Comparison of different types of particle counters with aerosolized polystyrene reference particles

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Introduction and experimental set-up

In this study, four instruments consisting of one ELPI (Electric Low Pressure Impactor), one SMPS (Scanning Mobility Particle Sizer) and two LSAPCs (Light Scattering Airborne Particle Counters) have been intercompared by the use of polystyrene test aerosols. The instrument types involved use different physical principles to count the particles and determine their sizes, see figure 1. The ELPI counts and sizes particles according to the aerodynamic equivalent diameter, the SMPS sizes particles based on the electrical mobility diameter and counts using a condensation particle counter. The LSAPC uses light scattering for counting and sizing. In this study 6 different sizes of polystyrene reference particles were nebulized from a liquid suspension. The particle sizes investigated were 300 nm, 500 nm, 700 nm, 1000 nm, 2000 nm and 3000 nm, see table 1. For each particle size, aerosols were generated at three different concentrations, approximately 5 counts/ccm (low), 20 counts/ccm (medium) and above 80 counts/ccm (high). Each concentration was measured for 20 minutes by all four instruments simultaneously. As two of the instruments only have coarse sizing capabilities due to large binning, the focus of the analysis was to compare the counting efficiencies. At particle sizes above 1000 nm, the SMPS could no longer be applied, and one LSPAC saturated for high concentration aerosols. Up to a particle size of 1000 nm, however, all four instruments were able to measure the low and medium particle concentrations with a good agreement.

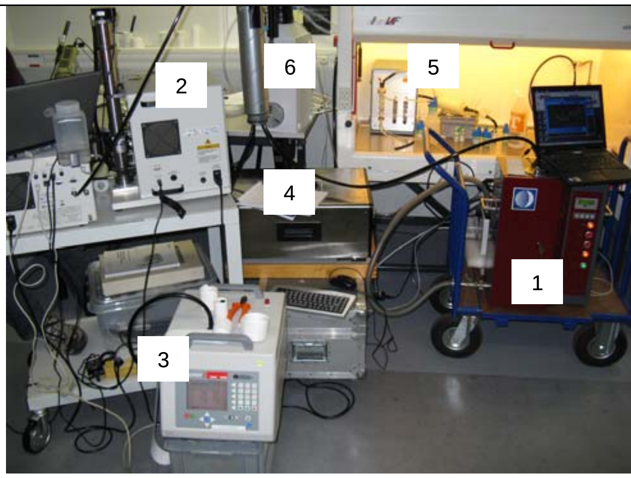

Figure 1: Instrumentation setup

Aerodynamic diameter:	(1) ELPI
Electric mobility diameter:	(2) SMPS
Optic scattering diameter:	(3) LASAIR II
	(4) LAS-X II
Aerosolgenerator:	(5) Nebulizer
	(6) Diluter

Reference particles
300 nm (Duke Scientific)
488 nm (Fluka)
707 nm (Duke Scientific)
992 nm (Fluka)
1840 nm (Fluka)
3090 nm (Fluka)

Table 1: List of used reference PSL spheres. The nominal average diameter is stated.

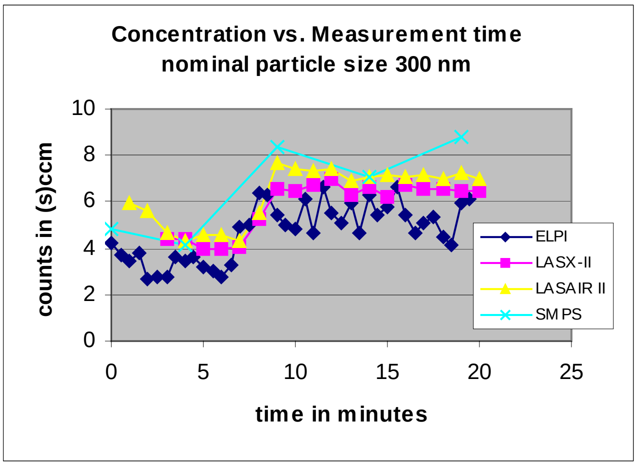

Figure 2: The concentration of an aerosol consisting of nominal 300 nm sized polystyrene particles measured by four different instruments simultaneously over a period of 20 minutes. A sudden uncontrolled change in the signature of the aerosol from the 7th minute is registered by all instruments simultaneously and at the same magnitude ratio.

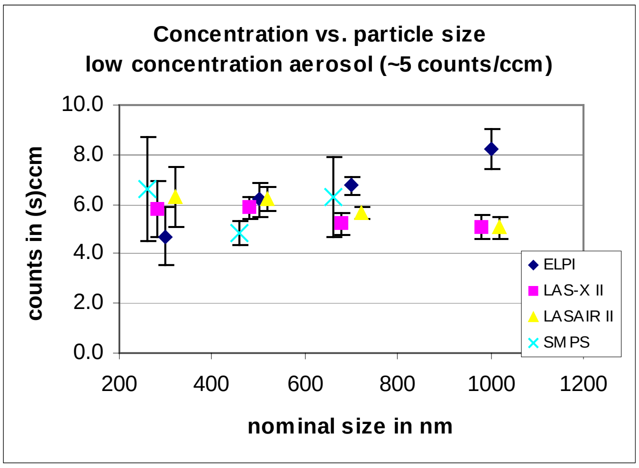

Figure 3: The average particle concentration per measurement interval of 20 minutes plotted versus the nominal particle size for nominal sizes 300 nm, 500 nm, 700 nm and 1000 nm. The error bars on the data dots for each instrument reflect the measured standard deviation of the concentration in the interval. For the small particle sizes, a good correlation is observed. Note that the data points are shifted slightly in x for better visibility.

Results

All instruments show the same signature of the particle concentration in the aerosol, as reflected from the example shown in figure 2 (300 nm particle size, low concentration). A sudden uncontrolled change of concentration in the generation of the reference aerosol is seen by all the instruments at the same time and to the same relative ratio. As shown in figure 3, the concentration average per instrument per particle size also agreed well within the individual standard deviations of the aerosol concentration. Figure 4 shows the problem when nebulizing large particles from a suspension. The surfactants that prevent the particles from agglutination in the suspension are also aerosolised and form a large amount of small particles below 500 nm. While the spectroscopic measurement of the LAS-X II clearly allows separating the PSL particles from the unwanted contamination, the large

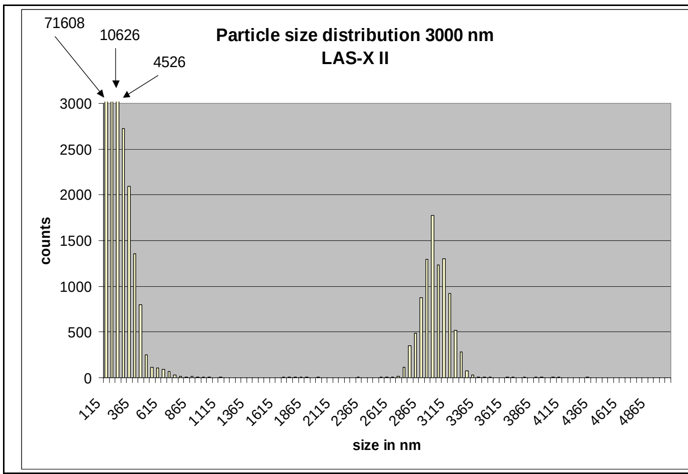

Figure 4: Nebulizing particle suspensions can cause contamination of the generated aerosol with unwanted particles from the suspension. Especially for suspensions with particles > 1 µm which contain a large amount of surfactants against agglutination, these surfactants form a main contribution of the particle contamination at sizes below 500 nm when nebulized.

amount of small particles often provokes coincidences or even causes saturation errors of the instrument's sensors. Therefore, only the LAS-X II and the ELPI were able to measure for high concentrations at particles sizes above 1 µm.

Regarding the determination of the size distribution of the aerosolised particles, an additional verification of the sizing capabilities of the SMPS and the spectroscopic LSAPC has shown good agreement on the measured size distribution for particle with an average diameter below 1 µm, see figure 5.

This work was supported by the The Danish Agency for Science, Technology and Innovation and Novo Nordisk in the national project "NaKIM": Nano- and microparticle characterisation, innovative application and environmental-friendly metrology.

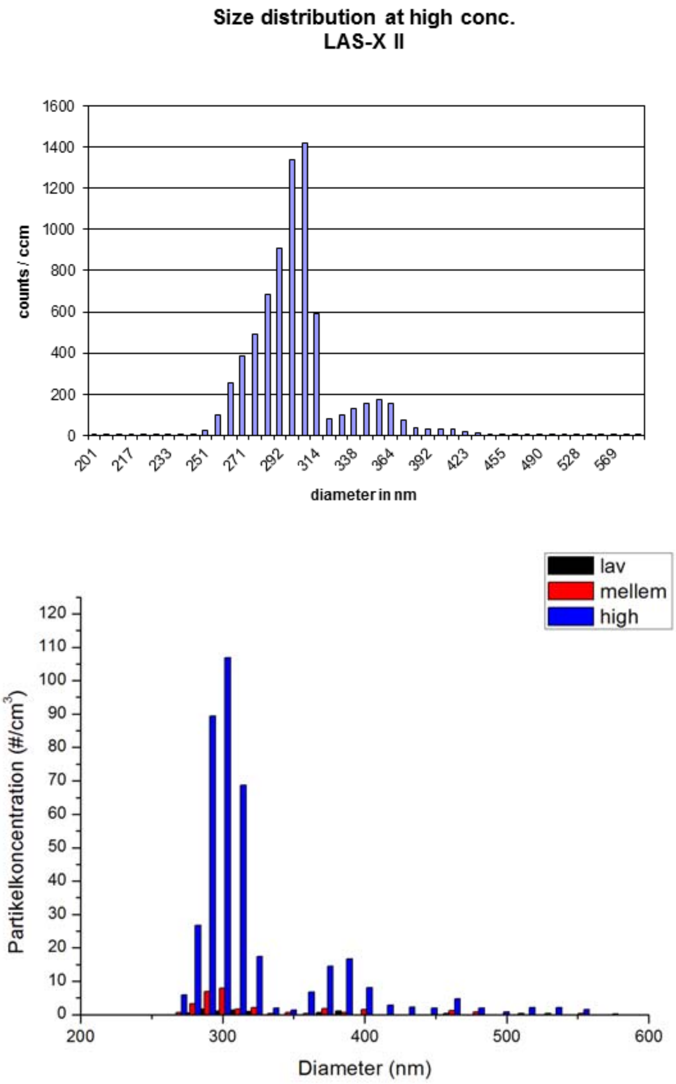

Figure 5: Good agreement between the particle size distributions as measured with the SMPS (above) and the spectroscopic LAS-X II. The scales of the x-axes are aligned. Note however, that the x-axis of the lower diagram are logarithmic caused by the sample setup.

Comparison of different types of particle counters with aerosolized polystyrene reference particles

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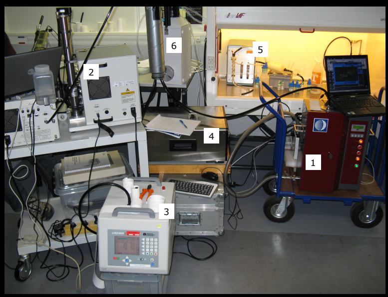
Introduction



In this study, four instruments consisting of one ELPI (Electric Low Pressure Impactor), one SMPS (Scanning Mobility Particle Sizer) and two LSAPCs (Light Scattering Airborne Particle Counters) have been intercompared by the use of polystyrene test aerosols. The instrument types involved use different physical principles to count the particles and determine their sizes. The ELPI counts and sizes particles according to the aerodynamic equivalent diameter, the SMPS sizes particles based on the electrical mobility diameter and counts using a condensation particle counter. The LSAPC uses light scattering for counting and sizing. In this study 6 different sizes of polystyrene reference particles were nebulized from a liquid suspension.

This work was supported by the The Danish Agency for Science, Technology and Innovation and Novo Nordisk in the project "NaKIM" : Nano- and microparticle characterisation, innovative application and environmental-friendly metrology.

Instrumentation:

Aerodynamic diameter:

(1) Electric Low Pressure Impactor (ELPI) – *Force Technologies*

Electric mobility diameter:

(2) Scanning Mobility Particle Sizer (SMPS) – *Teknologisk Institut*

Aerosolgenerator:

(5) Nebulizer: applied by Novo Nordisk

(6) Diluter: supplied by Lundbeck Pharma A/S

Optic diameter, light scattering:

(3) Light Scattering Airborne Particle Counter (LASAIR II) – *Novo Nordisk*

(4) Light Scattering Airborne Particle Counter (LAS-X II) – *Dansk Fundamental Metrology*

Experimental setup

The particle sizes investigated were 300 nm, 500 nm, 700 nm, 1000 nm, 2000 nm and 3000 nm. For each particle size, aerosols were generated at three different concentrations, approximately 5 counts/ccm (low), 20 counts/ccm (medium) and above 80 counts/ccm (high). Each concentration was measured for 20 minutes by all four instruments simultaneously. As two of the instruments only have coarse sizing capabilities due to large binning, the focus of the analysis was to compare the counting efficiencies. At particle sizes above 1000 nm, the SMPS could no longer be applied, and one LSPAC saturated for high concentration aerosols. Up to a particle size of 1000 nm, however, all four instruments were able to measure the low and medium particle concentrations with a good agreement.

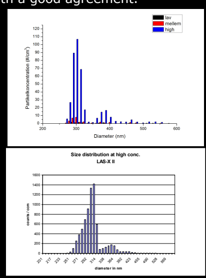
An additional verification of the sizing capabilities of the SMPS and the spectroscopic LSAPC has shown good agreement on the measured size distribution for particle with an average diameter below 1 µm, see to the right.

To the analogue circuit of the spetroscopic LSAPC, a high-speed 16 bit A/D converter was attached to monitor the sample-and-hold mechanism of the LSAPC's circuitry. The oversampling of the analogue sensor signal can be used to investigate the coincidence cases and verify the correct size conversion of the counter. The sample-and-hold circuitry take roughly 100 µs to perform the detection and conversion, while the applied A/D converter can monitor the signal with a 50 ns time resolution (20 MHz). One signal form is shown in figure 4 below.

Reference PSL spheres

Nominal average diameter

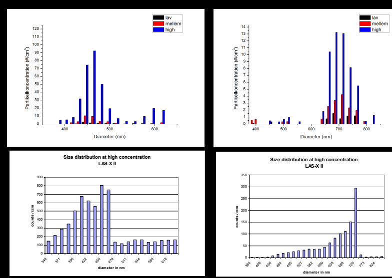
300 nm (Duke Scientific)
488 nm (Fluka)
707 nm (Duke Scientific)
992 nm (Fluka)
1840 nm (Fluka)
3090 nm (Fluka)



SMPS

Good agreement between the particle size distribution as measured with the SMPS (above) and the spectroscopic LSAPC. The scales of the x-axes are aligned. *Note that the x-axes in the lower diagrams are logarithmic caused by the sample setip.*

LAS-X II



Results

All instruments show the same signature of the particle concentration in the aerosol, as reflected from the example shown in figure 1 (300 nm particle size, low concentration). A sudden uncontrolled change of concentration in the generation of the reference aerosol is seen by all the instruments at the same time and to the same relative ratio. As shown in figure 2, the concentration average per instrument per particle size also agreed well within the individual standard deviations of the aerosol concentration. Figure 3 shows the problem when nebulizing large particles from a suspension. The surfactants that prevent the particles from agglutination in the suspension are also aerosolised and form a large amount small particles below 500 nm. While the spectroscopic measurement of the LAS-X II clearly allows to separate the PSL particles from the unwanted contamination, the large amount of smalll particles often provokes coincidences or even causes saturation errors of the instrument's sensors. Oversampling directly at the instruments analogue circuit can help identify cases of coincidence. Figure 4 shows the voltage generated by the sensor of a LSAPC a particle passes through the laser beam of the counter. Sampling the voltage with a faster speed than the sample-and-hold circuit of the instrument can potentially help to identify coincidences. An effective method for the removal or even avoidance of the contamination particles is required, however.

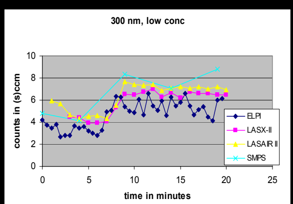


Figure 1.: The concentration of an aerosol consisting of nominal 300 nm sized polystyrene particles measured by four different instruments simultaneously over a period of 20 minutes. A sudden uncontrolled change in the signature of the aerosol concentration from the 7th minute is registered by all instruments simultaneously and at the same magnitude ratio.

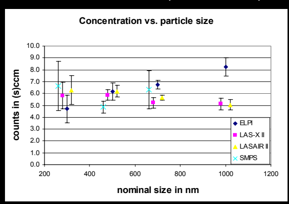


Figure 2.: The average particle concentration per measurement interval of 20 minutes plotted versus the nominal particle size for nominal sizes 300 nm, 500 nm, 700 nm and 1000 nm. The error bars on the data dots for each instrument reflect the measured standard deviation of the concentration in the interval. For the small particle sizes, a good agreement is observed. Note that the data points are shifted slightly in x for better visibility.

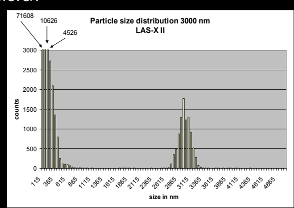


Figure 3.: Nebulizing particle suspensions can cause contamination of the generated aerosol with unwanted particles from the suspension. Especially for suspensions with particles > 1 µm which contain a large amount of surfactants against agglutination, these surfactants form a main contribution of the particle contamination at sizes below 500 nm when nebulized. The instrument sensors are often forced to saturation.

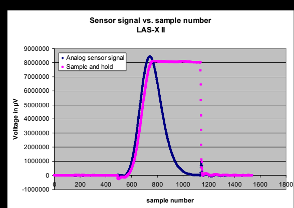
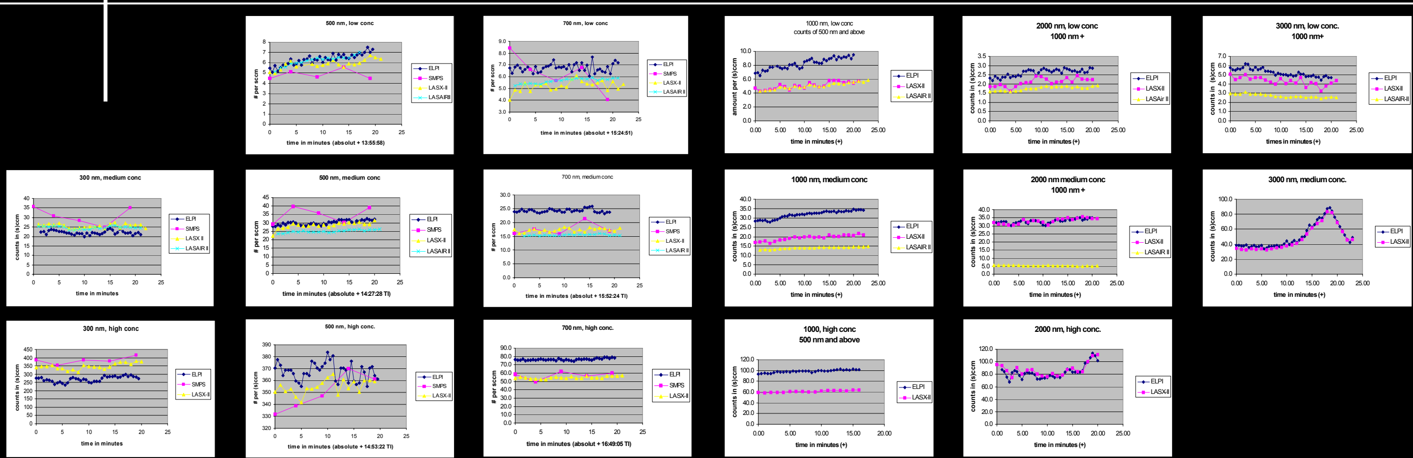


Figure 4.: One incidence of a particle spreading light to the sensor causes a voltage pulse of the sensor electronics (blue). This pulse is registered by the sample-and-hold circuit (purple signal). The sample-and-hold of the LSAPC has a temporal resolution of 100 µs, while the applied high-speed A/D circuit can register voltages with a temporal resolution of 50 ns (20 MHz sample frequence). Coincidences can be shown in this way.



All measurements performed sorted after particle size (horizontal) and particle concentration in the generated aerosol (vertical). The plot for 300 nm particles at low concentration is shown above, the plot for 3000 nm particles at high concentration is not shown as the instruments saturated. Some plot have less than 4 curves, as not all instruments could cope with the applied particles sizes (SMPS < 1 µm) or concentration (saturation).

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