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Online Particle Measurement under Industrieal conditions with the three Wavelengths Extinction Method

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Abstract

The three wavelengths extinction method is an optical bulk measurement method for submicron particles (e.g. Diesel soot, fog droplets). Information about particle diameter, width of the distribution function, and the concentration is gained from the extinctions of three rays of electromagnetic radiation. For calibration purposes the optical access needs to be free of particles from time to time. A recently for liquid aerosols developed bypass system has been tested and validated. It is able to measure particle sizes between 0.2 and 4 μm and particle concentrations between 10^5 and $10^8/cm^3$. The temperatures of the particulate system may range from ambient to 80°C .

1 Introduction

Flue gases from combustion processes are cleaned from environmentally hazardous components, such as HCl, with absorbers. It is expected that the gas is cleaned and the water contamined, afterwards. However, fog formation may take place and droplets of one micron size may be transferred to other parts of the plant [1, 2]. There they can cause severe problems like unexpected corrosion or emission. In many cases the problem of fog formation is not taken into account or is not predicted correctly [3]. Then it is solved with expensive and energy consuming demisters. So a task in research is to develop a qualitative and quantitative understanding of fog formation and a task in practice is to support industrial solutions by characterizing an aerosol problem.

Much research has been done on meteorological fog and is helpful to understand the industrial fog problem. On the other hand, in an industrial context residence times are far shorter, initial temperatures are higher, the amount of aerosol formation supporting substances is different, and the amount of ultrafine particles which serve as condensation nuclei is usually higher.

An aqueous fog consists of liquid spherical particles at high concentrations ($\sim 10^6/cm^3$). That makes it impossible to use particle counter which needs to detect single particles. Dilution and collection are impossible because the doplets would evaporate. That makes it necessary to use an online bulk measurement method like the three wavelengths extinction method.

2 Measurement unit

Fig. 1 shows the main components of the used WIZARD-DQ measurement unit. The intensities of emitted and received light (red and infrared) are the primary information and are evaluated on a PC as indicated in Fig. 2.

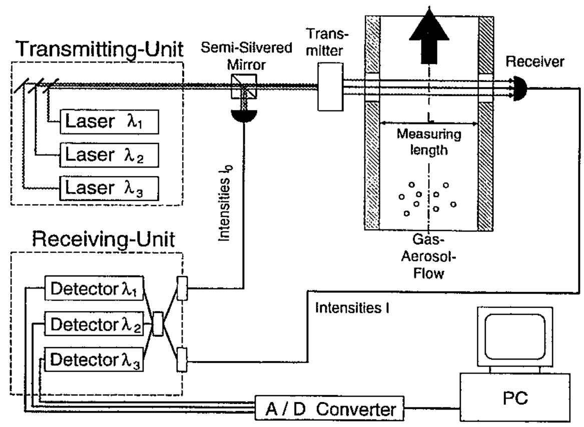

Figure 1: Principle of the measurement unit

The precalculated values for the transmissions I/I_0 and the corresponding dispersion quotients DQ are calculated from the following equations. Lambert-Beer's law for monodisperse particles calculates the transmissions from the number concentration of particles per unit volume c_N, the measuring length L, the particle diameter x, and

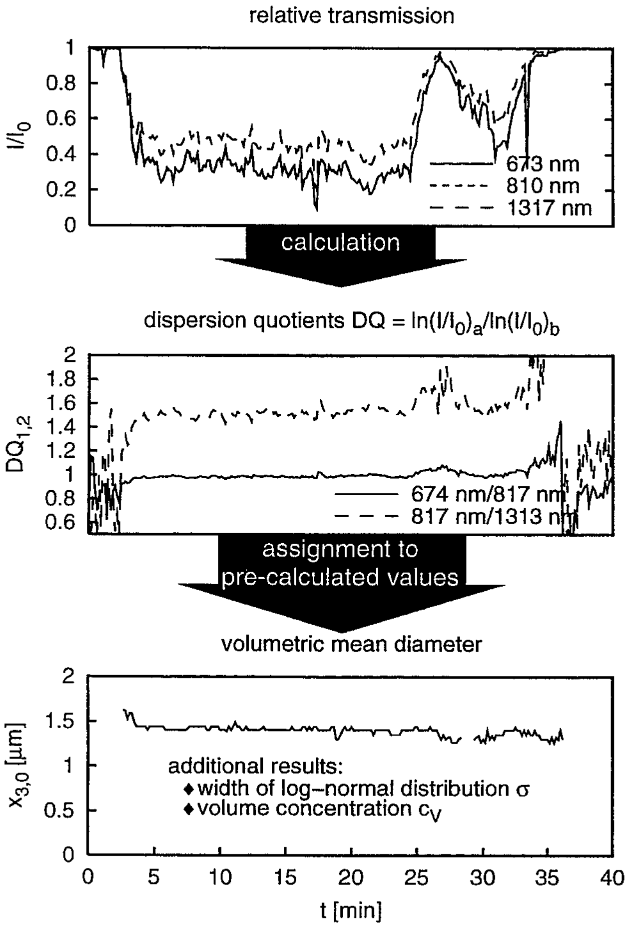

Figure 2: Evaluation process

the extinction coefficient Q_{ext}.

$$\frac{I}{I_0} = \exp\left(-c_N\ L\ \ \frac{\pi x^2}{4}\ Q_{ext}(x, \lambda, m)\right)$$

For particle sizes in the order of magnitude of the wavelengths the extinction coefficient is a strongly non-linear function of the wavelength. This dependency is responsible for the measuring effect. It is calculated from Mie's theory wich is a solution of Maxwell's equations for spherical particles [4].

Usually, particulate systems consist of particles of different size and a distribution function is needed. The measurement method yields three independent pieces of information, i.e. three light transmissions. As one of these is the particle concentration the distribution function must be representable with two parameters. The evalution algorithm uses a log-normal distribution. The characteristical paramters of its number density distribution function q_0 are the median diameter $x_{50,0}$ and the standard deviation $\sigma = \ln(x_{84,0}/x_{50,0})$.

Introducing q_0 into Lambert-Beer's law yields the equation for the dispersion quotients DQ. The DQ do not depend on the concentration which is why they are preferred to the transmissions for the evaluation.

$$DQ_{1/2} = \frac{\int_0^\infty q_0\ \frac{\pi x^2}{4}\ Q_{ext}(x, \lambda_{1/2}, m)\ dx}{\int_0^\infty q_0\ \frac{\pi x^2}{4}\ Q_{ext}(x, \lambda_{2/3}, m)\ dx}$$

The theory shows the ranges of the unit. The size of the particles must be in the order of magnitude of the used wavelengths. The shape must be known as the calculation of Q_{ext} depends on it. The refractive index m = n + ik must be known which implies that the particles consist of a homogeneous material. The imaginary part is needed for absorptive materials like Diesel soot [5]. The distribution function must have a single peak to be representable by the log-normal distribution function. So it is a suitable for aqueous aerosols.

3 Optical access

The relative transmissions do not only depend on the particulate system but as well on extinction caused by the windows of the optical access and the efficiency of the mirror. The intensity losses caused be these non-particle reasons must be measured in a calibration with an aerosol free system. In most cases aerosols cannot be removed from a plant. The optical access must be in a bypass which can be cleared with air. The setup is shown in Fig. 3.

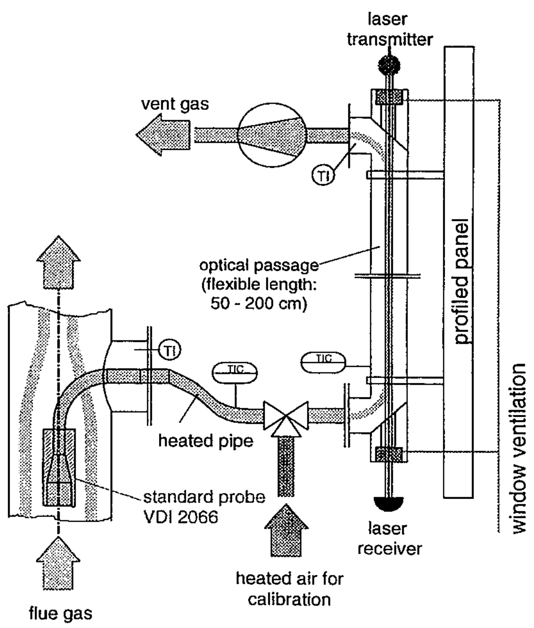

Figure 3: Setup of optical access

Most parts are made of polypropylene to avoid corrosion. The system implies probing problems.

The probe should be taken isocinetically. Deposition may take place. Due to temperature and pressure differences between the main flow and the bypass droplets may become smaller or larger as a result of evaporation or condensation, respectively. To compare bypass results with main flow results a semi-technical flue gas plant was used. In this plant an in-situ measurement is possible. Using the capability to measure at up to three positions simultaneously it was possible to compare the results online.

An obvious source of error is the temperature of the bypass. In the beginning of the measurement shown in Fig. 4 the temperatures of the heating systems for the heated pipe and the optical passage were purposely set to too high values. After setting the controls to the right temperatures (here 46°C) the measured values almost coincided.

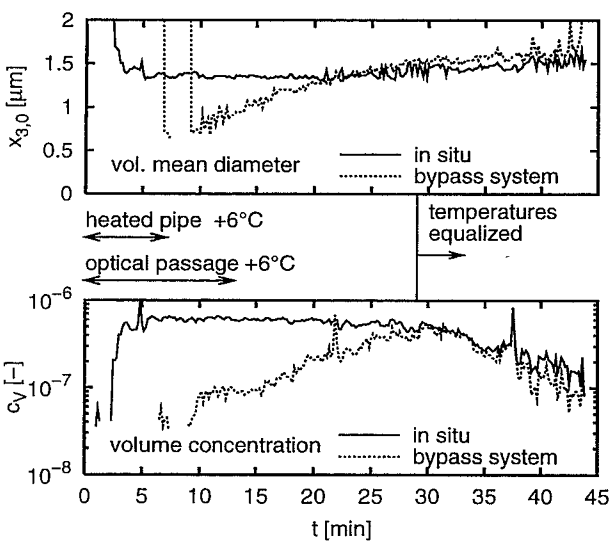

Figure 4: Comparison in-situ vs. bypass after initial superheating

The optical passage must be positioned vertically if it is longer than 50 cm. During the comparison measurements with a long horizontally positioned optical passage the measured particle diamter was close to the in-situ value but the concentration was far too low. The explanation was found with a completely optically accessible pipe where the fog sank down although calculations with Stoke's law yield that the effect should be negligable.

4 Conclusion

The three wavelengths extinction method is applicable in industrial contexts. An optical access exists which can be easily adapted to existing industrial plants. It was tested at a semi-technical plant for comparison purposes and at an industrial plant. With knowledge of the main error sources reliable results can be obtained.

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