Development of a portable instrument to determine the fractal dimension from angular light scattering measurements

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Black carbon is a major constituent of the atmospheric aerosols and has most of the time anthropogenic origin. It is produced during incomplete combustion processes, and forms usually fractal-like particles through aggregation. Fractal aggregates are scale invariant, which means that within limits they appear the same when viewed over a range of scales.

The angular light scattering of fractal aggregates depends on the wavelength of the incident light, the complex refractive index, the shape of the particle and the scattering angle. According to the scaling approach of angular light scattering by fractals from Sorensen and Oh (1998) the measured scattered light intensity as function of the magnitude of the scattering vector (q, proportional to the sinus of the half of the scattering angle) contains the information on the fractal dimension in the power law q regime.

At the University of Applied Sciences Northwestern Switzerland a portable instrument is being developed in order to measure the angular light scattering of aerosols. The goal is to be able to measure the scattering signal simultaneously at several angles and also to derive the fractal dimension of fractal-like soot particles. The aerosol is brought into a closed chamber where a laser diode illuminates the particles that can be found in the sampling volume. The scattered light is then detected by avalanche photodiodes at different angles. The cylindrical chamber has a diameter of 13 cm and therefore it is easy to transport and will be able to measure directly at the emission sources.

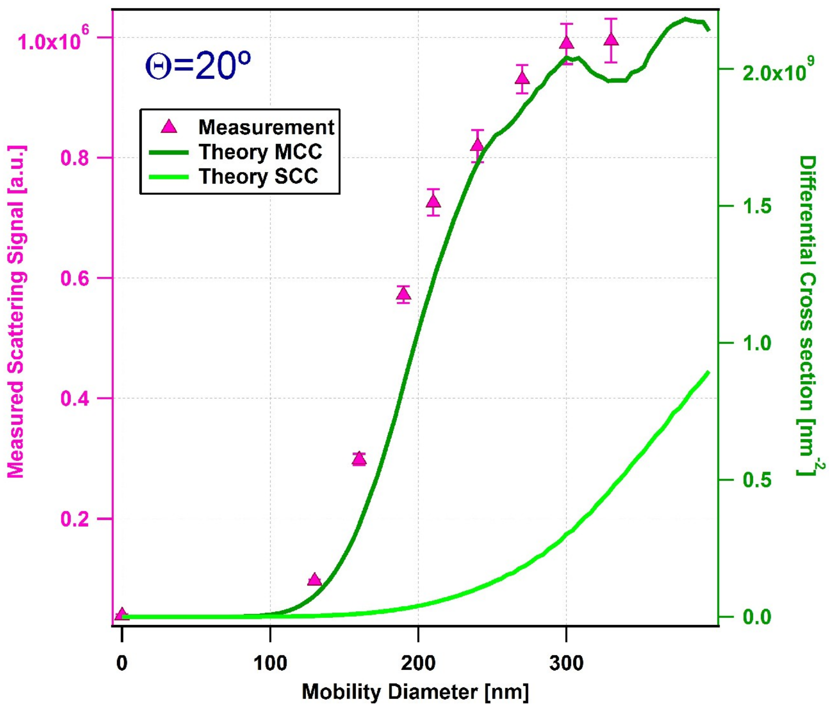

Figure 1. Calibration plot for a single scattering angle of 20 °

The first measurements aimed for the better understanding of the instrument's performance and for its calibration and therefore are performed using almost spherical salt particles. The nebulized salt particles were size selected by a differential mobility analyser (DMA) and with this a quasi monodisperse particle population entered the chamber. The number size distribution of the nebulized aerosol was paralelly measured. In Figure 1 a calibration plot is shown, measured at the scattering angle of 20 º. The theoretical calculations were done using Mie theory (Bohren and Huffmann, 2004), and it can be seen that it is not enough to consider only the single charged particles (SCC in Figure 1) correction for multiple charged particles (MCC in Figure 1) is necessary to capture the measured mobility diameter dependence of the scattering signal.

After calibration with spherical particles an aggregate test aerosol was chosen for further measurement. The multi-angle scattering signal from size-selected Aquadag (collection of small plate-like graphite fragments) was measured, and the fractal dimension of this material was determined from the measurements in the power law q regime.

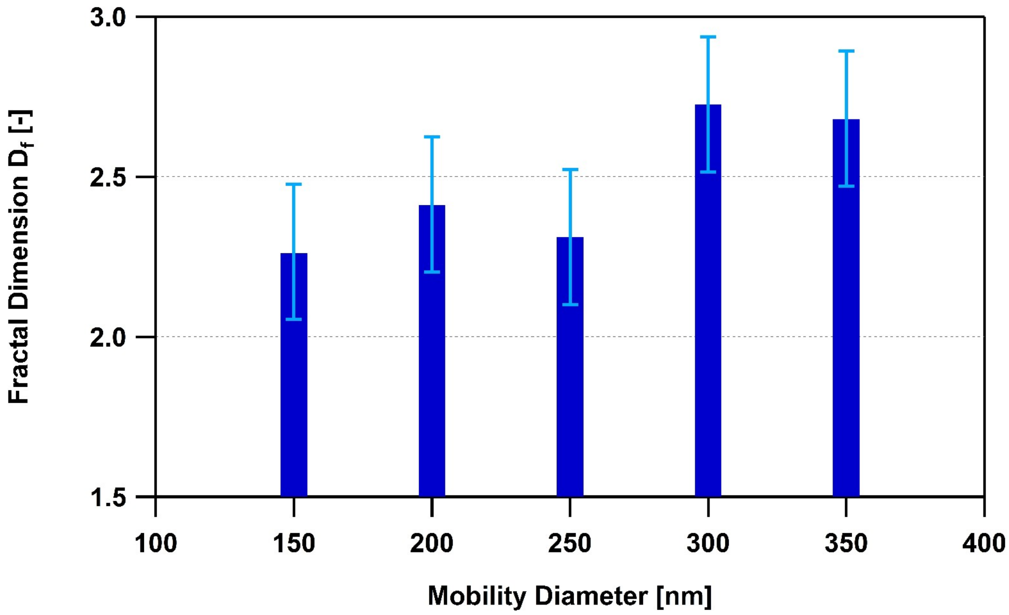

Figure 2. Fractal dimension of Aquadag particles derived from multi-angle scattering as function of the mobility diameter

The retrieved fractal dimensions (Figure 2) are in the expected range since the particles are compact aggregates with plate-like primary particles. Further tests will be conducted with particles with known fractal dimension and after complete characterisation of the instrument it will be ready for field deployment.

References:

Sorensen, C. M. and Oh, C. (1998) Phys. Rev. E 58, 4666–4672

Bohren C. and Huffman D. (2004) Absorption and Scattering of Light by Small Particles, Wiley-VCH.

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Introduction

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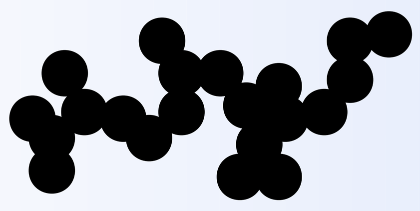
Fractal-like particles



$$N = k_0 (R_g / a)^{D_f}$$

- N number of monomers
- a radius of monomer
- R_g radius of gyration
- k_0 proportionality constant
- D_f fractal dimension

Scaling approach of angular light scattering of fractals

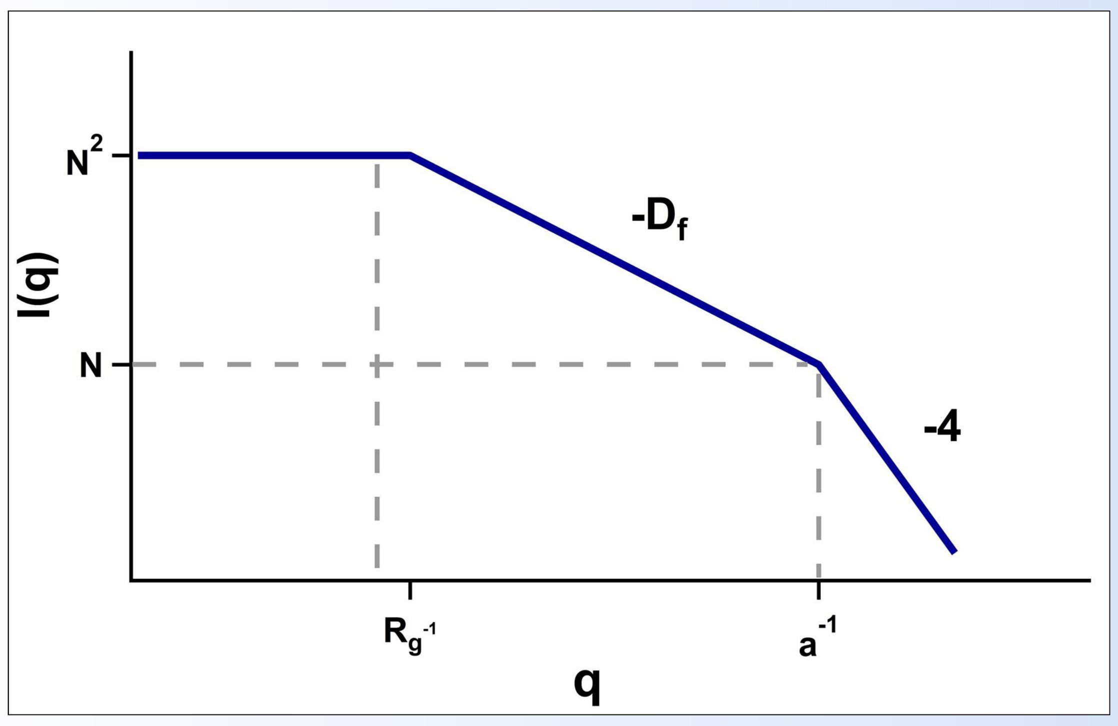


Figure 1. Logarithmic plot of the angular scattering intensity of fractal-like particles

Scaling approach from Sorensen and Oh (1998):

$$q = \frac{4\pi}{\lambda} \sin\left(\frac{\Theta}{2}\right)$$

the angular scattered light intensity as function of the magnitude of the scattering vector (q) contains the information on the fractal dimension in the power law q regime.

Measurement Setup

The scattering chamber

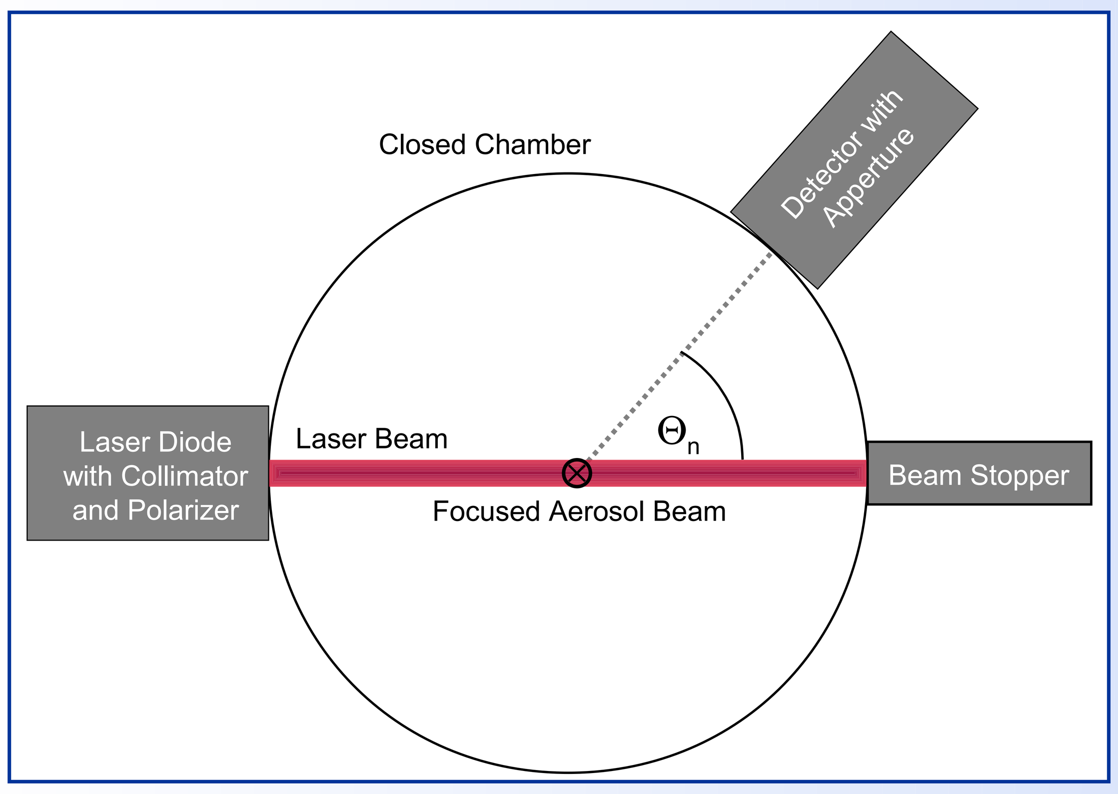
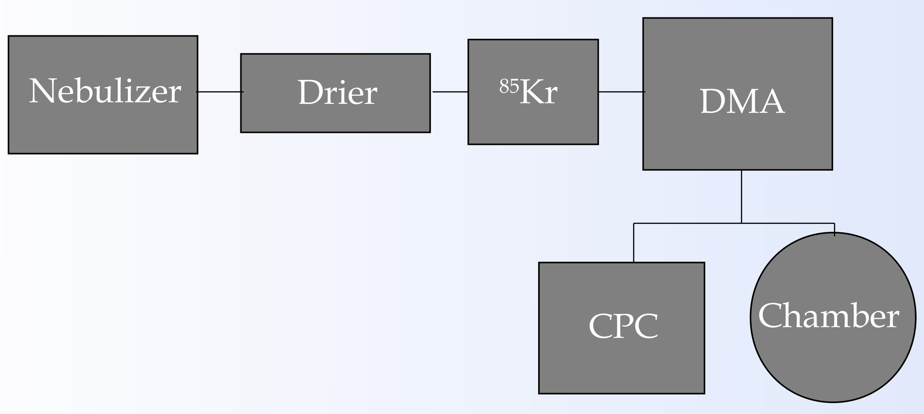


Figure 2. Schematic view of the portable, multi-angle light scattering chamber

- Sealed chamber with optical windows in front of the detectors
- 7 fixed scattering angles of 14°, 20°, 35°, 90°, 140°, 150° and 160°
- Adjustable and controlled laser power
- Portable: the chamber has a diameter of 13 cm

Measurement Setup during laboratory tests



- Nebulized salt or Aquadag
- Silica gel drier
- Size selection by a differential mobility analyser (DMA)
- Size distribution measurement with the DMA and CPC
- Angular light scattering properties

Results

Calibration with nebulized salt particles

- Using nebulized, monodisperse NaCl particles
- Theoretical values are calculated using Mie theory (Bohren and Huffmann, 2004)
- Separate calibration line is determined for every single angle

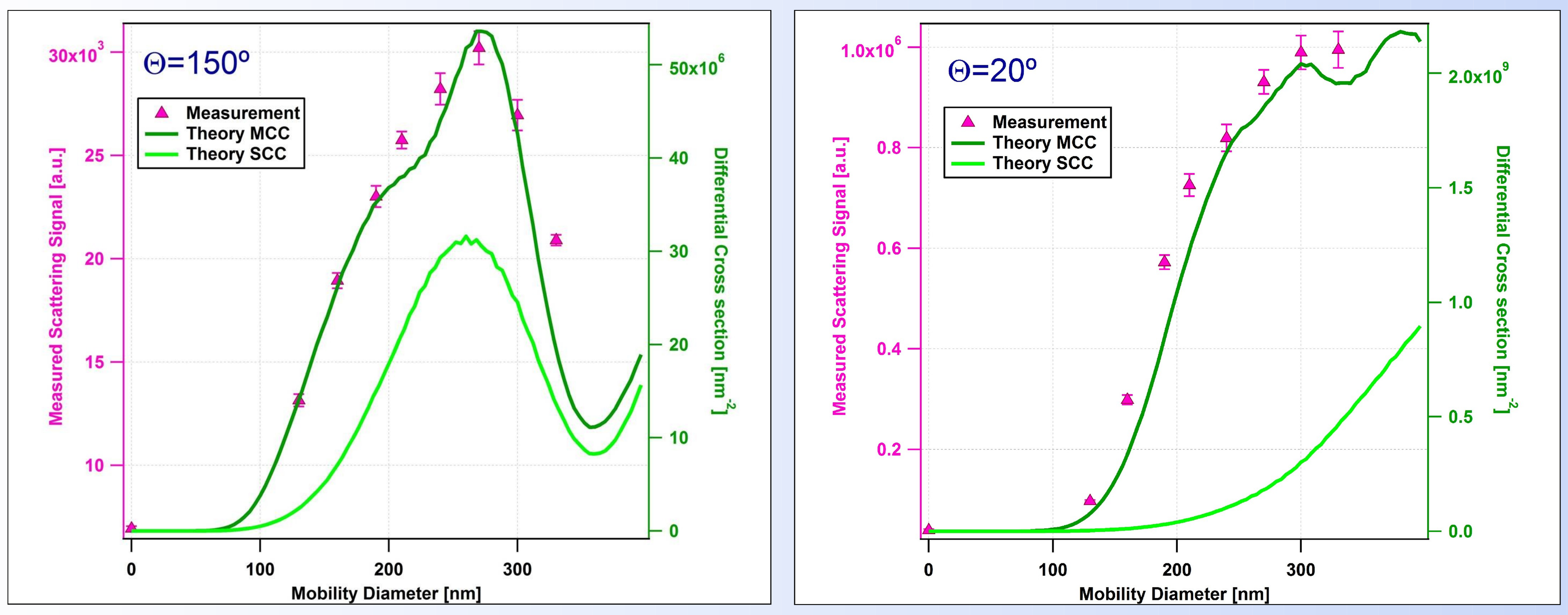


Figure 3. Calibration plots for two example scattering angles, the theoretical values were calculated using Mie theory and correction for either single charged parties (SCC) or multiple charged particles (MCC)

Measurement with nebulized aquadag particles

- Aquadag is a collection of small plate-like graphite fragments
- Likely more compact than a plane and therefore $D_f > 2.0$

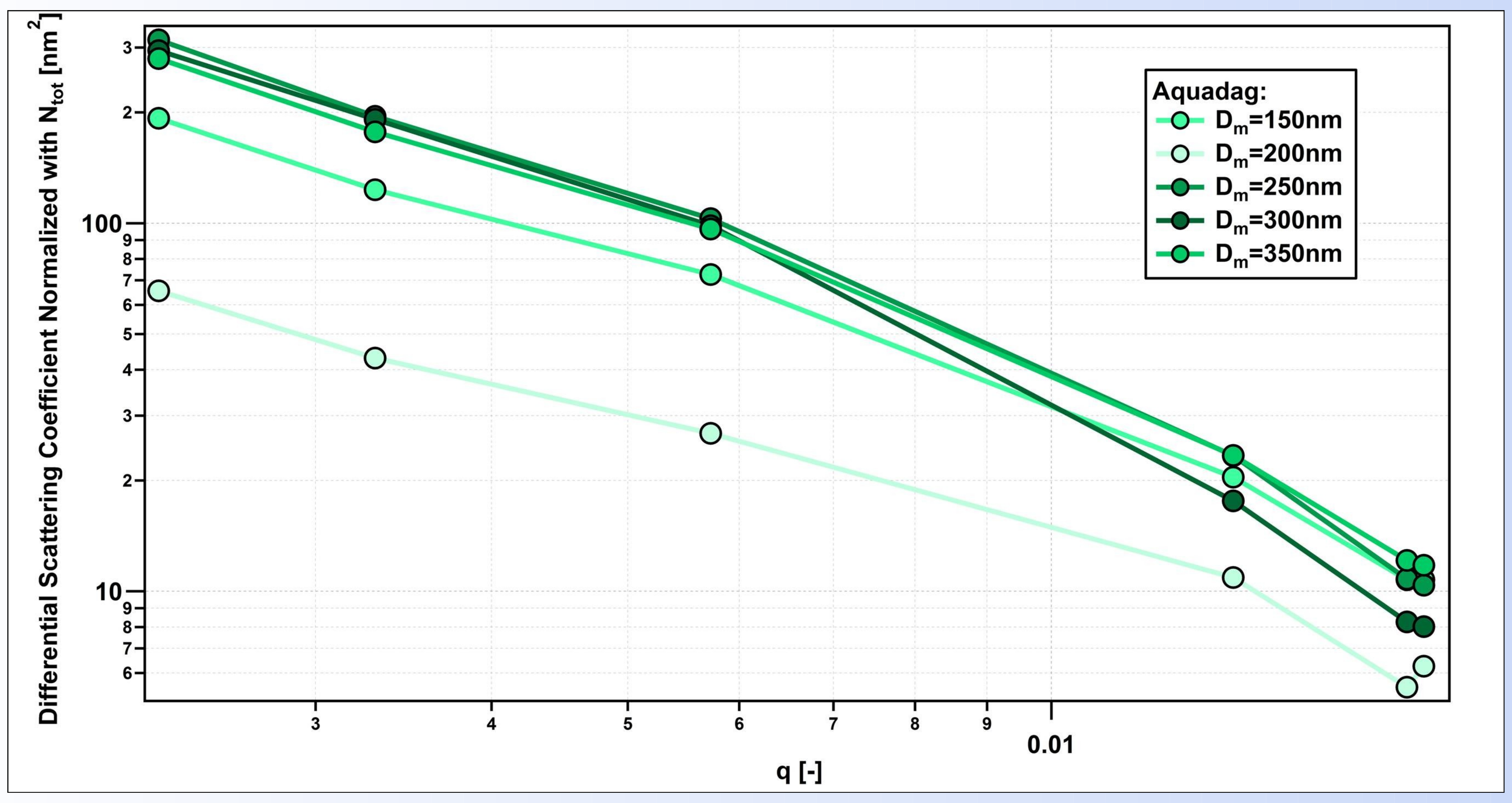


Figure 4. The measured angular scattering intensity for nebulized aquadag particles

Determination of the fractal dimension

- Using the scaling approach
- The slope of the scattered intensity is determined between 90 and 140 degrees (q of 0.0134 and 0.01789)

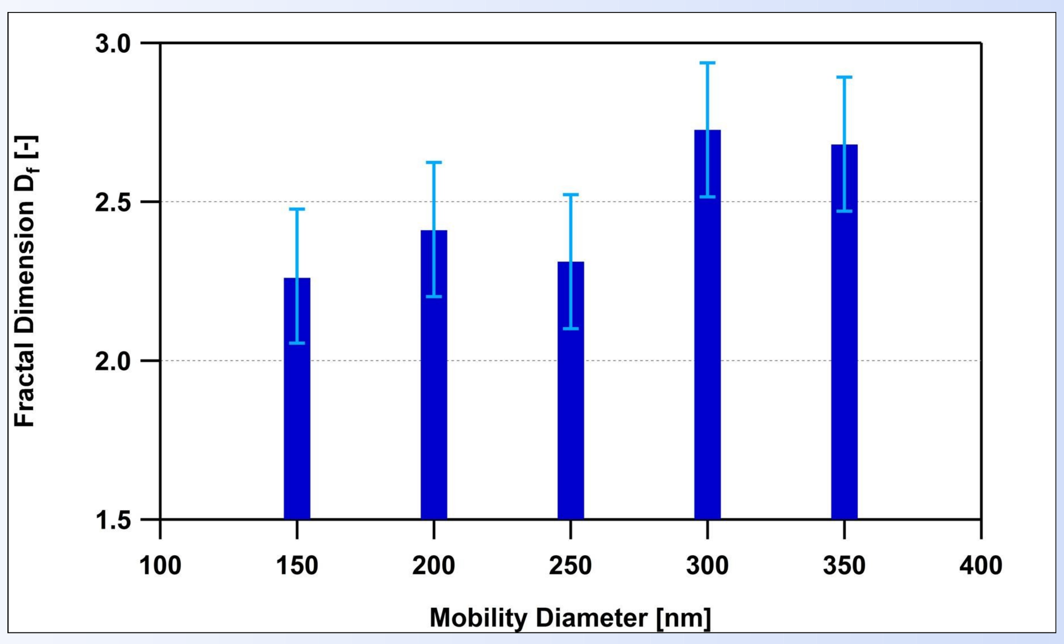


Figure 5. Fractal dimension of aquadag particles as function of the mobility diameter determined from angular light scattering

Outlook

- Further development of the automatization and electronics of the instrument
- Calibration with a blue laser diode in order to be able to determine the fractal dimension for smaller particles as well
- Measurement of combution aerosols (wood burning and diesel emissions)

Reference

Sorensen, C. M. and Oh, C. (1998) Phys. Rev. E 58, 4666–4672
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