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Report on results of the project *Characterisation of the Effectiveness of DEXWET Particle Filters*

1. Overview of measurements

In order to characterise the effectiveness of DEXWET particle filters for laser printers, comparative measurements and analyses of particle emissions for sizes from 10 nm to 20 µm as well as measurements and analyses with regard to a possible reduction of VOC emissions were carried out on three types of laser printer, in a 1 m³ emission testing cabinet, according to Instruction RAL UZ-122 (Test methods for the determination of chemical emission rates from hard copy devices for the award of the Blue Angel environmental label for office equipment by the UBA Federal Environment Agency). Table 1 lists the measurements carried out. For the measurements, both new filters and filters previously contaminated deliberately of the company Dexwet were used.

Table 1:

No.	Date	Printer [Serial No.]	Print stage from – to (hh:mm) period (min) no. of pages	TSI spectra (runs)	Grimm-spectra	Notes
-	17 Oct. 06	Printer 1 colour	9:28 –	MDW1 (#32–)	GRIMM-DW1+2	Without filter Standard position (1) Aborted due to SMPS error
DW1	17 Oct. 06	"	11:38–11:47 9.3 150	MDW1 (#97–#99)	GRIMM-DW1+2	Without filter Standard position (1) Runs #98 + #99 drain error, as of Run #100 ok!
DW2	17 Oct. 06	"	14:28–14:37 9.15 150	MDW2 (#56–#61)	GRIMM-DW1+2	With new filter Standard position (1)
DW3	-	-	-	-	-	With used filter No measurements
DW4	18 Oct. 06	Printer 2 colour	9:30–9:45 15.3 200	MDW4 (#31–#38)	GRIMM-DW4+5+6 Test1	Without filter Standard position (1) Cabinet door (2)
DW5	18 Oct. 06	"	12:28–12:45 15.9 200	MDW5 (#62–#69)	GRIMM-DW4+5+6 Test1_with	With 3 new filters Standard position (1) Cabinet door (2) Lateral filter fallen down during last third of print job
DW6	18 Oct. 06	"	15:28–15:44 15.8 200	MDW6 (62–#69)	GRIMM-DW4+5+6 Test1_with_contami-nated	With 3 used filters Standard position (1) Cabinet door (2) Lateral filter fallen down at 15:31 during 1st third of print job
DW7	19 Oct. 06	Printer 3 monochrome	9:29 - 9:43 14.0 390	MDW7 (#25–#31)	GRIMM-DW7+8+9 Lex_without	Without filter Standard position (1) Cabinet door (2)
DW8	19 Oct. 06	"	12:32–12:46 14.0 390	MDW8 (#66–#72)	GRIMM-DW7+8+9 Lex_without	With new filter Standard position (1) Cabinet door (2)
DW9	19 Oct. 06	"	15:30–15:44 14.0 390	MDW9 (#62–#68)	GRIMM-DW7+8+9 Lex_with_contami-nated	With used filter Standard position (1) Cabinet door (2)
DW10	20 Oct. 06	Printer 1 colour	9:28–9:38 9.8 150	MDW10 (#33–#37	GRIMM-DW10+11 Panasonic_without	Without filter Standard position (1) Cabinet door (2)
DW11	20 Oct. 06	"	12:26–12:36 9.8 150	MDW11 (#62–#66)	GRIMM-DW10+11 Panasonic_with	With new filter Standard position (1) Cabinet door (2)

2. Equipment and materials

Printers:
The three types of laser printer listed in Table 1 were used. The later printers, which had previously been used already to an extent not quantified in more detail, were equipped with used original toner cartridges. Before the tests were started, the printers were checked for adequate functioning and response to print commands. The laser printers were selected in cooperation with the Dexwet company and the BAM German Federal Institute for Materials Research and Testing.

Filters:
The Dexwet company provided new filters from its inventory. According to information by the company Dexwet, the filters previously contaminated deliberately were prepared as follows: coloured toner material was manually applied/spread on new filters by Dexwet staff. After this preparation, the entire filter rods were visibly covered with coloured toner dust. The toner powder that had been applied adhered well to the surfaces of the filter rods. No further quantitative or qualitative details regarding type and scope of this previous deliberate contamination of Dexwet filters were specified either by the company Dexwet nor during the tests at the BAM Institute. The printers were equipped with the Dexwet filters by staff of the Dexwet company.

Paper:
The paper used for the tests was in conformity with the requirements of the standard DIN-EN 12281 (2003-01): white paper, 80 g/m^3, type Desk-Top, X'tensa; supplier: Roy Schulz, Berlin, Germany.

Test cabinet:
1 m^3 test cabinet (manufacturer: Weiss) with the following characteristics:

- ultrapure air supply (reduced VOC, ozone and dust)
- ultrapure water supply
- cabinet walls of special steel
- minimum use of sealing materials
- effective air distribution
- temperature 23°C ± 2 K
- relative air humidity 50% ± 5%
- air exchange rate control
- air flow speed 0.1–0.3 ms^{-1}

Particle spectrometer:

- TSI 3080 Scanning Mobility Particle Sizer (SMPS), with Differential Mobility Analyser (DMA) 3081, Water-Based Condensation Particle Counter (WCPC) 3785; measuring range 10 nm to 470 nm, resolution 105 logarithmic actual size channels; time resolution: 90 seconds per full scan, sample flow rate 1 L/min; sample transport LF silicone, 0.5 m x 0.19” interior diameter.
- GRIMM 1.108 laser counter, measuring range 300 nm to 20 µm, 16 logarithmic actual size channels, time resolution 6 seconds / full scan, sample flow rate 1 L/min, sample transport V2A, 0.5 m x 2 mm interior diameter.

Measuring positions:

Kammertür = cabinet door
Papierauswurf = paper exit
Drucker = printer
Hauptluftstrom = main air flow

The laser printers were positioned in the centre of the cabinet in each case. Position (1) was the standard air sampling position for the particle spectrometers. At position (2) in a few tests additional measurements were carried out with a second Grimm 1.108 spectrometer (see Table 1).

3. Standard measuring procedure

The measurements were carried out in accordance with Instruction RAL UZ-122: Test methods for the determination of chemical emission rates from hard copy devices for the award of the Blue Angel environmental label for office printing devices by the UBA Federal Environment Agency.

a. **Cabinet loading**
   The test object was placed in the cabinet, then the cabinet was closed.
b. **Conditioning stage, duration ~ 60 min**
   Standard atmosphere (23°C, 50% RH), AE 1, test object with paper inserted in the cabinet for conditioning. (AE = air exchange rate [h^{-1}])
c. **Ready stage, duration ~ 50 min**
   Standard climate, AE 1, test object turned on and ready for operation so that printing could be started as soon as possible, start of VOC and particle measurements.
d. **Change to AE 4, duration ~ 15-20 min**
e. **Printing stage, duration ~ 15 min**
   Testing of test object during print operation, continuation of VOC and particle measurements.
f. **After-print running time ~ 45 min**
   VOC measurements stopped after 15 min, reduction of particle concentration in the test cabinet was observed.

4. Assessment of particle retention

The printers tested here primarily emit particles of diameters lower than 500 nm. The share of particles with diameters larger than 500 nm typically accounts for considerably less than 1 per mil of total particle count, but because of the larger volume of these particles, they account for approx. 90% of overall particle mass.

Particle retention in the filters is determined in two different ways:

- size-related particle retention, R_G
- integral particle retention R_Σ

In order to determine size-related particle retention R_G, the relationship of differential or size-related particle size spectra measured immediately after the print job with and without filters is calculated:

$$R_G \text{ particle size}[\%] = \frac{100\,(S_1 - S_2)}{S_1}$$

S_1 refers to the size spectrum measured without a filter, and S_2 refers to the size spectrum measures with a filter.

In order to determine cumulative retention R_Σ, the relationship of cumulative particle concentration in the measuring range of the TSI spectrometer (10 nm to 470 nm) measured directly after a print job with and without filters is calculated:

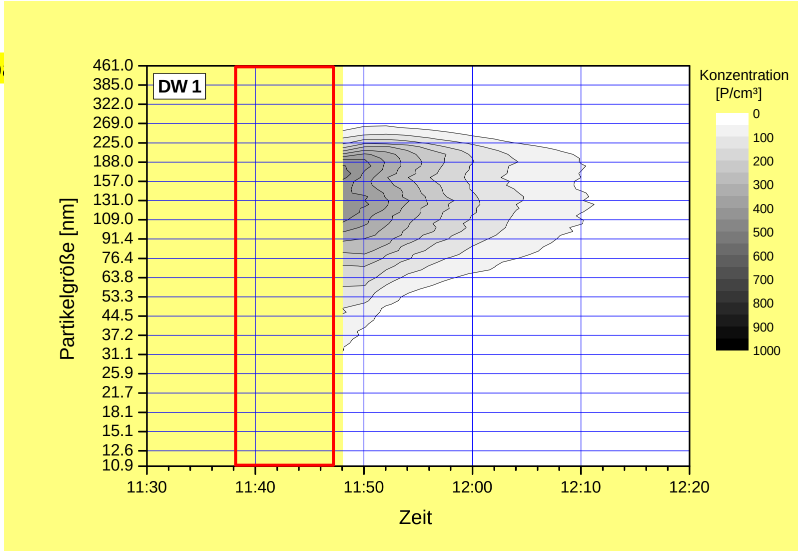
$$R_\Sigma(10\,\text{nm} - 470\,\text{nm})[\%] = \frac{100 \cdot (\Sigma_1 - \Sigma_2)}{\Sigma_1}$$

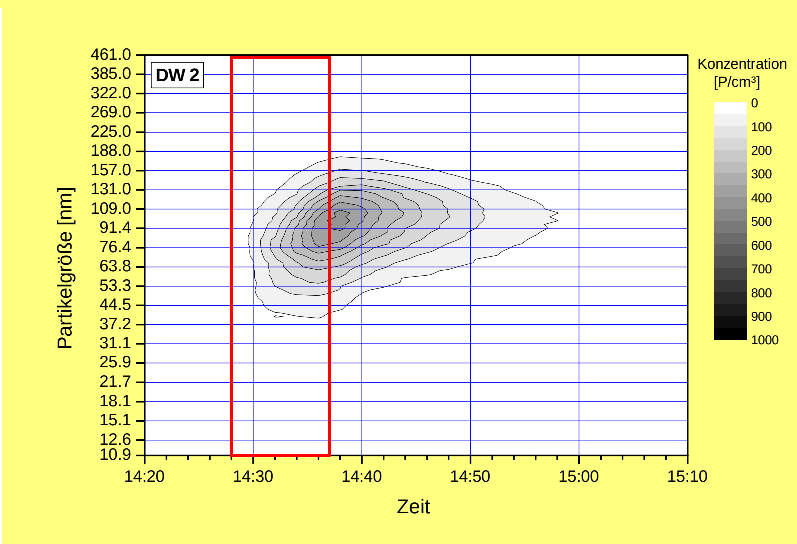
Σ_1 refers to the cumulative particle concentration measured without a filter in the measuring range, and Σ_2 refers to the cumulative particle concentration measured with a filter.

5. Results

5.1 Emission spectra of measurements DW1, DW2, DW10 and DW11 (red boxes refer to time periods of print jobs):

Partikelgröße = p
Zeit = time

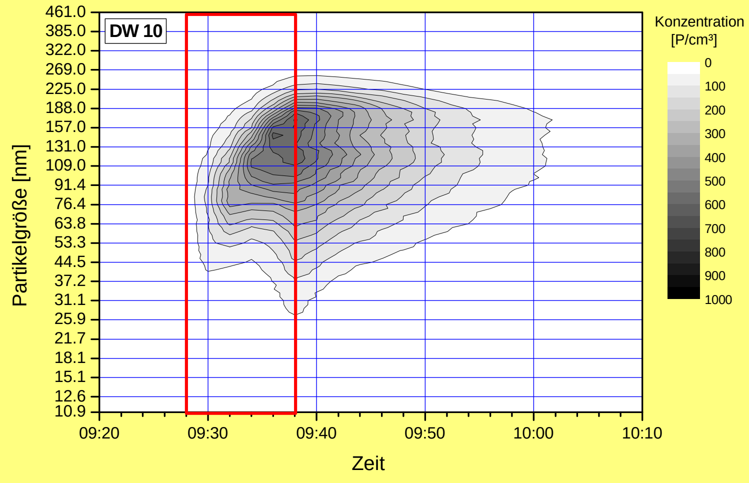


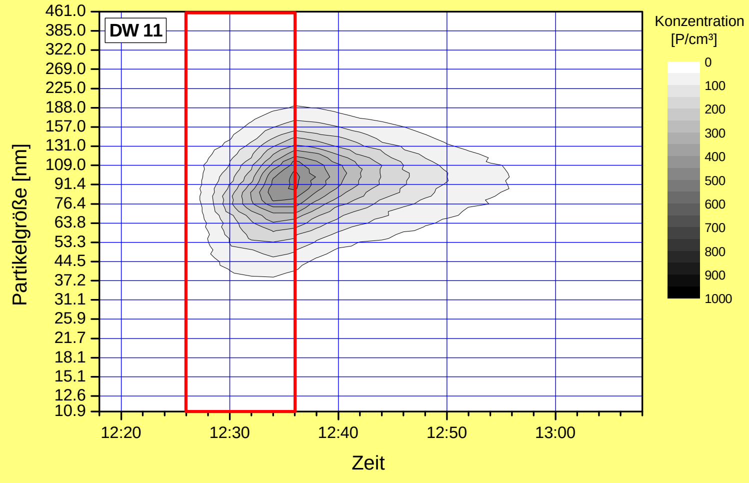


In spectrum DW1, due to a technical error, the time period of measurement was not recorded completely.

(5.1 continued)

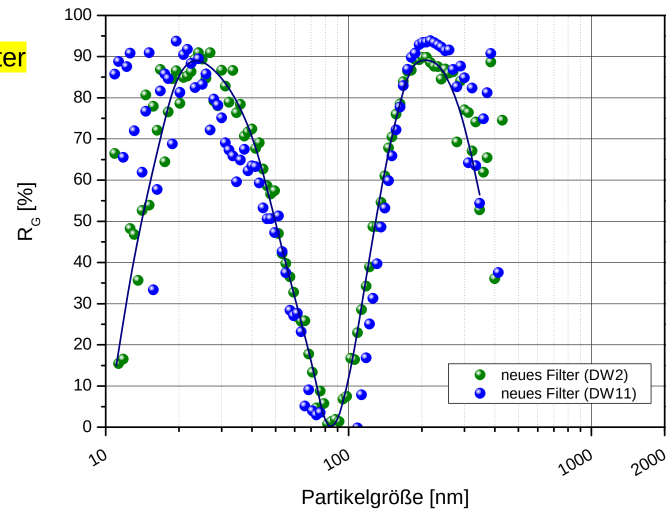
Konzentration =





Size-related retention R_G:

neues Filter = new filter

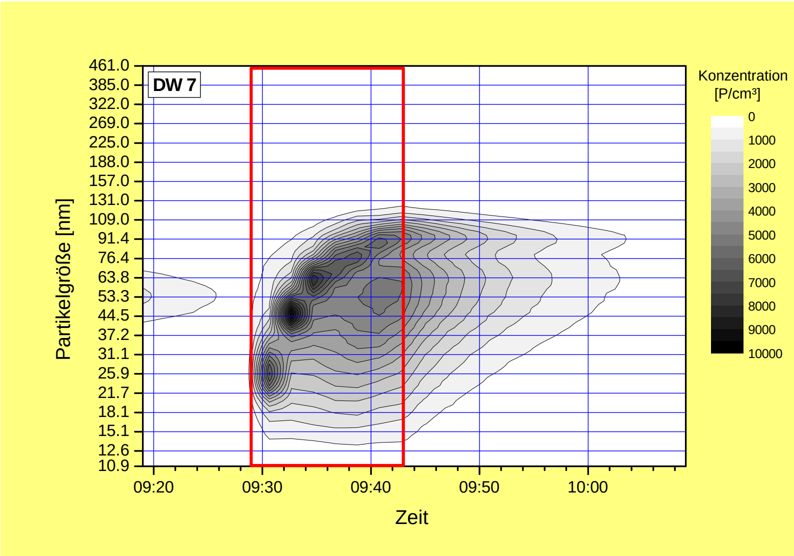


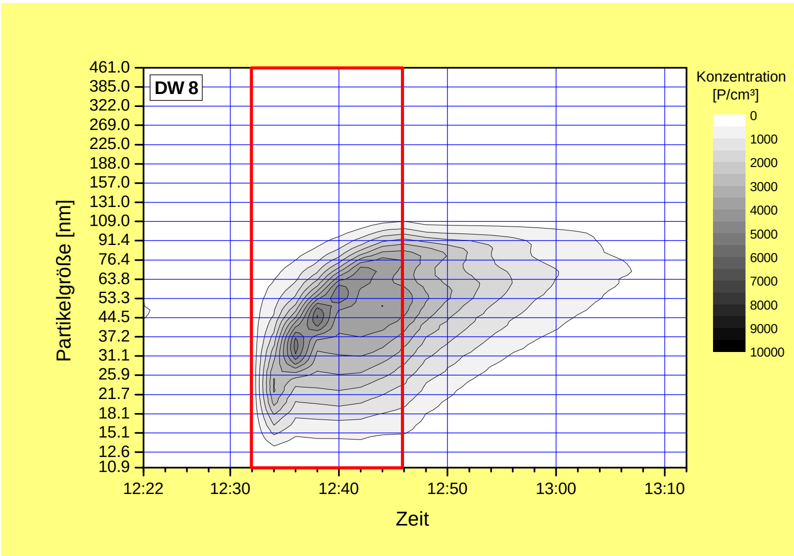
(5.1 continued)

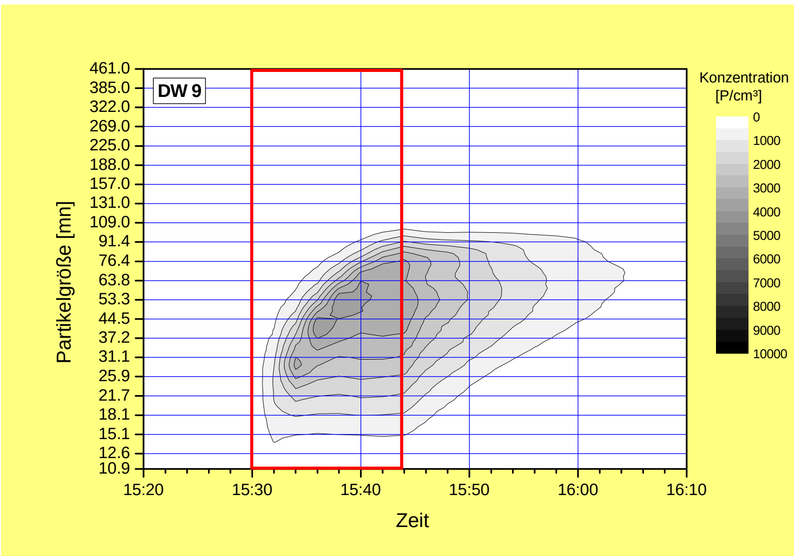
Cumulative retention R_{Σ}:

Measurement	Cumulative concentration (Range 10 nm to 470 nm)	R_{Σ} (10–470 nm)
Reference – DW1 /Run #100	$1.5*10^4$ particles/cm^3	-
New filter – DW2 / Run #62	$0.79*10^4$ particles/cm^3	47 ± 1%
Reference – DW10 / Run #38	$2.0*10^4$ particles/cm^3	-
New filter – DW11 / Run #67	$1.12*10^4$ particles/cm^3	44 ± 1%

5.2 Emission spectra of measurements DW7, DW8 and DW9 (red boxes refer to time periods of print jobs):



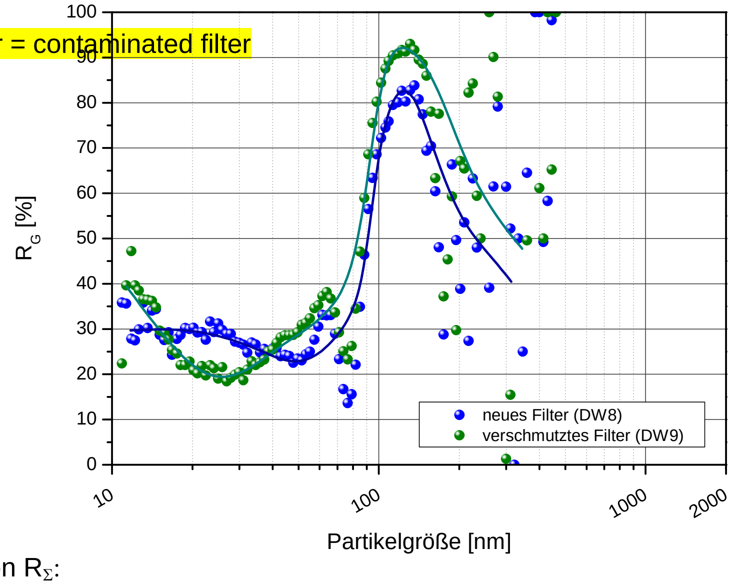




(5.2 continued)

Size-related retention R_G:

verschmutzes Filter = contaminated filter

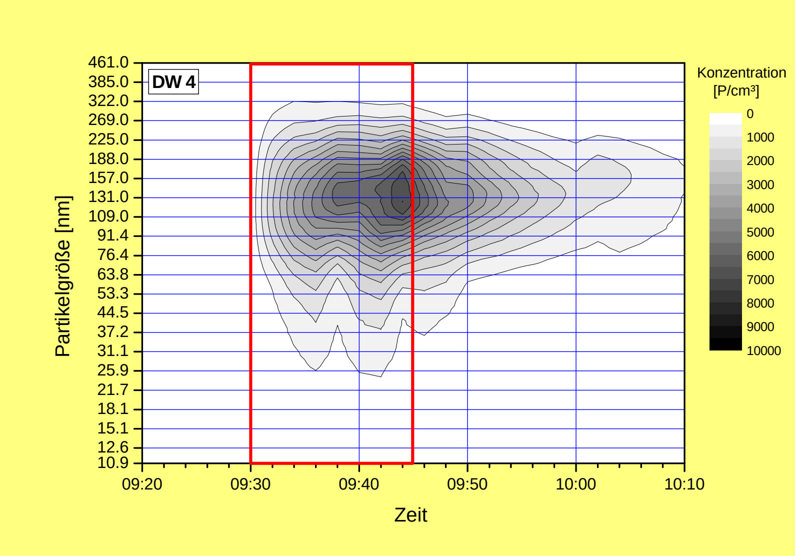


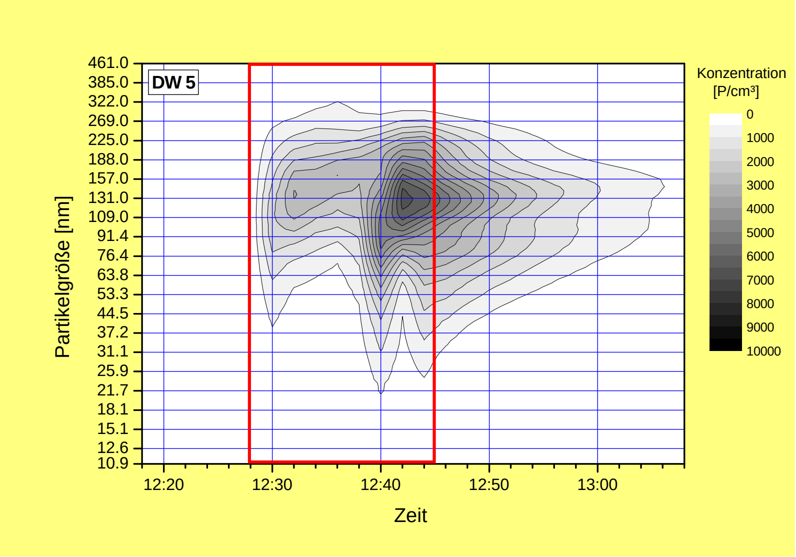
Cumulative retention R_Σ:

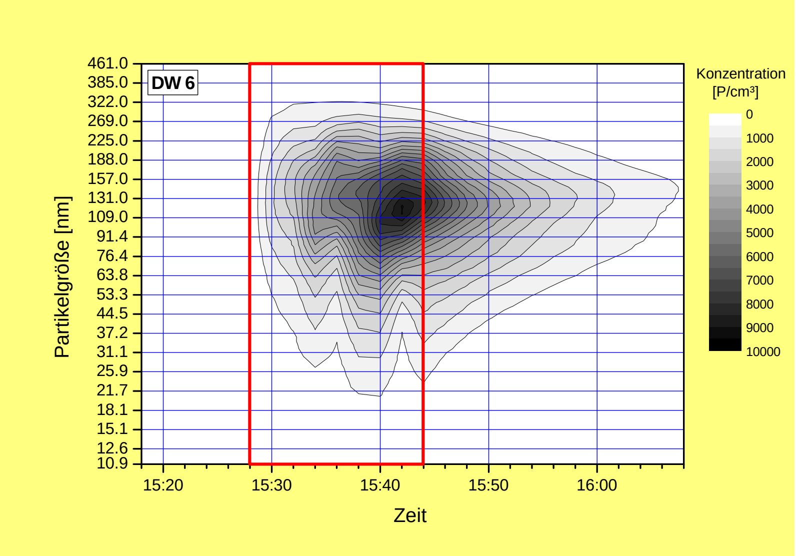
Measurement	Cumulative concentration (range 10 nm to 470 nm)	R_Σ (10–470 nm)
Reference – DW7 / Run #32	1.96*10^5 particles/cm^3	-
New filter – DW8 / Run #73	1.32*10^5 particles/cm^3	33 ± 1%
Used filter – DW9 / Run #69	1.25*10^5 particles/cm^3	36 ± 1%

5.3 Emission spectra of measurements DW4, DW5 and DW6:

The emission spectra of measurements DW5 and DW6 cannot be interpreted in the same way as the above measurements because in these cases one of three Dexwet filters (positioned on the side of the printer casing) fell down during the print job. Therefore the retention capacity cannot exactly be derived from these measurements.







(5.3 continued)

Measurement	Cumulative concentration (range 10 nm to 470 nm)	R_{Σ} (10–470 nm)
Reference – DW4 / Run #39	$1.7*10^5$ particles/cm^{-3}	-

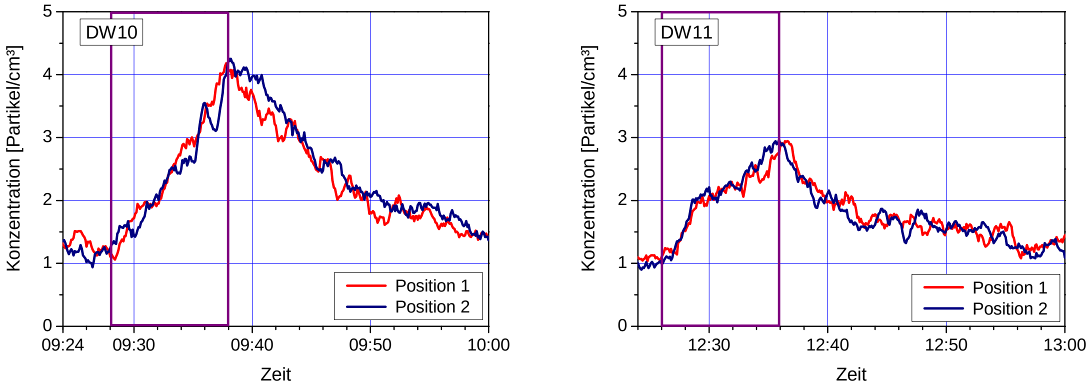
The measurement logs indicate that during the first half of the print job, at least in the case of measurement DW5, the filter was still in its correct position. An estimate of the maximum particle emissions in the spectra DW4 and DW5 during the first half of the print job leads to the following results:

DW4: maximum at 5760 P/cm³ in particle size class 136 nm
DW5: maximum at 2850 P/cm³ in particle size class 136 nm

Thus, the estimated retention rate R_G (131 nm) is ~ 50%.

Because of these details of the emission spectra DW4 and DW5, a reduction of particle emissions due to the use of new Dexwet filters may also be established for the Kyocera FSC 5016 NUX printer.

5.4 Comparison of the measurements to GRIMM particle spectrometer results



The two graphs show the total particle concentration measured at positions 1 and 2 in the measuring range 0.3 µm to 20 µm during measurements DW10 and DW11. The coloured boxes refer to time periods of print jobs. The time shift due to different time settings in the two Grimm instruments has been corrected. The spectra thus show a very good detailed quantitative correspondence. The other comparative measurements at positions 1 and 2 show the same results. Thus, it is safe to assume that, under the conditions described, the measuring positions 1 and 2 are equivalent with regard to measurements with the Grimm spectrometer.

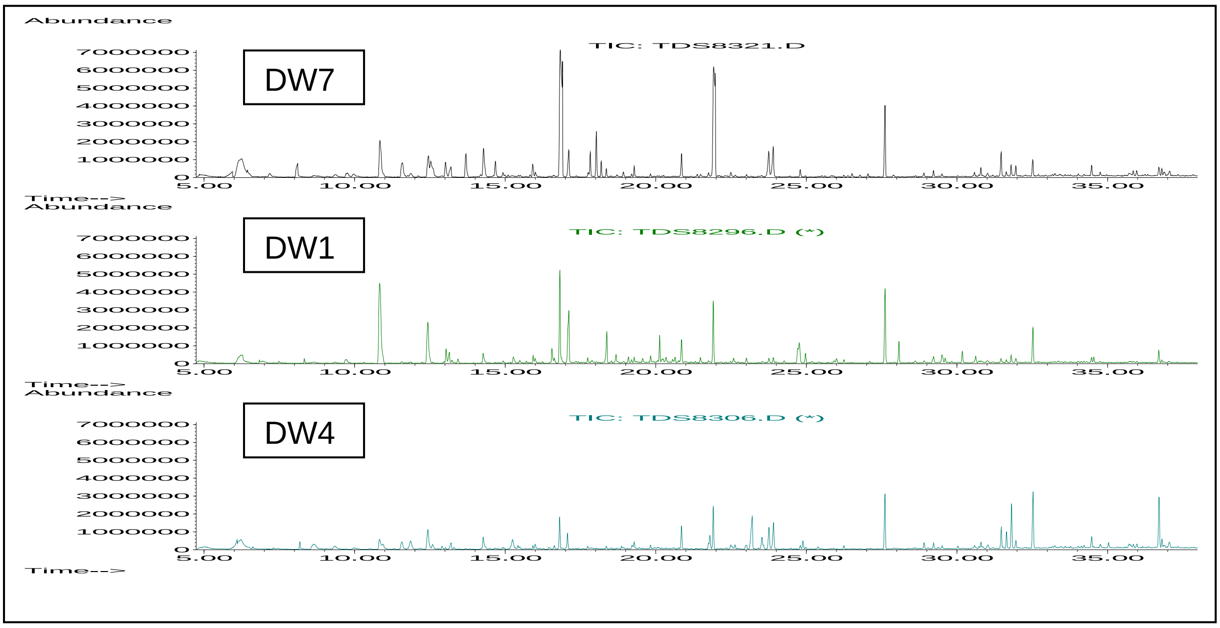
6. Analyses of VOC measurements

The VOC measurements were carried out at the ready stage and at the printing stage in the case of the tests DW 1, 2, 4, 5, 7 and 8. For tests DW 6 and 9, VOC measurements were made only at the printing stage.

In this way, the VOC emission measurement results permitted a distinction between printer (material) emissions, printing (process) emissions and emissions from the Dexwet filter(s).

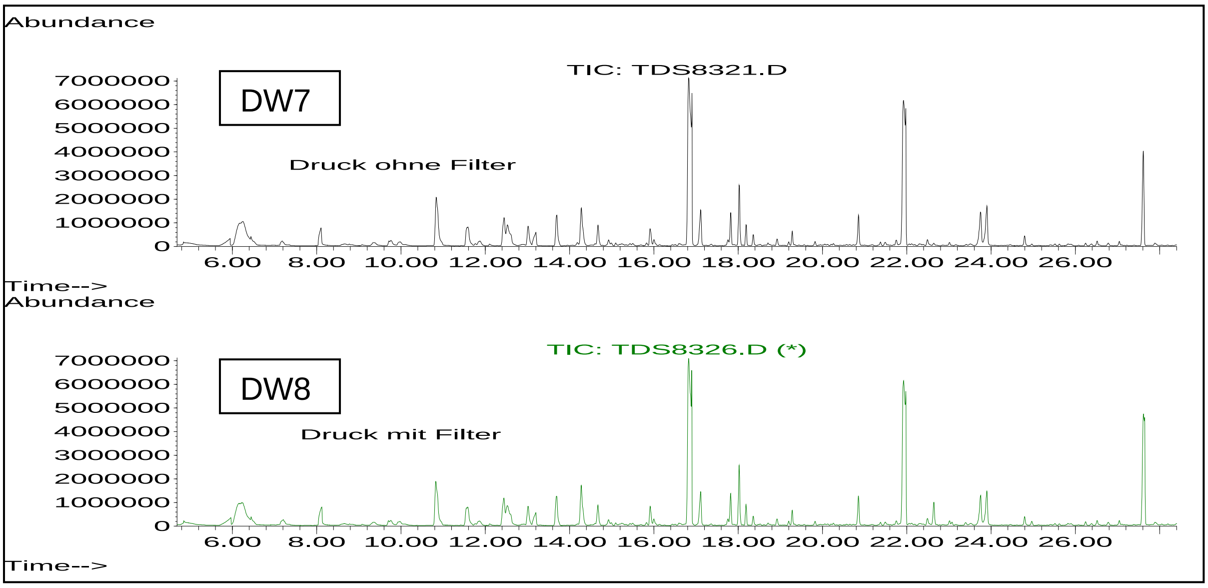
As expected, for the three printers tested (Panasonic, Kyocera, Lexmark), different VOC emissions were found.

Chromatograms of measurements at the printing stage without Dexwet filter:



The largest VOC spectrum was found for the Lexmark printer, which emitted ethylbenzene, styrene, propylbenzene and ethylhexanol, among other substances. With regard to these VOCs as well as other VOCs that are not listed here or that could not be identified, a comparison of measurements with and without Dexwet filters did not show differences in the concentrations measured in the test cabinet for any of the three printer tested.

Chromatograms for comparisons of printer tests with (above) and without (below) Dexwet filters:



Druck ohne Filter = printing without filter
Druck mit Filter = printing with filter

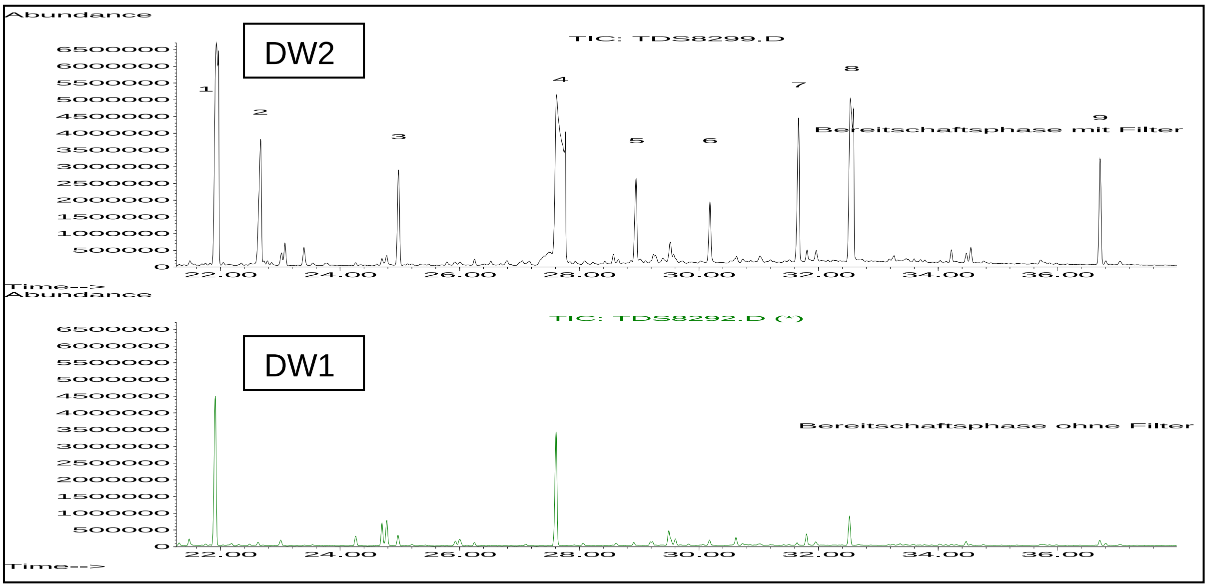
The Dexwet filters themselves emit a few VOCs or SVOCs, i.e., the following substances: decamethylcyclopentasiloxane (1), dodecene (2), dodecamethylpentasiloxane (3), tetradecene (5), phenol (7) as well as two other siloxanes (4 and 6) in the VOC range that could not be identified specifically, as well as a siloxane (9) in the SVOC range (see DW2 graph).

With regard to TVOC emission of a newly produced Dexwet filter, emission rates between **0.12 and 0.22 mg/h** were determined at the ready stage. (The TVOC limit to be met for the Blue Angel label according to RAL UZ 122 is **1 mg/h** at the ready stage.)

At the printing stage, the TVOC emission of a Dexwet filter measured was between **0.29 and 1.50 mg/h**. (The TVOC limit to be met for the Blue Angel label according to RAL UZ 122 is **10 mg/h** at the print stage.) The higher emission rate compared to the ready stage is probably due to the warmer exhaust air from the printer during printout that passes the filter. Apparently, the TVOC emission rate of the Dexwet filters strongly depends on the printer used.

The TVOC emissions of newly produced Dexwet filters were thus lower than the TVOC limit for Blue Angel according to RAL UZ 122 both during the ready stage and during the printing stage.

Chromatograms for a comparison of emission at the ready stage with (above) and without (below) Dexwet filters:



Bereitschaftsphase mit Filter = ready stage with filter
Bereitschaftsphase ohne Filter = ready stage without filter

Summary

7.1 Retention of ultrafine particles in DEXWET filters

The retention capacity of DEXWET filters with regard to ultrafine particles emitted from laser printers was established both quantitatively and qualitatively. The particle emissions from printers with and without DEXWET filters show significant differences in the particle size range typical of laser printers, from approx. 20 nm to approx. 300 nm.

However, the overall results obtained cannot be interpreted as a general confirmation of the effectiveness of the filters because the test design used (measurements in a test cabinet) does not distinguish between filtered and unfiltered partial air flows containing particles that are emitted from a laser printer.

Still, the test design chosen makes it possible, on the basis of the measurement results obtained, to assess the retention capacity of DEXWET filters with regard to particle emissions from laser printers by comparison to particle concentrations at a reference position in an environment simulation cabinet.

The individual types of printers showed significant differences in the details of particle emissions and the effects the filters had on particle emissions. These differences are due to the following factors:

1. different emission characteristics of the printers equipped with different toner cartridges and toner powders. These emission characteristics have been documented by means of the reference measurements (DW1, DW4, DW7, DW10). While the DW7 measuring results showed marked variations in emissions with regard to time and particle size during the print job, the measurements DW1, DW4 and DW10 show rather constant emissions without rapid time-related variations.
2. different air flows in the printers. It is possible that a part of the total air flow emitted from the printer does not pass the equipped DEXWET filters but escapes unfiltered, e.g., through the paper exit or other openings. Depending on the type of printer and the geometry of flow paths as well as size and speed of partial air flows, particles of a certain size may tend to be transported in these partial air flows more often than others and consequently escape in this way. Neither in this research project nor elsewhere have such partial air flows been quantified with regard to their particle contents so far. This hypothesis provides a plausible informal explanation of the retention differences found in the individual printers.

There are differences in size-related retention capacity due to the reasons described above, however, it should be pointed out that the emissions of individual particle size fractions in the area from 130 nm to approx. 200 nm were reduced very effectively, i.e., by considerably more than 50%. For individual classes of particle size, even retention rates around 90% were achieved.

The cumulative retention rate of DEXWET filters is at least 33% in the range from 10 nm to 470 nm. Thus, the number of particles emitted from a laser printer is reduced by at least 33% if the printer is equipped with DEXWET filters.

A number of filters were artificially contaminated with toner dust, which typically has particle diameters around 4 µm. Under these conditions, the contamination was not found to have negative effects on the retention capacity. The filters previously contaminated with toner material were effective to a similar extent as new filters; and allowing for variance in the measuring results to be considered, no significant reduction of the filtering effect of filters contaminated in this way could be proven.

7.2 Retention capacity of DEXWET filters with regard to VOCs

No retention capacity of the DEXWET-Filter could be established with regard to VOCs.

7.3 Recommendations for further research

The tests carried out by BAM to characterise the effectiveness of DEXWET particle filters have shown that use of DEXWET filters definitely contributes to a minimisation of particle emissions from laser printers. For a better utilisation of the potential for development of the DEXWET technology it is recommended to do additional research in the context of a cooperation between BAM and Dexwet Technology Vertriebs GmbH, focusing on the following aspects:

- Further tests should be carried out to examine whether a change in the geometry of the DEXWET filters (e.g., three rows of filter rods, more tightly packed filter rods, etc.) may improve the particle retention capacity (particularly with regard to sizes around 90 nm) without disadvantages or problems for the cooling performance.
- For a further improvement of the DEXWET filters, it would be interesting to analyse to which extent additional air flows occur and which type and amount of particle emissions are released via these air flows (e.g., through the paper exit) without passing the filter. A type-related modification of filter geometry might be an option in this context.

- At present, it cannot yet be stated whether, and to which extent, the retention capacity of DEXWET filters is affected by a contamination with, or the influence of, ultrafine particles with sizes around 100 nm that are typical of laser printer emissions. This would be relevant for determining the period of effective use, however.

- Further examinations of the period of effectiveness of DEXWET filters should be performed. In particular, it would be interesting to define criteria that make it possible for users to see when the period of effective use is ending.

- The elements for attaching DEXWET filters to curved casings could be improved. It should be tested whether the fixing device attached by means of adhesive tape might come off due to climatic influences.

Berlin, 2 January 2007

BAM Federal Institute for Materials Research and Testing

p.p. ORR Dr. Stefan Seeger

AG IV.24 – Characterisation of fibres and particles