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The electrical diffusion battery for dynamic classification of nanoparticles

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For dynamic measurements of particle emissions from combustion engines, a fast and continuous measurement of the size distribution is required. Typical time constants are of the order of one second. Commonly mobility analysis is used to determine size distributions in the range of interest for engine emissions, which extends from some nm to some hundred nm. Mobility analysis yields a high size resolution, however, it is a scanning technique which means it is not very fast. In its fastest implementation as Scanning Mobility Particle Sizer (SMPS) at least one minute is required to measure a size distribution.

For many applications the high size resolution is not required. As an example Fig. 1 shows the size distribution of particles in the exhaust of a diesel engine before and after a particle trap.

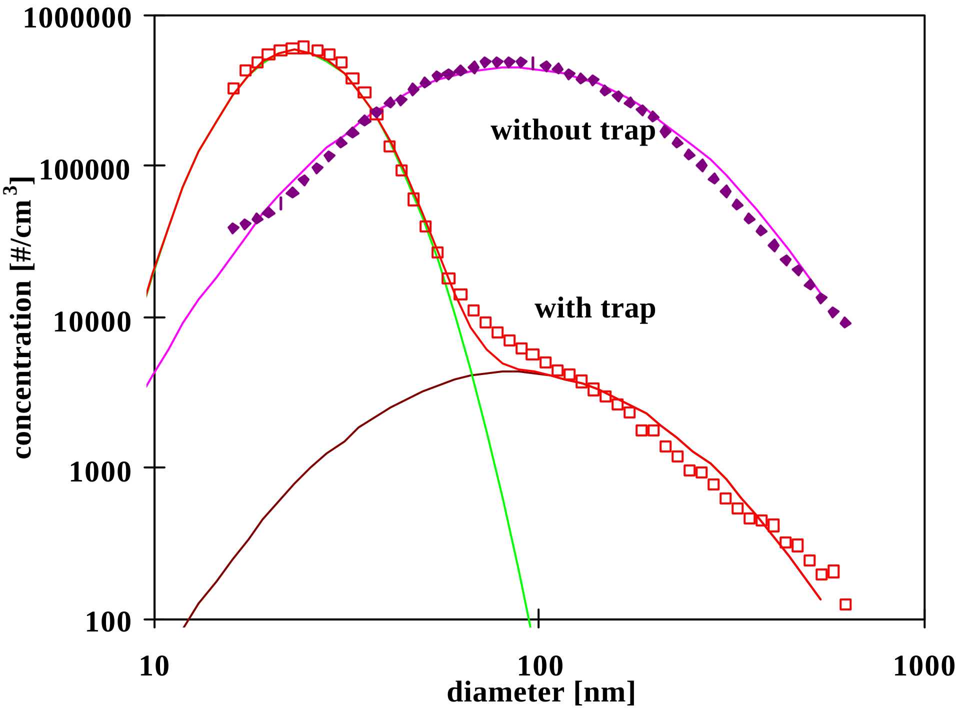

Fig. 1: Size distribution of particles in diesel exhaust, measured before and after a particle trap. The solid lines are a fit to the measured data by a uni- and bimodal log-normal distribution.

The engine is operated in a mode where formation of new particles by homogeneous condensation of volatile material takes place after the trap. The soot distribution before the trap can well be approximated by a unimodal log-normal distribution. After the trap a bimodal size distribution allows a good fit, the larger mode representing the soot, the smaller mode the newly formed condensation particles. Mean diameter and standard deviation of the soot mode before and after the trap are identical in Fig. 1, only the concentration has been changed. This shows that the size distribution can well be represented by a uni- or bimodal log-normal distribution. Figure 2 shows the same for a measurement with and without fuel additive. Again a good approximation by log-normal distribution is obtained. For the soot mode the same mean diameter and standard deviation as in Fig. 1 are used for the fit. To determine the parameters of the distribution much less information than obtained by mobility analysis is sufficient. Assuming some parameter to be constant, as in the previous examples mean size and standard deviation of the soot mode, even less information is needed.

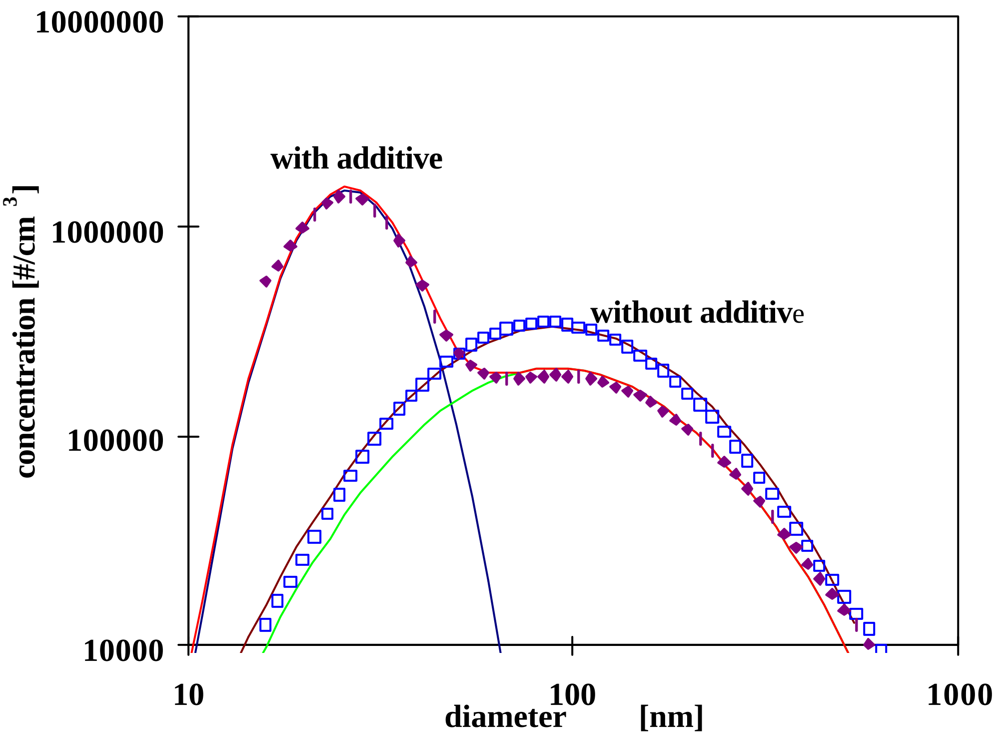

Fig. 2: Size distribution of particles in diesel exhaust with and without fuel additive. The solid lines are approximation of measured data by log-normal distributions.

The majority of particles in engine emissions exhibit sizes below 300 nm. To detect additive particles or particles arising from nucleation of volatile material, it is important to resolve the range below 50 nm.

Diffusion batteries (DB), classifying particles according to their mobility, are well suited to operate in this size range. In the well known cascade diffusion batteries the size is scanned by pneumatically switching from one stage to the next. The penetration of the DB is measured by measuring input and output concentration, for example by a condensation nucleus counter. Similar to scanning mobility analysis, this procedure does not allow a fast and continuous measurement. However, another type of diffusion battery allows one to directly measure the particles, precipitated in the different stages of the DB. This yields the size spectrum in a parallel measurement. The particles are charged by attachment of ions as shown and explained in Figure 3 before entering the DB. The charging efficiency (number of elementary charges per particle) versus particle size is plotted in Fig.4

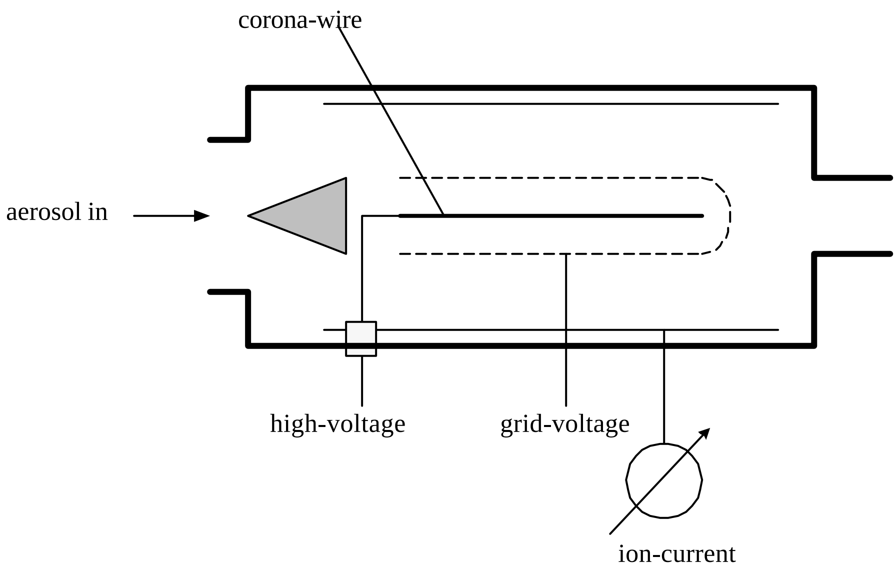

Fig. 3: Charging of particles by ion attachment. Ions are produced in a corona discharge at a thin wire. A grid screens the corona field to prevent small particles from being precipitated. The ion current can be measured or kept constant by a feedback control.

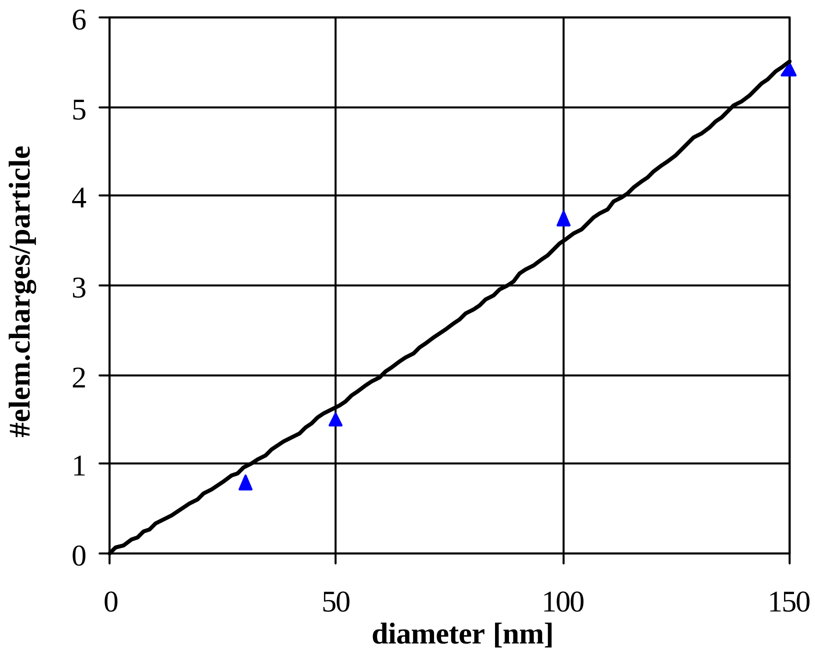

Fig 4: Charging efficiency as function of particle size. Monodisperse neutral particles are charged and measured by the backupfilter only. Their number concentration is determined by a condensation particle counter.

The stages of the DB are electrically isolated. Each stage is connected to a current amplifier. The measured current corresponds to the concentration of particles precipitated in each stage. The last stage is a backup filter where particles penetrating all stages of the DB are collected. The setup is shown in Fig. 5.

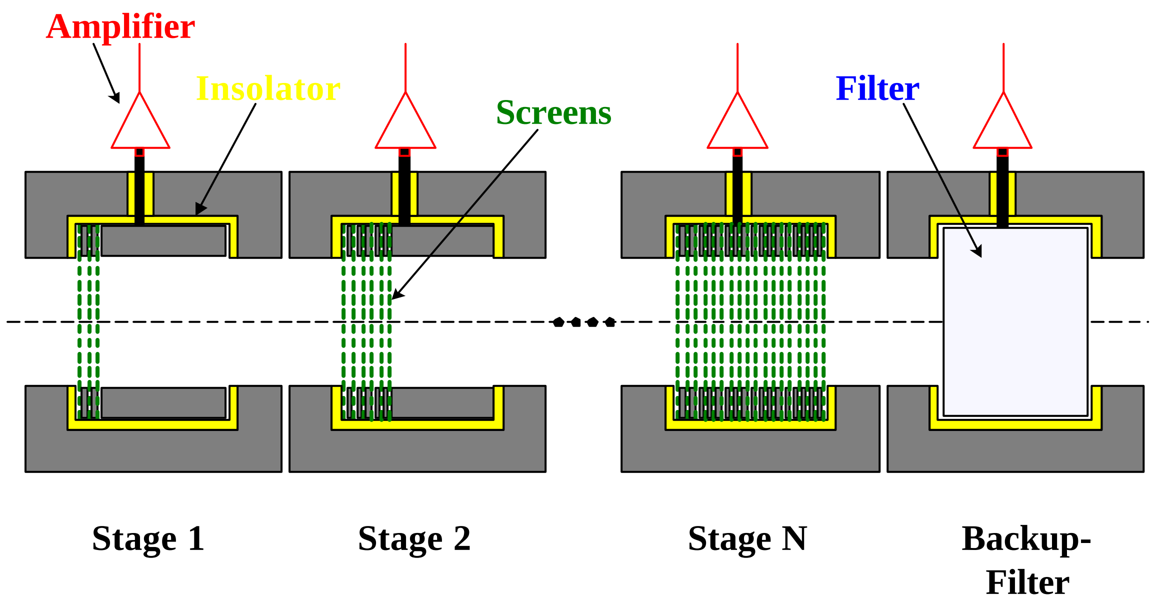

Fig. 5: Setup of the electrical diffusion battery. A PC-based data acquisition system, not shown here, is used to process the measured data.

A screen type DB is used. According to Scheibel and Porstendörfer (1984) the penetration of this DB is

$$P = \exp(-k \cdot n \cdot (\frac{Q}{D})^{-2/3}) \,, \qquad (1)$$

where k is a constant depending on the screen properties, n is the number of screens, Q the flow rate and D the particle diffusion constant.

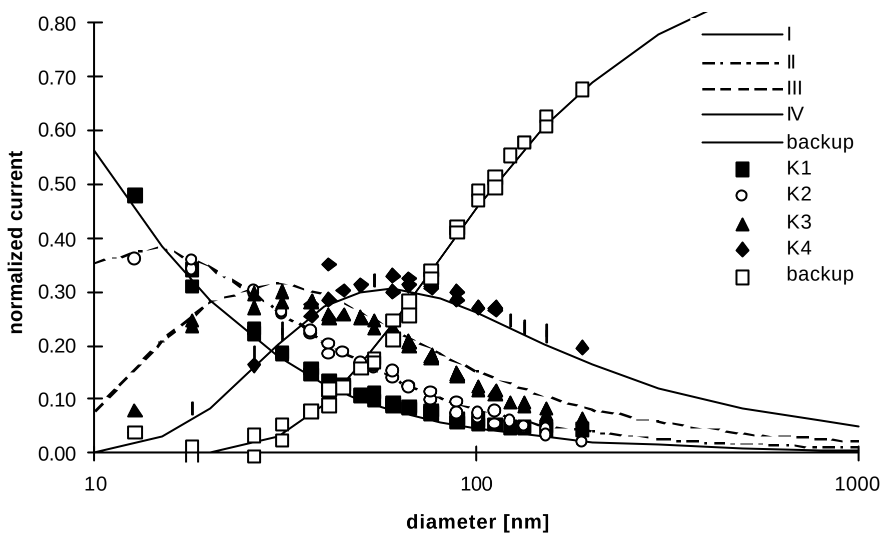

Fig 6: Normalized response of the electrical diffusion battery to monodisperse particles (NaCl particles) produced by a nebulizer and size-classified by a differential mobility analyzer). Lines: values calculated from eq. (1), dots: measured values.

Fig. 6 shows the normalized currents, measured for a DB with 4 stages (3, 6, 13 and 30 screens) plus backup filter. Monodisperse single charged NaCl particles, produced by a nebulizer and classified by a differential mobility analyzer, are used for this measurement. The solid lines in Fig. 6 are the results obtained from equation (1). This shows that the observed values agree very well with theory.
The significant overlap between the kernel functions of each stage requires adequate data inversion to obtain the size distribution from the measured data. An algorithm is currently developed. In parallel, test measurements with very high particle loading are performed to see if contamination problems occur.
Instead of charging the particles independently of their material properties by attachment of ions, it is also possible to charge them by uv-photoemissison (Burtscher and Siegmann, 1994). Photoelectric charging is efficient for soot particles, but inefficient for example for particles due to fuel additives or sulfuric acid droplets. Doing both ways in parallel leads to a setup shown in Fig. 7. This configuration allows one to obtain size resolved information on the particle composition. Additive particles or particles from condensation of volatile material, as shown in Fig. 1and Fig. 2 can then be very easily be distinguished from soot.

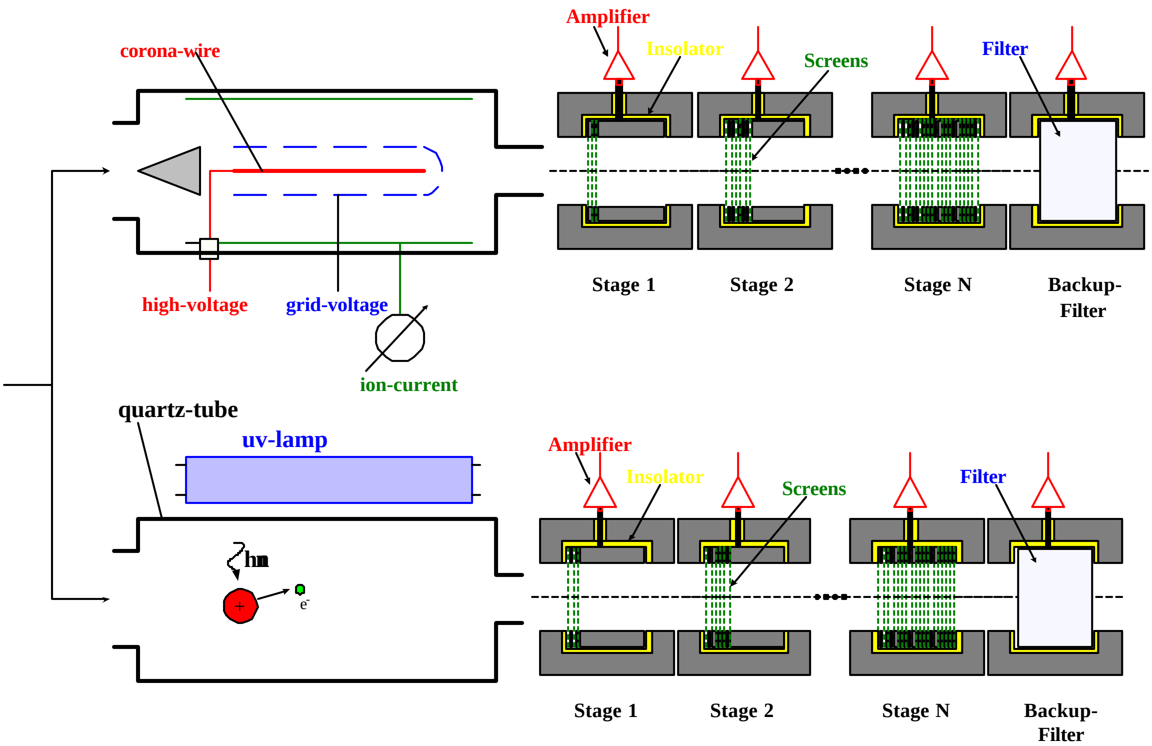

Fig. 7: Setup for the parallel measurement with photoelectric charging and charging by ion attachment.

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