

Effects of different sampling heads such as PM1, PM2.5, PM10 and Sigma 2 on the particle size determination with aerosol spectrometers

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Abstract

From epidemiological research it is well-known that gravimetric emission and immission measurements do not supply all information which is crucial for the effects of atmospheric particles on human health. Counting measuring methods (e.g. optical aerosol spectrometers) offer the advantage of the particle size and particle quantity determination in time high resolution, thus quasi real time determination.

A representative sampling is crucial for the information content of the particle size and particle quantity measurement both during emission measurements (e.g. in exhaust ducts) and measurements in ambient air or in stables.

In exhaust ducts the particle sampling must be accomplished in an isokinetic and representative way concerning the particle size and particle quantity over the duct cross section. During the immission measurement with counting measuring methods the sampling concerning particle size and particle quantity has to be likewise representative. For the adherence to the appropriate definitions of particle fractions often pre-separators (e.g. sampling heads such as PM1, PM2.5, PM10) and passive collectors like Sigma 2 (VDI 2119 part 4) are used.

With the white-light-aerosol-spectrometer-system welas® both the representative sampling place in an exhaust duct and the collecting efficiency of different sampling heads can be found and/or determined fast and safely.

In this paper we are going to present results which were determined in the exhaust air duct of a turkey hen stable and in a turkey hen stable in November 2006.

Keywords: collecting efficiency, representative sampling, isokinetic sampling, pre-separator

1 Basics concerning isokinetic and representative sampling in exhaust air ducts

During the particle size and particle quantity determination of aerosols the selection of the measuring method, of the measuring device and the proceeding with the sampling are of crucial importance. The unclear answer to the following questions not seldom leads to serious errors during the particle size and particle quantity determination:

- What is to be measured?
- Where is to be measured?
- How is to be measured?

A typical measurement chain for the on-line measurement of particle sizes and particle quantities is represented in figure 1. This figure also shows that the weakest element of the measurement chain determines the quality of the measurement.

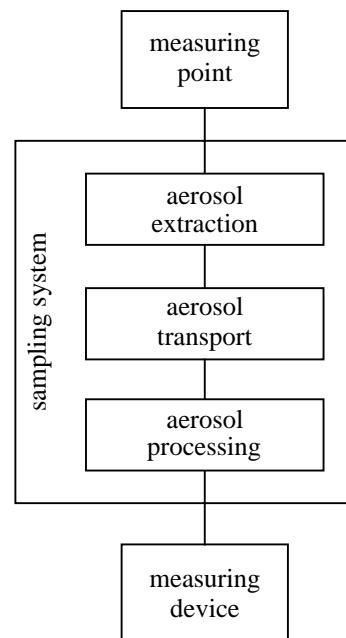


Figure 1:
Typical measurement chain

During the particle size and particle quantity determination in exhaust ducts (e.g. of forced ventilated stables) one must sample in an isokinetic and representative way. An

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isokinetic sampling makes sense only if the constancy of the flow rate at the sampling place is not higher than the indicated tolerance to the isokinetic sampling.

The effect of the non-isokinetic sampling can be easily made understandable with the help of figure 2.

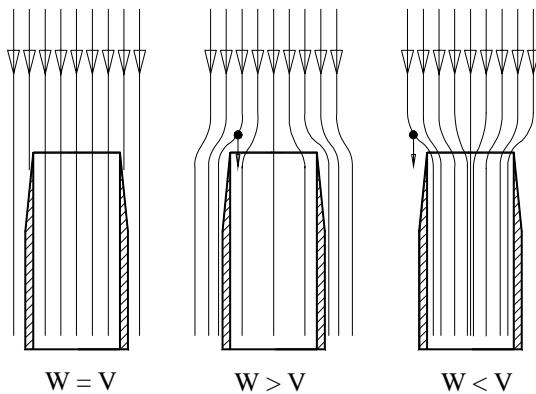


Figure 2:

Representation of the isokinetic sampling (W = flow rate in the duct, V = flow rate in the probe)

Isokinetic case $W = V$: All particles, which flow against the probe within the flow cross-section, are collected. In case of a too slow suction $W > V$, more large (inertial) particles get into the probe opening. Those particles cannot any longer follow the flow lines due to their inertia. In case of a too fast suction $W < V$, more small particles are sucked in, since the large (inertial) particles not being able to follow the flow lines fly by at the outside.

The error of the non-isokinetic sampling is not linear and depends according to (Hinds W. C. 1999) on the ratio of the particle concentration C_v/C_w , on the ratio of the gas flow W/V and on the particle diameter (C_v = concentration in the sampling probe, C_w = concentration in the exhaust duct).

The representative sampling place concerning particle size and particle concentration can be determined fast with a counting measuring method at sufficient particle concentration by scanning the cross section.

Different particle losses in the sampling lines can occur by selection of the material (metal or plastic), of the inside diameter, of the length of sampling lines and by sedimentation and impaction effects.

1.1 Results for the determination of the representative sampling

The numbers in figure 3 represent the distance to the duct wall in cm from the north and/or west side. Thus, position 30 is the duct centre.

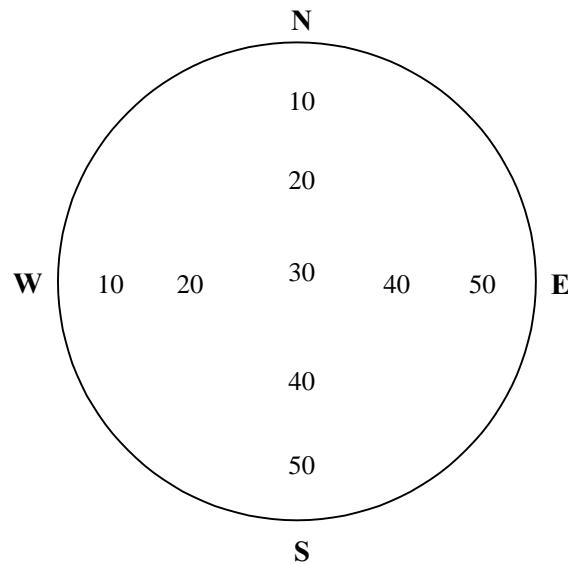


Figure 3:

Alignment of the measuring points in the exhaust duct, duct diameter 60 cm

The incident-flow rate was measured with a thermo-anemometer. Since the incident-flow rate is not constant over the duct cross section, it was specified with 5 m/s for the setting of the diameter of the isokinetic sampling probe.

The particle size and particle quantity determinations were detected with:

optical aerosol spectrometer:	welas®-system 2000
	welas®-sensor 2300
sampling volume flow:	5 l/min
measuring ranges:	0.3 – 17 µm or 0.6 – 40 µm
selected measuring range:	0.6 – 40 µm
measuring times:	at each position 2 x 60 s

The measuring range of 0.6 - 40 µm was selected on the one hand because particles as large as possible should be measured and on the other hand because the data should be compared with a parallel operated optical aerosol spectrometer of the company Grimm, whose measuring range was indicated from 0.5 to 30 µm.

With the welas®-sensor 2300 the particle concentration can be measured practically coincidence-free up to $C_N = 10^4$ particles/cm³. The measured particle numbers \dot{N} increased from the outside inward from $\dot{N} = 1036 - 2423$ particles/min.

Due to the particle number distribution in the exhaust duct, the sampling point for the welas®-system was defined in position 40 of the N-S axis and the suction flow rate for the gravimetric mass determination in position 20 of the W-E axis.

The Grimm-spectrometer was attached with an isokinetic part flow consumption probe in the suction flow rate for the

gravimetric mass determination. Over the measuring time of 15 min both the welas®-system and the Grimm-spectrometer could register at the same time the fluctuations of the particle numbers. Afterwards the welas®-system was attached at the part sampling probe of the Grimm-spectrometer, in order to determine there the particle size distribution. Following, an axial cyclone (Hinz T. 1983) with the separation function according to figure 4 was inserted in front of the part sampling probe, in order to determine its separation function.

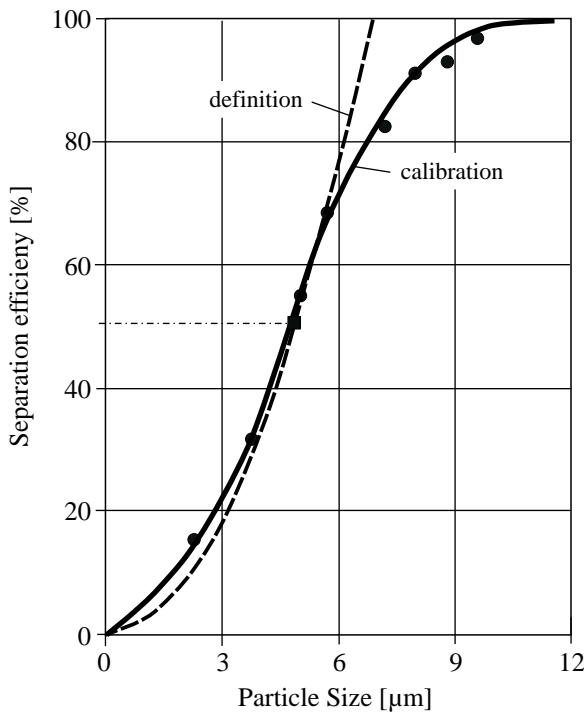


Figure 4:
Johannisburger separation function
Theoretical curve and actual calibration while sampling with a flow rate of $50 \text{ m}^3/\text{h}$

For this cyclone the cut-off-diameter is indicated with 5 μm . All particles larger than 7.5 μm should be separated.

In figure 5 the measuring curves are represented which were measured with the welas®-system after the part flow consumption with and without measuring cyclone. Since the theoretical separation function (figure 4) of the cyclone does not let pass practically any particles above 10 μm , the measuring range at the welas® was selected from 0.3 - 17 μm .

Figure 5 shows clearly that the cyclone has a cut-off-diameter of 5 μm and does not let pass practically any particles larger than 10 μm .

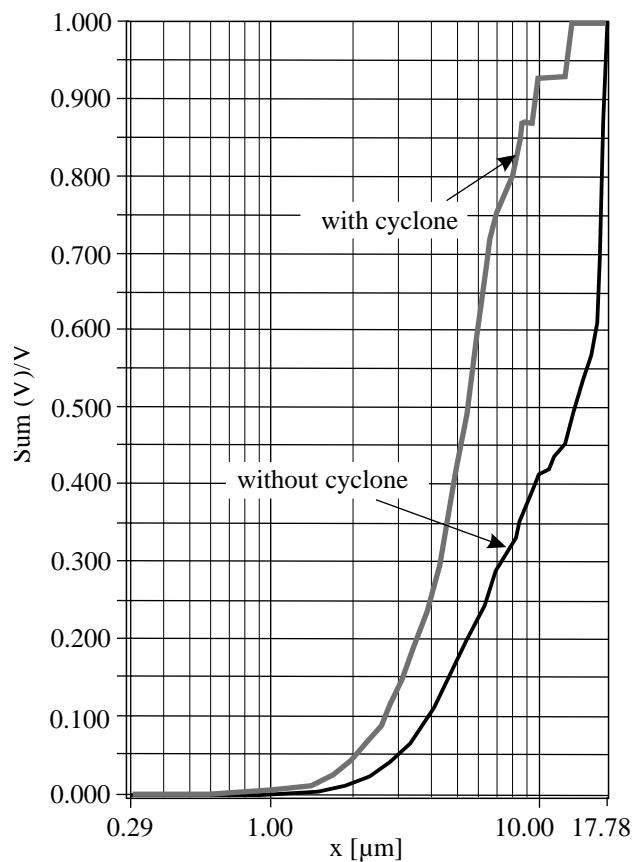


Figure 5:
Measured relative volume distributions of the particles in the exhaust duct, welas®-sensor 2300 behind the part sampling measuring section with and without cyclone, measuring range 0.3 – 17 μm

2 Definitions concerning separation devices and separators

The evaluation of separation degrees and separation efficiency curves can be quite complicated on closer inspection, since here the dependence of the separation process on the particle size and possibly also still further material and operation properties are to be considered. The selected measuring method and the measurement setup can affect the separation degree and the separation efficiency curve likewise substantially.

The separation degree (figure 6) indicates which portion of the feed arrived after the separation in the coarse fraction and/or in the fine fraction.

The mass balance during the two-fraction separation, i.e. during the separation with a separation cut (1 coarse fraction and 1 fine fraction), is very helpful during the evaluation of separation devices and separators.

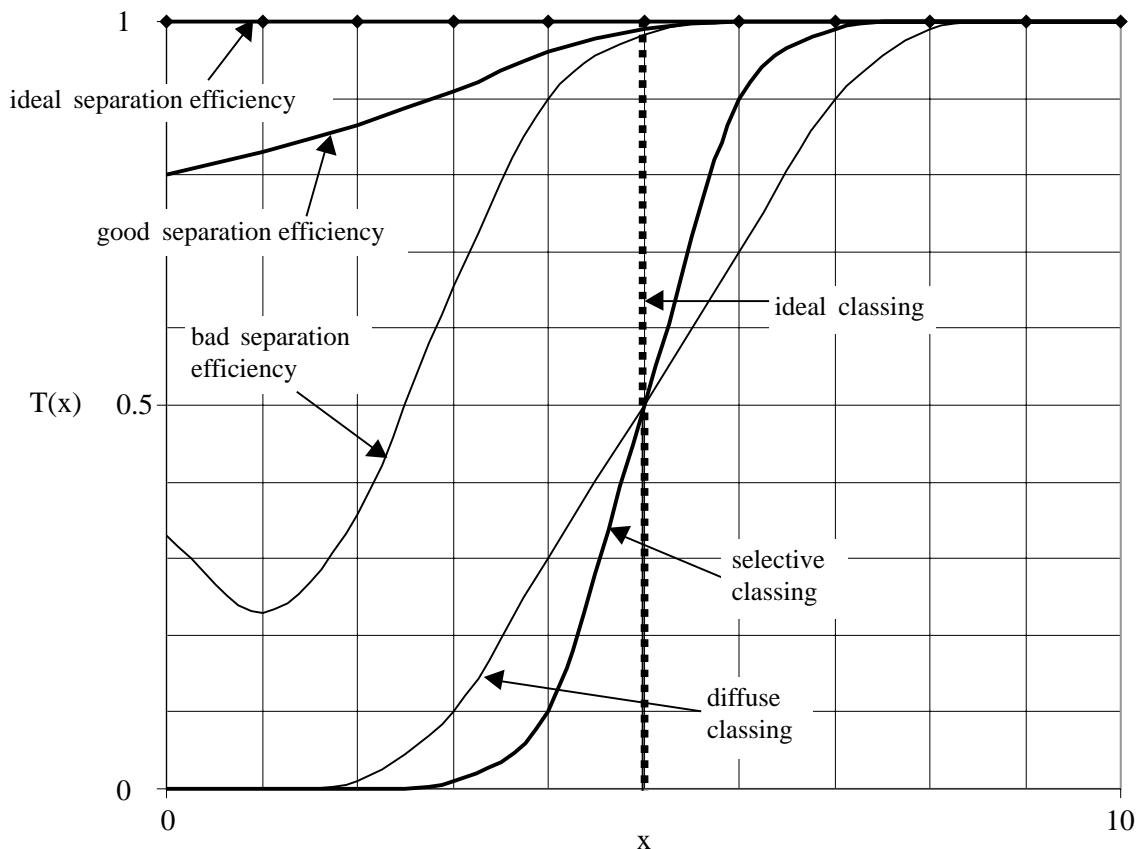


Figure 6:
Separation curves of separation devices (e.g. cyclones) and separators (e.g. filters)

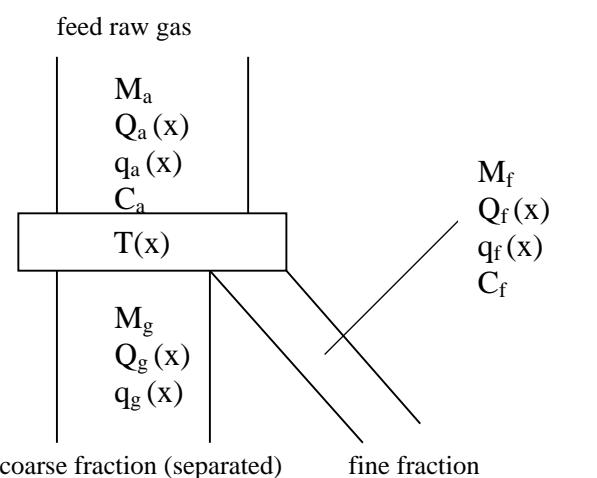


Figure 7:
Mass flows of a separation

The integral mass balance supplies: $M_a = M_g + M_f$

The total separation efficiency: $T \triangleq$ coarse mass fraction

$$T = \frac{M_g}{M_a} = \text{Retention}$$

The total penetration grade: $P \triangleq$ fine mass fraction

$$P = \frac{M_f}{M_a} = \text{Penetration}$$

If one refers all masses to M_a , then one gets: $1 = T + P$

With the dust concentration $C_{raw} = C_a$ in raw gas and $C_{clean} = C_f$ in clean gas one can also write:

$$T = 1 - \frac{C_{clean}}{C_{raw}} \quad T = \text{total separation efficiency}$$

$$T(x) = 1 - \frac{C_{clean}(x)}{C_{raw}(x)}$$

$T(x) =$ separation degree depending on the particle size \triangleq fractional separation efficiency

$C_{clean}(x)$ = particle concentration in clean gas depending on x

$C_{raw}(x)$ = particle concentration in raw gas depending on x
x = particle size

A classifier can be described meaningfully only with a separation curve. Just like during the description of a particle size distribution at least two parameters are needed: a location parameter and a distribution parameter.

Often, only the location parameter $T(x) = 50\%$ is indicated as value of the separation limit, cut-off. Since separators frequently do not show a symmetrical run of the separation curve (figure 6), it has to be advised against this approach. The exclusive indication of the separation limit in point $T(x) = 50\%$ does not supply any information about which form shows the separation curve and/or which selectivity shows the separation device.

The selectivity is described by the distribution parameter χ .

This parameter can be calculated at different particle sizes:

$$\chi = \frac{x_{25}}{x_{75}}, \quad \chi = \frac{x_{16}}{x_{84}} \quad \text{or} \quad \chi = \frac{x_{10}}{x_{90}}$$

E.g. x_{10} means the particle size x at which the separation curve is $T(x) = 0.1 = 10\%$.

The values x_{10} to x_{90} describe the run of the separation curve within a certain range below and/or above x_{50} . The more closely is selected this range, the fewer information contains the curve on the border areas of the separator.

For the critical evaluation of the selectivity and/or of the cut-off of a separation device or of a separation efficiency curve the meaningful indication of the used measuring technology and a clear sketch of the measurement setup are necessary. For this measuring task the welas®-system proved particularly of value, since here also large particles can be clearly detected.

A separation device has always a separation curve, and no step function, as this is described also in (John A. C. et al. 2001 and VDI 2066 part 10).

2.1 Measurement results related to collecting efficiency of sampling heads

With the welas®-system, one determined the different collecting efficiencies of the sampling heads and/or without sampling head but only with sampling tube with an inside diameter of 8 mm.

It was determined in a measurement-technological way that the particle number within the measuring range from 0.6 - 40 µm with the Sigma 2 according to VDI 2119 part 4 is around the factor 2 higher than with only the sam-

pling tube of diameter 8 mm. After these measurements, the different sampling heads PM1, PM2.5 and PM10 were connected with the welas®-system and their collecting efficiencies were determined.

In figure 8 the respective relative cumulative frequency distributions of the measurements with the individual PM-heads are represented. The different separation functions are clearly recognisable.

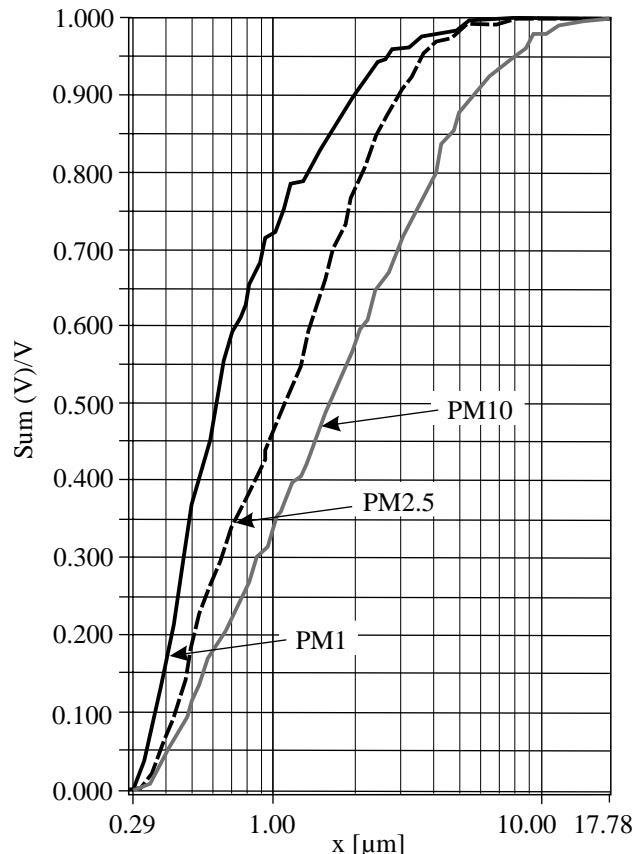


Figure 8:
Relative number cumulative distribution in the turkey hen stable with different PM-heads

Figure 9 shows the relative volume distributions of the particles let pass by the different PM-heads. One can clearly recognise that this is also a separation curve and not a step function.

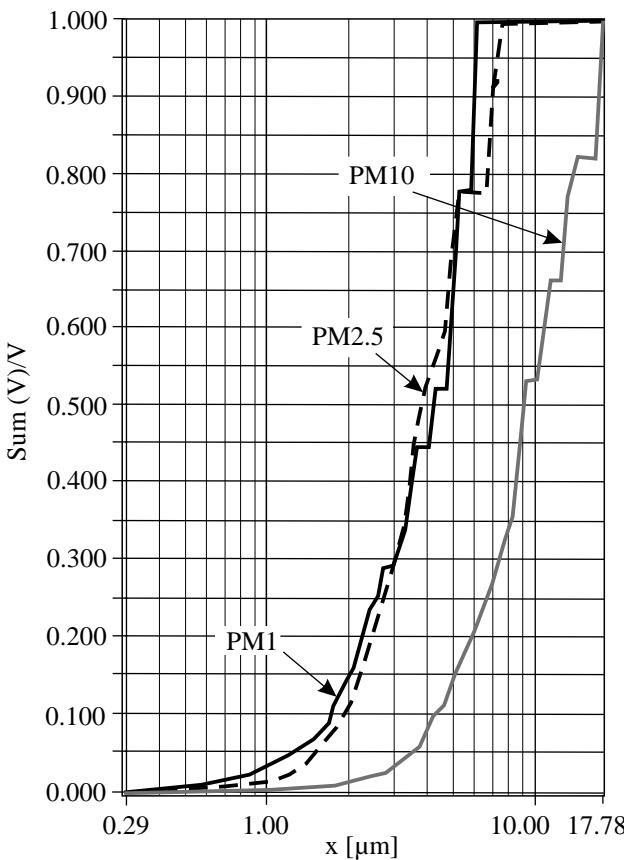


Figure 9:
Measured relative volume distributions in the turkey hen stable with different PM-heads

These measurement results confirm the definition and representation in VDI 2066 part 10.

PM10	$d_{50/3} \leq 10$
PM2.5	$d_{50/3} \leq 2.5$
PM1	$d_{50/3} \leq 1$

There is a variation of definition at the result of PM1.

Table 1:
 $d_{50/3}$ values of the measured PM-heads

PM	10	2.5	1
$d_{50/3}$	9 μm	2.5 μm	2.5 μm

During the sampling with Sigma 2 there were measured a higher number of particles and larger particles than with the PM10-head. Thus, at the discussion on the evaluation of the total dust examination the sample collector Sigma 2 is to be absolutely considered.

For the evaluation of a measured separation function of a

separator it is necessary to know the device characteristics of an aerosol spectrometer.

In the VDI 3867 part 4 draft and in the ISO/CD 21501-1 e.g. the size resolution, the size classification, the border zone error as well as their effect on the particle size distribution are described. These new guidelines will be useful for the users of particle measuring technology with counting measuring methods for the determination of the mass concentration.

3 Conclusions

With optical aerosol spectrometers the collecting efficiency difference of different sampling heads and the function of pre-separators can be determined fast. Also the representative sampling place in exhaust tubes can be found fast and safely.

The measurements shown above including setup and dismantling were accomplished in 6 hours.

4 References

- Hinds W. C. (1999). Aerosol Technology: properties, behaviour and measurement of airborne particles – 2nd edition. In: A Wiley-Interscience publication, 1999.
- Hinz T. (1983). Untersuchungen zur Staubexposition in der Getreideproduktion. Staub-Reinhalt. Luft 43, Nr.5, S203-S207.
- ISO/CD 21501-1: Determination of particle size distribution – Single particle light interaction methods – Part 1: Light-scattering aerosol spectrometer
- John A. C., Kuhlbusch T. A. J., Fissan H., Geueke K.-J., Bröker G. (2001). Development of a PM10/PM2.5 cascade impactor and in-stack measurements. In: Journal of Aerosol Science 32, Suppl. 1, S967-S968 (2001)
- VDI 2066 part 10: Particulate matter measurement – Dust measurement in flowing gases – Measurement of PM10 and PM2.5 emissions at stationary sources by impaction method
- VDI 2119 part 4: Measurement of particulate precipitations – Microscopic differentiation and size fractionated determination of particle deposition on adhesive collection plates – Sigma-2 sampler
- VDI 3867 part 4 draft: Measurement of particles in ambient air – Methods for characterizing test aerosols – Determination of the particle number concentration and particle size distribution – Optical aerosol spectrometer