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The testo 380: New Portable Apparatus for Real-Time Gravimetric Measurement of Particulate Matter in the Sub-Micrometer Range

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1. Background and Legislation

- **Adverse health effects of particulate matter (PM)** on the human health have been widely recognized [1,2].
- Increase of wood based residential heating in Germany.
- German **legislation enforces surveillance** of PM emitting sources [3,4].
- All plants, starting from 4 kW, have to be periodically inspected (biannually).
- Since 2013: dust-limit-values of 60 and 150 mg/m³, respectively
- From **2015**: reduction of **dust-limit-value to 20 mg/m³** (for newly installed devices)
- Need for **online measuring devices**, which agree well with standard gravimetric filter measurements according to VDI-Richtlinie Nr. 2066 [5] and report the result directly after the measurement.

2. The Device: testo 380

The testo 380 is an apparatus developed by the Testo AG and launched in 2013. It was particularly designed to fulfill the demands for online PM emission measurements at residential heating systems based on solid fuel combustion.

Features of the testo 380

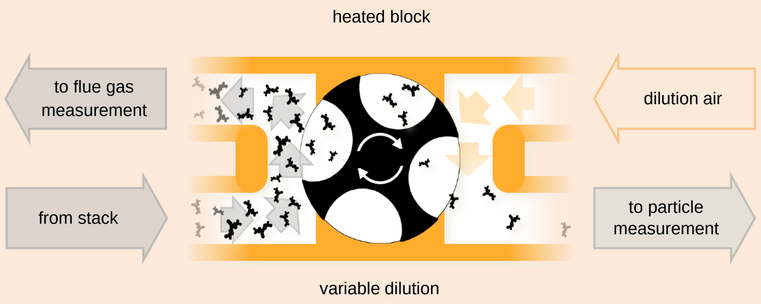
- Measures total mass concentration (0 – 300 mg/m³; Resolution 0,1 mg/m³)
- Certified for a number of solid fuels (wood chips, wood pellets, wood logs, lignite, black coal)
- Online measuremnt with high time resolution (value every 5 sec; trace of dust concentration can be followed during measurement)
- Compact and portable instrument (weight: 7,9 kg; size: 48 x 36 x 19 cm)
- Easy and fast to operate (setup + stabilization time < 15 min)
- Allows for flue gas analysis (O_2, CO) with the same probe as for particle measurement
- Low maintanance (no consumables)

Dilution: The Rotating Disc Diluter

- Optimization and miniaturization of Matter Aerosol MD19-3E diluter, patented by Testo AG [6]
- High dilution ratios (approx. 1:100)
- Dilution ratio is adaptable by changing rotation speed; automatic adaption of dilution ratio based on actual concentration implemented.
- Heated to 80°C
- Effective reduction of humidity to avoid condensation

Operating principle:

- Cavities of the rotating disk are filled with raw gas.
- During the rotation, the cavities move to the other side of the stator (sealing disc) with the dilution air duct.
- Cavity empties its filling of raw gas → A defined quantity of raw gas is added to the dilution air.

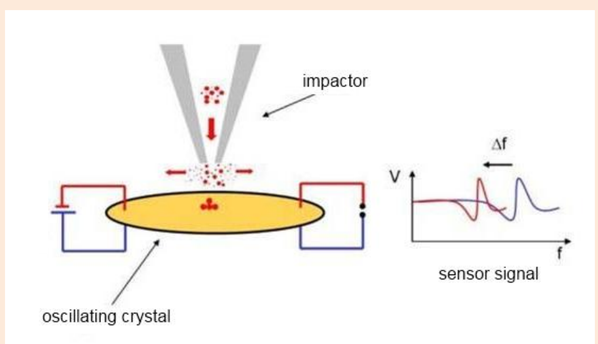


Sensor: Impactor with Oscillating Quartz Microbalance

- Combination of impactor- and oscillating quartz crystal microbalance-principle, patented by Testo AG [7].
- Impactor consists of two fine nozzles (approx. 0,1 mm).
- Particles are accelarated directed and impacted on the oscillating quartz crystal.
- The resonance frequency of the quartz changes upon mass loading and can therefore be used for mass determination (quartz crystal microbalance, QCM).
- The quartz crystal rotates during the measurement (higher mass loadings possible).
- Particle size range at lower end determined by impactor cutoff (< 100 nm) and at higher end by precipitation in the sampling and dilution system (> 1 µm).

The **impactor oscillating-crystal principle** allows measurements of particle mass in short time intervals (<1 sec).

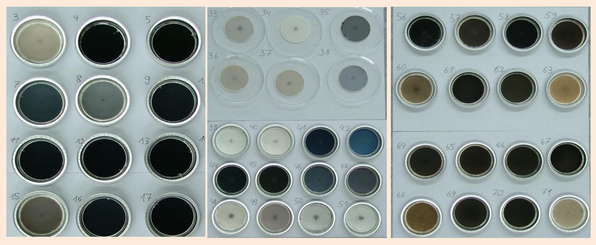
The replaceable quartz crystal module of the testo 380



Typical dust pattern on the quartz crystal – semi-circles result from rotation movement of the quartz plate.

3. Measurements and Results

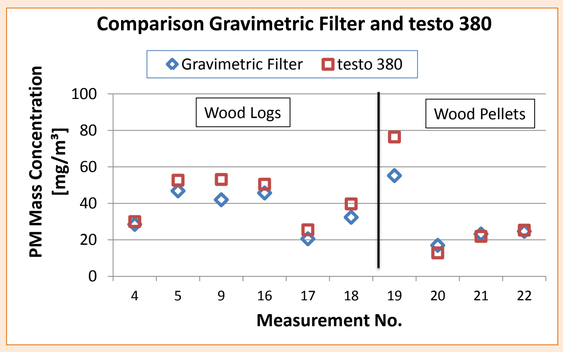
Challanges of quantifying PM emission from solid fuels



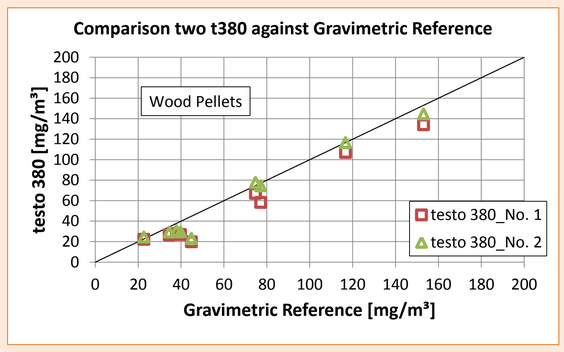
Filters with PM emissions from wood burning
(from left to right: wood pellets – wood chops – wood logs)

Different colors of the PM emissions collected with gravimetric filters proof the variing nature of the emission from wood burning processes. The color is not correlated with the amount of mass on the filter.
→ Changing refractive index causes problems for optical methods.
→ Direct gravimetric methods promise better agreement with standard filter technique.

Comparison of Testo 380 and gravimetric filter reference

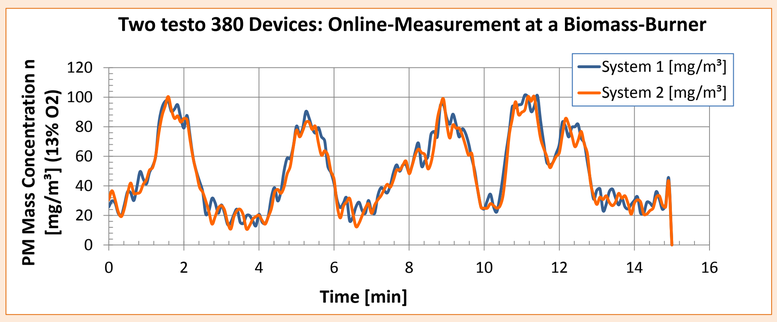


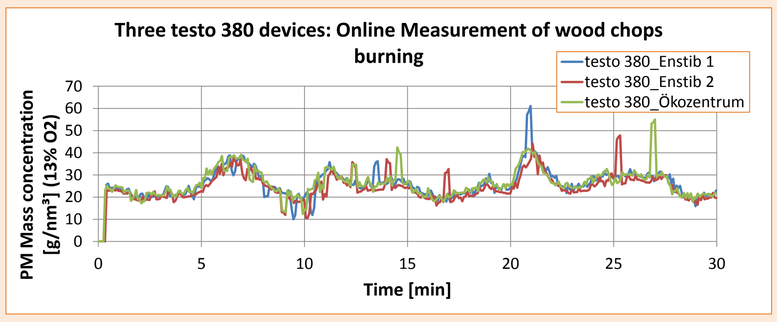
Comparison between gravimetric filter reference and testo 380: wood logs (left) and wood pellets (right)
(Measurements by Ökozentrum Langenbruck, Switzerland)



Two testo 380 devices compared against gravimetric filter for a broad concentration range (20 – 150 mg/m³),
(Measurements by Ökozentrum Langenbruck, Switzerland)

Real-time Traces and Reproducibility

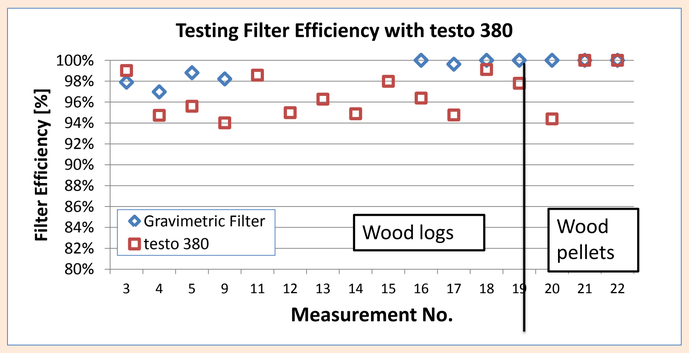


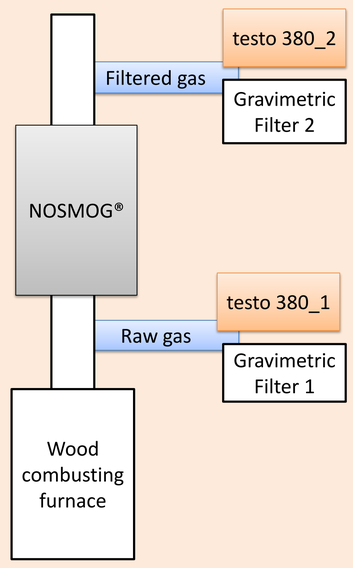


- testo 380 devices show very good reproducibility (time-resolved values as well as mean values are in very good agreement).
- Online traces show details of burning cycles. → They can be used to evaluate the burning process in real-time.
- testo 380 offers a handy tool for the adjustment of burners in order to minimize PM emissions.

New Application: Filter Testing

- A new flue gas treatment for residential wood burners (NOSMOG®) to reduce PM emission was tested with standard gravimetric filter measurement and with testo 380 (collaboration with the Ökozentrum Langenbruck, Switzerland).
- Two devices of each type were installed before and after the electro filter; efficiency is calculated by ratio of the two devices ($1 - c_{filtered\ gas} / c_{raw\ gas}$)
- Good agreement of determined efficiency from both methods.
- → New application for filter development or on-site testing of filters.





References

[1] World Health Organization, Technical Report, *Health Effects of Particulate Matter*, WHO Regional Office for Europe, Denmark (2013)
[2] International Agency for Research on Cancer, Press Release No. 221 (2013)
[3] 1. Bundes-Immissionsschutzverordnung (Verordnung über kleine und mittlere Feuerungsanlagen) (2010-01)
[4] VDI-Richtlinie Nr. 4206 Blatt 2 (2013-11)
[5] VDI-Richtlinie Nr. 2066 Blatt 1 (2006-01)
[6] Testo AG, Patent Application, *Handheld sampling-removal head, analysis arrangement and method for characterizing an aerosol* (2012)
[7] Testo AG, Patent Application DE102011013697 A1, *Impactor and method for characterizing a carrier gas enriched with suspended particles* (2012)
[8] Hinds, W.C., *Aerosol Technology*, Chapter 5, Wiley & Sons, Inc. (1999)