of the pollutant in the entire city.

Other particle metrics, such as particle number or particle surface area are dominated by local sources, mostly traffic. Therefore, they show a much larger variability over a city, and measuring them at a single point only is insufficient to characterize such pollutants. Many researchers have tried implementing urban air quality monitoring networks with many sensor nodes. The sensors can be stationary or mobile. For mobile sensors, mounted e.g. on public transport, the sensors must be fast so that their temporal resolution translates into a good spatial resolution on the mobile platform. The partector has been applied successfully by a team at EPFL for monitoring the air quality in Lausanne. The instruments are mounted on buses of the public transport. Data is transmitted via mobile phone network to a central server.

Partector Application: drone-based measurements

Summary: Due to its light weight, the partector can be used on drones

Aerosol instrumentation is often stationary and heavy, and well suited for the lab, but less for fieldwork. The partector is miniature, easy to use and light-weight. At only 400g, it is one of the lightest nanoparticle detectors available today. This makes it an ideal choice when nanoparticles should be measured with drones, where every gram of payload counts.

One of our customers was interested in the 3-dimensional particle distribution around a highway, and mounted a partector on a drone. The drone flew predefined patterns over the highway for an entire day, thus creating a 3D, temporally resolved profile of the pollution plume created by the traffic on the highway.

Similar applications may include the measurement of nanoparticle distributions in street canyons.

Partector Application: measuring DPF integrity

Summary: The integrity of Diesel particle filters (DPFs) can easily be measured at idle with the partector

Diesel particle filters are extremely efficient at removing the cancerogenic soot particles from the engine exhaust. Unfortunately, these filters may develop cracks, and lose their function. Up to now, it is rather hard to detect broken filters with a simple measurement due to the complexity of sampling and conditioning engine exhaust. The recent realization that the DPF integrity can be simply tested at "low idle" (i.e. with the engine just idling, without pressing the gas pedal) has changed this. At low idle, Diesel engines have a large air to fuel ratio so that there is no need for exhaust conditioning. A group of TNO has shown that handheld CPCs can be used to measure DPF integrity, and we have recently demonstrated that the partector is even more suitable for this application.

For detailed information on this application, see our poster of the 2017 ETH nanoparticle conference:

http://www.nanoparticles.ch/archive/2017_Fierz_PO.pdf

Partector Application: permanent workplace monitoring

Summary: Due to its high reliability, the partector can monitor air quality in nanoparticle production or processing workplaces.

Engineered nanoparticles are finding ever wider applications, and are therefore becoming increasingly common in workplaces. The persons producing or handling such particles need to be protected from adverse health effects – the infamous case of Asbestos comes to mind. Of course, there are many approaches for the safe handling of nanoparticles in workplaces, such as local ventilation and protective gear for workers. Nevertheless, it is nice to know whether or not any nanoparticles are inadvertently being released, and for this a nanoparticle detector is necessary. There are many nanoparticle detectors available, with many different operating principles. Two commonly used instruments are the condensation particle counter (CPC) and optical particle counters (OPC). The CPC is extremely sensitive and can detect particles as small as 2-3nm, but it is expensive and needs to continuously be supplied with a working fluid, leading to a high total cost of ownership. The OPC is much simpler and more reliable but is typically unable to detect particles smaller than around 300nm. It is a great tool to measure microparticles or large nanoparticles, but when working with smaller nanoparticles with sizes of 100nm or below, a different instrument is necessary.

The partector is somewhere in between these two devices in terms of sensitivity, and may be used as a simpler-to-use tool than a CPC in workplaces where small nanoparticles may be present to monitor air quality. It is robust enough to run continuously for approximately 1 year, especially when only operated at 40-50 hours per week (worktime). One of our customers is using the partector in his nanoparticle production, to monitor the workplace for high concentrations due to a leak in the apparatus where the nanoparticles are produced.

Partector Application: workplace safety in laser cutting

Summary: the partector was used to determine when it is safe to open laser cutting machines

Industrial lasers can be used to cut or otherwise process nearly any material. The laser cutting process generates enormous amounts of nanoparticles, and, since lasers are often used to process metals, these particles are probably quite unhealthy. Therefore, laser cutting machines are usually enclosed, and local ventilation with filters is used to clean the air full of the metal nanoparticles before it is exhausted into the workplace again. Despite the ventilation, the entire space of the laser cutting machine is full of nanoparticles just after the cutting process has finished. It takes some time until the nanoparticles have been removed by the ventilation. Therefore, the machine operator should wait some time before opening the machine when processing is done. Unfortunately, he does not know how long he should wait. A too short wait may pose a health hazard, while a too long wait will reduce productivity.

One of our customers used the partector to determine how fast concentrations go down inside the machine – under different ventilation conditions, with different types of materials being processed etc.

As a result, the customer now knows how long to wait before opening his laser cutting machine.

Partector Application: Emissions from 3D-Printing

Within the EU Project "DIMAP" (digital materials for 3D-Printing), the partector was used to measure nanoparticle emissions from 3D-printing processes.

Source/Image: http://www.dimap-project.eu/fileadmin/introduction/downloads/DIMAP_Flyer.pdf

Figure 2A: Partector – Nanoparticle Dosimeter, Source : naneos

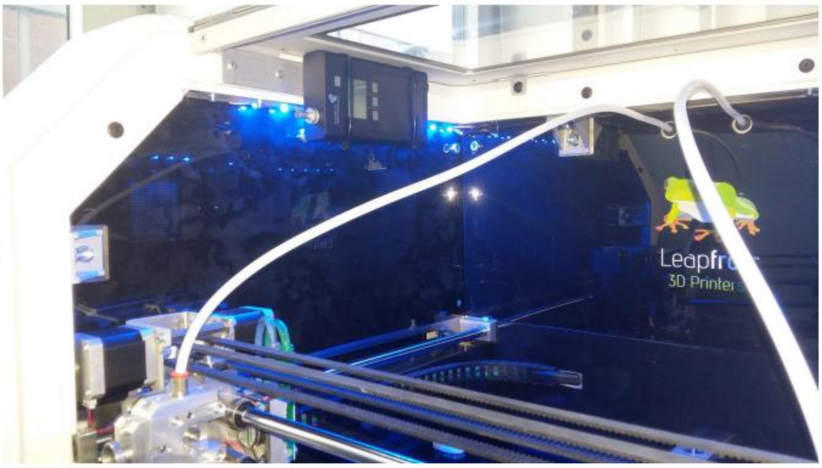
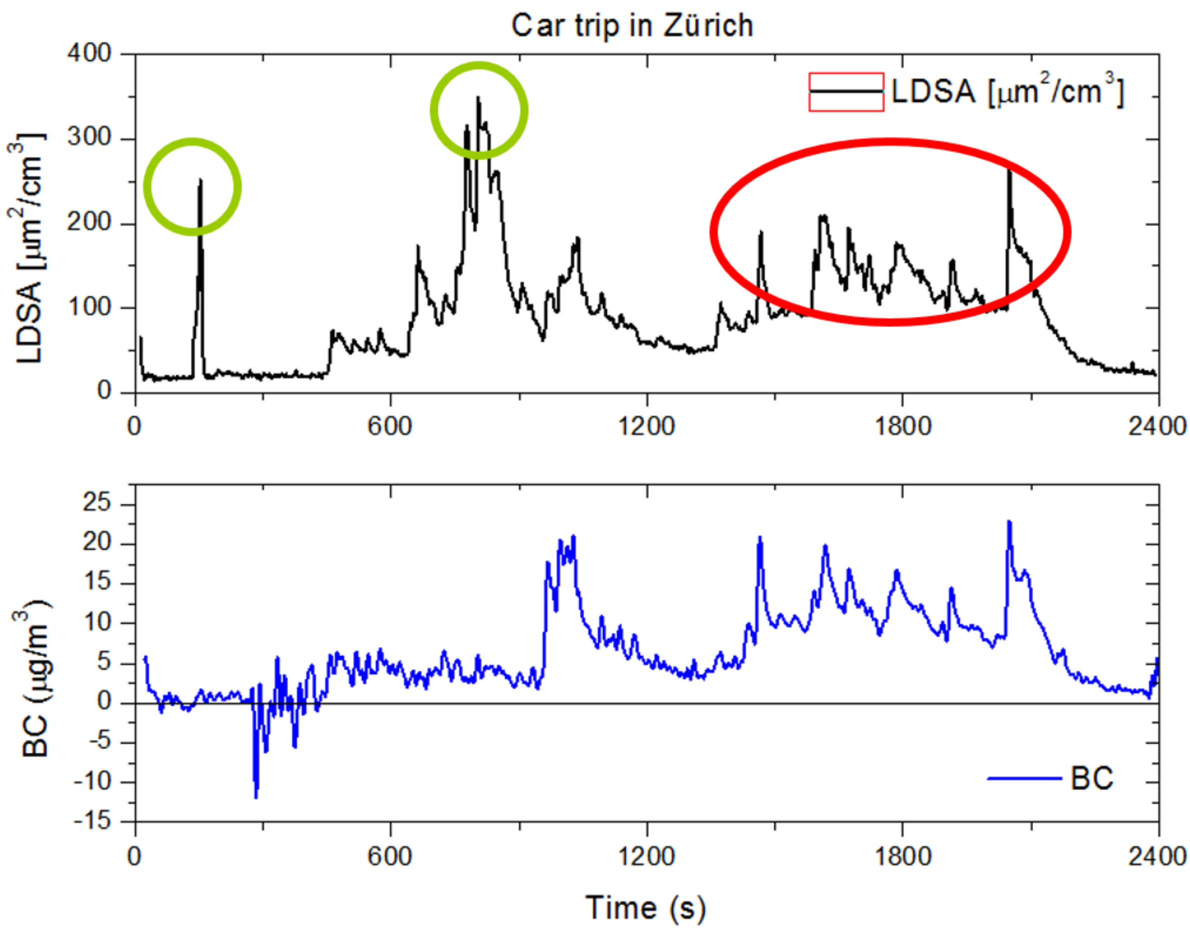


Figure 2B: partector working inside a 3D printer @ KIT

Partector Application: combination with the microAeth

Summary: 1 + 1 = 3 – the combination of the partector with the micro-Aethalometer allows a coarse chemical characterization of an aerosol.

The partector is a miniature, lightweight, battery-operated instrument for measuring nanoparticles. It does not discriminate between different particles. The micro-Aethalometer is another miniature, lightweight and battery operated instrument, which measures light transmission through a filter sample. Due to its operating principle, it is sensitive to any material that blocks the light transmission, i.e. mainly to black material, and the most important of these is black carbon (BC), or soot, from combustion processes. Since the partector is unspecific, and measures all particles, while the micro-Aethalometer is specific to one of the most important traffic pollutants, the two can be combined to gather more information on an aerosol than what could be learned from each instrument individually. Since both instruments are very small and light, they can easily be carried by a person. The following graph shows a personal exposure measurement during a car trip with the two devices.



Both instruments record a time series of the pollutant measured, which is interesting in itself. However, looking at the differences and similarities of the time series gives additional information: the two peaks in the partector data circled in green have no correspondence in the micro-Aethalometer data. Therefore, these cannot have been soot particles. The peaks in the second half of the measurement, circled in red, have a perfect correspondence to the Aethalometer data, suggesting that these were indeed soot particles.

Partector Theory: Occupational exposure limits for LDSA

Summary: translate occupational exposure limits from mass/number to LDSA

Occupational exposure limits (OEL) for workplaces are usually given for particle mass, in the units of μg/m3 or μg/m3. From many toxicological studies, it appears that particle surface area is a better metric to determine biological activity of nanoparticles. Nevertheless, it would be nice if one could translate an existing, mass-based OEL to the reading of the partector, and this application note describes how this is possible. A recent paper made such a calculation for particle number [1]. The idea is as follows: One takes a mass-based limit and derives a number-based or LDSA-based limit by straightforward calculation of particle volume. Naturally, this approach needs an assumption on particle size or particle size distribution, and here, we use a particle diameter of 100nm as this is the upper limit of the rather arbitrary definition of what a nanoparticle is. We can thus calculate the particle mass concentration from a particle number concentration:

$$M = N \cdot \rho \cdot V = N \cdot \rho \cdot \frac{\pi}{6} d^3$$

And then we can solve for N

$$N = \frac{6}{\pi} \frac{M}{\rho \cdot d^3}$$

Substituting the following values: M = 0.1 mg/m^3, ρ = 6000 kg/m^3, d = 100nm, we arrive at N = 32'000 particles/cc. In the paper, the suggestion was made to use a value of 20'000 pt/cc for high-density particles (ρ > 6000 kg/m^3), and 40'000 pt/cc for low-density particles (ρ < 6000 kg/m^3). This distinction is somewhat arbitrary, but if we follow it nevertheless, we can translate the number concentration to LDSA value: at 100nm diameter, it takes about 225 particles/ccm to produce an LDSA value of 1 μm^2/cm^3. Therefore, the limit values for LDSA would be given as in the table below:

Mass-based limit value	Material density	Number-based limit	LDSA based limit
0.1 mg/m^3	> 6000 kg/m^3	20'000 pt/cm3	90 μm^2/cm^3
	< 6000 kg/m^3	40'000 pt/cm3	180 μm^2/cm^3

Looking at the above table, one might be inclined to suggest an OEL of 100 – 200 μm^2/cm^3. Whether or not such a limit value is sensible is an interesting question, but in any case, it is possible to suggest LDSA-based limit values based on existing mass- or number based OELs.

[1] Van Broekhizen & Dorbeck-Jung (2013), Journal of Occupational and Environmental Hygiene, 10:1, 46-53 (2013).

Partector Theory: the biological relevance of surface area

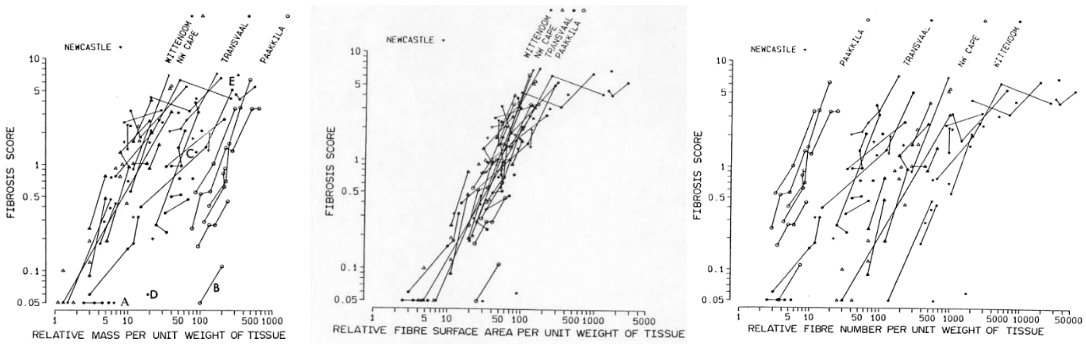
Summary: Interaction of the body with nanoparticles takes place at the particle surface. Even for asbestos fibers, it is documented that biological effects scale with surface area.

When considering different metrics to measure exposure to nanoparticles, the most common ones used are particle mass with either a 10 or a 2.5 μm cutoff – PM10 and PM2.5. Mass-based limits exist for ambient air and also for workplaces. Another metric that has found its way into legislation is particle number, which is for example measured in type approval for cars in the EU, and which is also used for the most deadly particle in human history, asbestos fibers.

The partector measures lung-deposited surface area (LDSA), a metric which is not regulated anywhere. Nevertheless, there are good reasons to use this metric: From a mechanistic point of view, it is clear that an ingested or inhaled particle will interact with the body on its surface, i.e. the potential for interaction, and thus also for adverse effects, scales with the particle surface area. Nanoparticles can also serve as a vehicle to transport toxic substances into the human lung. For example, carcinogenic polyaromatic hydrocarbons (PAH), form in all combustion processes and then condense onto existing soot particles, and coat their surface. The soot particles are inhaled and deposited in the lung, and the PAH can interact with the body. Again, from a mechanistic point of view, the amount of PAH transported is proportional to the particle surface area.

Besides these simple arguments for the relevance of particle surface area, there is an enormous amount of publications showing that particle surface area nearly always scales best with biological effects, better than particle mass and particle number.

Even for asbestos, where the according to the “fiber paradigm”, the number is measured rather than the mass, it is known that the damage done by these fibers scales best with their surface area. The following two graphs from [1] show this clearly:



Why, then, are people still measuring mass and numbers? This appears to be a question of history: the first particle measurements were made by sampling particles on filters, which were subsequently weighed. Later, reliable but cumbersome particle number counters (condensation particle counters) became available. Surface area instruments are still quite new, and it usually takes decades for a new metric to find its way into legislation.

[1] V. Timbrell et al. “Relationships between retained amphibole fibres and fibrosis in human lung tissue specimens.” Ann. Occup. Hyg 32, Suppl. 1:323-340