Measurement and evaluation of ultra-fine particle emissions from laser printers

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1) WKI, Braunschweig, Germany
2) QUT, Brisbane, Australia
WKI: Institute location
# Scientific Collaboration

<table>
<thead>
<tr>
<th>Institution</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waseda University</td>
<td>Tokyo, 1996 - 2001</td>
</tr>
<tr>
<td>DTU, Lyngby</td>
<td>Guest Professor 2006 - 2007</td>
</tr>
<tr>
<td>QUT Brisbane</td>
<td>since 2001, Adjunct Professor since 2007</td>
</tr>
<tr>
<td>Tsinghua University</td>
<td>Beijing, Guest Professor 2007</td>
</tr>
<tr>
<td>University of Kuopio</td>
<td>Lecturer 2005</td>
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<td>Virginia Tech</td>
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Dynamics of a molecule in the indoor environment

- Deposition in sink (or reaction)
- Attached to particles
- Deposition in house dust
- Exhust with air exchange
- Gas phase
- Emission

VOC/ SVOC Source
Thermodesorptions GC/MS

Tenax / Carbotrap

Thermal Desorption (300 °C)
GC/MS Standards 2007 in WKI

available GC/MS Standards: 910
used in 2007: 542

Frequently used GC-Standards
• Benzene
• Toluene
• 2-Chlornaphthalene
• Ethyldiglycol
• Cyclohexane
• Chlorobenzene
• 4-Phenylcyclohexene
• Ethylenglykolmonomethylether
• Ethylbenzene
• Xylene (o-, m-, p-)
• 1-Chloronaphthalene
• Ethylglykolacetate
• 2-Phenoxyethanol

• Pentanal
• trans-2-Decenal
• Ethoxypropylacetat
• n-Hexane
• Benzaldehyde
• Acetone
• Methylacetate
• Hexanal
• α-Pinene
• Limonene
• Nonanal
• Styrene
• 2-Butanone
Online-Methods

• Photoacoustics
  → CO₂, TVOC_PAS (calibrations vs. propane)

• Chemoluminescence
  → NO, NO₂

• UV/Fluorescence
  → Ozone

• Proton-Reaction-Mass-Spectrometry (PTR-MS)
  → Selective mass monitoring [M+1]

• Online-Derivatisation
  → Formaldehyde (Acetylacetone-Method)

• Particle counting methods
  → Size distribution
Research

Building product terpene/ozone-reactions and particle formation
Toftum et al. (2008) Atmospheric Environment, available online
Gas-/Particle distribution of SVOCs

Weschler et al. (2008) Atmospheric Environment, 42, 1449
Research

Degradation of TDCPP

Indoor Chemistry
Uhde and Salthammer (2007), Atmospheric Environment, 41, 3111
Research

Photocatalytic reaction on indoor wall paint
Salthammer and Fuhrmann (2007), ES&T, 41, 6573
Research

Emission of nanoparticles from electronic equipment

Schripp et al. (2008), ES&T, 4338

Research

Emission of formaldehyde from mineral wool
Salthammer and Mentese (2008), Chemosphere, available online
Particle Emission Characteristics of Office Printers

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e-t他知道在原子能领域，发现新粒子是科学家们的一大挑战。这是一项需要大量时间和精力的工作，但它的重要性不言而喻。科学家们通过实验和观察，不断探索未知领域，为人类的科技进步作出贡献。
Particle concentrations in a Brisbane office room

He et al. (2007) ES&T, 41, 6039
IT'S GETTING CROWDED OUT HERE!

SMOKING AREA

Laser Printer

Microwave Popcorn
Emissions from Electronic Devices

Particles

VOCs

SVOCs

O3 Ozone

Destaillets et al. (2008) AE, 42, 1371
Performance of a chamber emission test

- Loading factor: 1 unit/chamber
- Chamber size: 1 m³; 8 m³, 24 m³
- Printing duration: Cascade, 10 min each
- Temperature: 23°C
- Rel. humidity: 10% → 80%
- Air exchange rate: 3.0 h⁻¹

Air inlet → Adsorption → GC/MS

Online monitoring → Identification

Loading factor: 1 unit/chamber
Chamber size: 1 m³; 8 m³, 24 m³
Printing duration: Cascade, 10 min each
Temperature: 23°C
Rel. humidity: 10% → 80%
Air exchange rate: 3.0 h⁻¹
WKI 1 m³ chamber for printer particle emission testing

Fast Mobility Particle Sizer (FMPS)
5.6 – 560 nm
32 channels
time resolution: 1 s
Chamber experiments at QUT

Diagram:

- SMPS
- CPC
- PID
- Tenax Tube, Filter and Pump
- Chamber 2
- Printer
- VH-TDMA
- DustTrak
- CPC
- APS
- Q-Trak
- Ozone Analyser
- Particle & VOC free air
- Thermo-Couple 3
- Chamber 1

Logos:
- QUT International Laboratory for Air Quality and Health
- Fraunhofer Wilhelm-Klauditz-Institut Material Analysis and Indoor Chemistry
Flow tunnel experiments at QUT

- Printer
- TEM grids
- Transparent polycarbonate
- O-Trak
- Anemometer
- PID
- CPC
- DusiTrak
- SMPS
- APS
- Ozone analyser
- Tenax Tube, Filter and Pump
- Flexible metallised polyester 400mm diameter ducting
- HEPA module
- Speed controlled fan module
VOC-Emissions from a laser printer

**Standby**

**Printing**

**Typical Emissions**
- BTEX-aromatics
- Phenol
- Benzaldehyde
- 2-Ethyl-hexanol
- BHT
- Alkanes (C6 – C14)
- Siloxanes
Measuring Ozone using UV-Absorption (254 nm)
Emissions in flow tunnel (experiments at QUT)
Sum of particle number concentration (5.6-560 nm) vs. time (1 m³ chamber)

Printed Particle Emissions – LBL, 9.10.2008

k₁ → ACH

k₂

Deposition
Condensation
Calculation of the true printer emission rate (SER)

True Particle Emission Rate
SER(t)

Chamber Response Function
D(t) = e^{-kt}

Experimental Concentration Curve
C(t)

Convolution

Deconvolution

Schripp et al. (2008) ES&T, 42, 4338
The Convolution Integral

\[ c(t) = [L \cdot \text{SER}(t)] \ast D(t) = \int_0^t [L \cdot \text{SER}(\tau)] \cdot D(t - \tau) \, d\tau \]

numerical solution
with \( D(t) = e^{-kt} \) \((k = k_1 + k_2)\)

\[ \text{SER}_u(t) = \frac{c(t) - c(t - \Delta t) \cdot e^{-k \cdot \Delta t}}{L \cdot \Delta t \cdot e^{-k \cdot \Delta t}} \]

Schripp et al. (2008) ES&T, 42, 4338
Calculation of the Specific Emission Rate \( \text{SER} \) – experimental data

Schripp et al. (2008) ES&T, 42, 4338
Hardcopy device: particle number concentration vs. particle size and time (25 m³ chamber)
Hardcopy Device: particle number concentration vs. particle size and time (25 m³ chamber)
Laser printer UFP emission – FMPS results particle number concentration vs. particle size and time bimodal size distribution

print-to-print repeatable

constant emitter

initial burst emitter

Print without toner and paper – fuser only

Results from real-room and chamber measurements with one printer

Volutility of UFP - TSI Thermodenuder 3065

400°C

320°C

160°C
Volatalisation temperature of particles generated by printer

![Graph showing volatalisation temperature of particles generated by printer]
Fuser unit as major source for heat (ca. 170 °C)

Thermography of fuser roller switch on and 5 min printing without paper
Chemical characterization of UFP

Nanometer Aerosol Sampler

Gas Chromatography

Mass Spectrometry

Analysis of collected „Aerosol“

Trixyl phosphate, MW = 410
Flame retardant; content of fuser unit

Di-isopropynaphthalene
Traces; content of paper

Analysis of SVOCs sampled on a particle filter

![Graph showing analysis of SVOCs](image-url)
Release of particles from a laser printer

- board cooler (21,667 ± 4,784)
- rear of printer (214,333 ± 90,754)
- paper tray (206,000 ± 68,644)
- fan & toner waste (50,000 ± 20,000)
Efficiency of filters

Summary and Conclusion

- Chamber measurements are useful for characterizing the physical and chemical nature of UFP emissions from laser printer → standardization of a test method required.
- The available results indicate that laser printers can be classified in view of different UFP emission behaviors, e.g. “constant emitter” and “initial burst emitter”.
- UFP release can also be detected in the absence of paper and toner.
- The particles are formed in the printer from VOC and SVOC by nucleation and condensation.
- The particles evaporate at higher temperatures.
- The (hot) fuser unit seems to be one important source for the release of UFPs.
- The time vs. concentration behavior of emitted particles is different in the test chamber and in real rooms.
- If negative health impacts of the released UFPs can be verified, the necessary minimization procedures should be done by variation of construction details and thus modulating sources, not by adding filter accessories.