Characterization of Dust and Water Steam Aerosols in False Alarm Scenarios - Design of a Test Method for Fire Detectors in Dusty and in Highly Foggy Environments

kruell@nts.uni-due.de  http://nts.uni-duisburg.essen.de
Heinz Luck Fire Lab, University of Duisburg-Essen, Germany

**Fire Lab**
- Surface area: 34.5 ft * 29.5 ft
- Flexible room height: 9.4 ft … 21.5 ft

**Test scenarios**
- Fire tests in the initial stage of a fire (EN 54)
- Experiments concerning the distribution of smoke and fire gases under variable conditions
- Nonstandard test scenarios (e.g. Airbus A400M-reproduction)
- Dust tests
- Nuisance tests of smoke detectors in high humidity environments
Motivation

Sensors of Automatic Fire-Detection Systems
• Smoke (optical, ionisation)
• Temperature
• Gas
• Flames (IR and UV radiation)
• Video (radiation and opacity)
• …

Task  Fast alerting in case of a fire,
      best at its very beginning (100% detection)

Target  Keep the damage as low as possible

Requirement  Almost no alarm in the “fire-free” time
Motivation

Sensors of Automatic Fire-Detection Systems

Difficult detection situation for an optical smoke detector

⇒ Similar situation for multi-sensor detectors
Motivation

Fire brigade Duisburg data, 2008

- 374 Automatic Fire Alarm Systems
- 533 Alarms from Automatic Fire Alarm Systems

- technically regular alarm, however no fire!
- fire: 44%
- technical failure: 21%
- unclear: 16%
- malicious alarm: 3%
• False alarms are unwanted
• False alarms are expensive
Motivation

Situation in aviation

• Very high safety standards
• Highly sensitive systems due to FAA rules
• Inaccessible areas during flight
• High false alarm rate, about 100:1

Causes of false alarms in aviation

• Insecticides
• Wet Cargo
• Fog
• Dust
Motivation

Examples for causes of false alarms of optical smoke detectors

- Drilling
- Sawing
- Other mechanical works
- Cooling
- Cooking
- Cleaning (e.g. in playschools)
- …

\( \sim 10\% \) of false alarms are caused by dust

\( \sim 10\% \) of false alarms are caused by water steam
Motivation

Examples for causes of false alarms of optical smoke detectors

- Drilling
- Sawing
- Other mechanical works
- Cooling
- Cooking
- Cleaning (e.g. in playschools)
- …

Causes of false alarms in hotels

- Extended showering
- Extended damping of clothing in bathrooms
- 60% of hotel alarms in Frankfurt
Motivation

Approaches to reduce false alarms

- Implementation of filters for point type detectors / aspirating systems
- Additional detection algorithm elements
- Combination of different sensor principles
  - Light-Scattering & Temperature & Gas
- Enhanced optical analyses
  - Different scattering angles (forward, backward)
  - Different wavelengths (blue, infra-red)

Companies offer smoke detectors that promise to be resistant to dust and water steam.
- What is the value of such statements?
Motivation

Fire-Tests

- Standards for sensitivity of smoke detectors to detect a fire are well defined, e.g. EN54 defines the fire types as well as the smoke levels to be detected
- Long tradition performing fire tests
- The focus of these standards is smoke detecting
Motivation

Fire-Tests

Unfortunately the developer has no test methods to quantify new developments.

Non-Fire-Tests
Motivation

Objectives of non-fire sensitivity dust and water steam tests

- Providing a tool for developers to quantify reproducible new developments to minimize the false alarm rate.
- Providing a decision criterion to find an adequate detector for a specific place of installation.
- Finding an objective and reproducible test method to measure the response characteristic of fire detectors in foggy and dusty areas.
- Classifying optical smoke detectors during the certification process.
Motivation

Objectives of non-fire sensitivity dust and water steam tests

• Knowledge of dust sources and dust properties
• Standardized dust test material
• Reproducible dust production
• Knowledge of water steam properties
• Professional components and measurement equipment
• Realistic and reproducible test procedure
• Easy to copy apparatus

1 Dust  2 Water steam

Wolfgang Krüll, Thorsten Schultze, Robert Tobera & Ingolf Willms

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Characterization of Dust and Water Steam Aerosols in False Alarm Scenarios
Characterization of dust particles
Sources and properties of dust

**Man-made dust**
- Soot
- Power plants
- Agriculture
- Industrial processes
- Rubber scrubbed from tyres

**Natural sources**
- Volcanic eruptions
- Sea salt
- Forest and grassland fires
- Dust storms
- Pollen
Material and tools for the performed measuring campaign

<table>
<thead>
<tr>
<th>Material</th>
<th>Tools for work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glued Laminated Timber (Glulam), spruce wood</td>
<td>Belt sander</td>
</tr>
<tr>
<td>Glued Laminated Timber (Glulam), beech wood</td>
<td>Belt sander</td>
</tr>
<tr>
<td>Gypsum wallboard</td>
<td>Belt sander</td>
</tr>
<tr>
<td>Cellular concrete</td>
<td>Angle grinder</td>
</tr>
<tr>
<td>Lime sand brick</td>
<td>Angle grinder</td>
</tr>
<tr>
<td>Concrete block</td>
<td>Angle grinder</td>
</tr>
<tr>
<td>Brick (red)</td>
<td>Angle grinder</td>
</tr>
<tr>
<td>Cement</td>
<td>Hair dryer</td>
</tr>
<tr>
<td>Cellular concrete</td>
<td>Twist drill for power sockets</td>
</tr>
<tr>
<td>Lime sand brick</td>
<td>Twist drill for power sockets</td>
</tr>
</tbody>
</table>
Distribution density $q_3$ of particle sizes of dust

Grinding a red brick

5 ft / 1.6 m distance

13 ft / 4 m distance

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Distribution density $q_3$ of particle sizes of dust

**Sanding spruce wood**

![Image of sanding spruce wood](image)

![Graphs showing distribution density](graphs)

<table>
<thead>
<tr>
<th>Distance</th>
<th>Measurement 1</th>
<th>Measurement 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 ft / 1.6 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 ft / 4 m</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Distribution density $q_3$ of particle sizes of dust as a function of the distance to the measuring device

1.6 m

4.0 m

1.6 m

4.0 m
Distribution density $q_3$ of particle sizes of dust as a function of the distance to the measuring device

1.6 m

4.0 m

The sedimentation velocity of airborne particles is strongly dependent on their size.

A particle of 10 $\mu$m settles about 5 mm in 1 s.

A particle of 0.1 $\mu$m settles about 0.05 mm in 1 s.
Apparatus for the test of optical smoke detectors in dusty environments
New concept of duct type test apparatus

- Ultra-small test chamber
- EN54-like test procedure & reference measurement system
New concept of duct type test apparatus

**Advantages**
- Compact construction, low weight and portability
- Easy cleaning due to fast dismounting and small volume (40 l)
- Extremely low amount of dust needed
- Almost laminar airflow in the measuring zone
New concept of duct type test apparatus

**Advantages**

- Compact construction, low weight and portability
- Easy cleaning due to fast dismounting and small volume (40 l)
- Extremely low amount of dust needed
- Almost laminar airflow in the measuring zone

- Velocity and direction of inflow in the detector can be adjusted
- Airflow adjustable between 0.2 m/s ... 1 m/s
- Controllable and reproducible dust supply
Controllable and reproducible dust supply

**PALAS powder disperser RBG 1000**, adjustable parameters

![Diagram of the PALAS powder disperser RBG 1000](image)

- **aerosol**
- **dispersing air**
- **brush**
- **powder reservoir**
- **transportation piston**
- **feed**
Controllable and reproducible dust supply

**PALAS powder disperser RBG 1000** , adjustable parameters

- Rotation speed of the brush
  600 U/min ... 1200 U/min

- Use of standardized dust types
  Dolomite < 90 µm

- Cross section of the powder reservoir
  7 mm, 14 mm, 28 mm

- Dispersing air
  0.5 bar ... 2 bar

- Feed rate
  1 mm/h ... 590 mm/h
Aging process inside the test apparatus

Boundary condition
(23 ± 5) °C
(55 ± 15) % relative humidity

Controlled dust supply
Slowly increasing dust exposure of optical smoke detectors

0.05 \leq \frac{\Delta m}{\Delta t} \leq 0.07 \text{ (dB m}^{-1} \text{ min}^{-1})

Typical slew rate of aerosol concentration for EN54 tests \approx 0.06 \text{ dB m}^{-1} \text{ min}^{-1}

(e.g. measurement of the response behaviour and directionality)
Fast increasing dust concentration

- In order to determine the typical increase of the dust concentration caused by construction works the mean increase of the aerosol concentration in the dust scenarios has been calculated.

- The resulting curve of the extinction $m_{\text{Ext}}$ [dB/m] shows a non-linear behaviour. $\Delta m / \Delta t = 0.5$ (dB m$^{-1}$ min$^{-1}$)

Typical alarm threshold of optical smoke detectors for fire tests
Fast increasing dust concentration

$0.4 \leq \frac{\Delta m}{\Delta t} \leq 0.6$ (dB m$^{-1}$ min$^{-1}$)

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Characterization of Dust and Water Steam Aerosols in False Alarm Scenarios

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Comparison of the RTV-value in an EN54 smoke channel with a slowly and fast increasing dust exposure

Response behavior in an EN54 smoke channel
Slowly increasing dust exposure
Fast increasing dust exposure

Response behavior in an EN54 smoke channel
Slowly increasing dust exposure
Fast increasing dust exposure

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Characterization of water steam
Characterization of water steam

Field test

• 6.5 ft x 6.5 ft shower cubicle
• Devices mounted at a height of 7.5 ft
• Two different measuring positions
• 5 min showering before the door was opened
• Measurement until all particles were evaporated
Distribution density $q_3$ of particle sizes of water steam

Position 1
3.3 ft distance

Position 2
6.6 ft distance
Emulation of the nuisance aerosol

Airbrush as an aerosol generator

- Good correlation with the shower scenario measurement.
- Works with compressed air and demineralized water at ambient temperature.
- Aerosol generation without heating up the air inside duct and DUT.
- No condensation on optics!
Emulation of the nuisance aerosol

Controlling aerosol concentration

- Airbrush works with dry pressured air
  - No condensation (dew point)
- Aerosol size at DUT determined by
  - Evaporation
    - Temperature
    - Relative humidity
  - Deposition
- Remote controlled aerosol concentration
  - Airbrush connected to servo motor
  - PID control realised with Labview
Duct type test apparatus for fog tests

Advantages

- Compact construction, low weight and portability
- Small volume (32 l)
Duct type test apparatus for fog tests

Advantages

• Compact construction, low weight and portability
• Small volume (32 l)
• Temperature range
  18 °C – 28 °C
• Relative humidity range
  10 % rH – 99 % rH
• Airflow 1 m/s

• Allows operation in high humidity environment
  ➔ Essential for a reproducible and controlled aerosol concentration
Duct type test apparatus for fog tests

**Linear ramp approach**

- Reproducible ramp
- $0.5 \text{ dB m}^{-1} \text{ min}^{-1}$
- Offers a reliable measure for the response characteristic of an optical smoke detector
Comparison of the RTV-value in an EN54 smoke channel with fog tests

0.402 dB/m
0.152 dB/m
0.123 dB/m

5.00 dB/m
3.37 dB/m
2.43 dB/m

mean values of 3 optical smoke detectors
Duct type test apparatus for fog tests

Emulation of the shower induced extinction

- Step function approach as a strong reference to the real false alarm scenario in e.g. hotels.
- Maps the fast concentration increase measured during the test campaign.
- Implementation as a stress test for optical smoke detectors is possible.
Summary and outlook

✓ 2 test devices for the evaluation of optical smoke detectors in non-fire scenarios have been developed
  ➔ simple cleaning, small volume, portable, easy to handle
✓ Aerosol concentration slew rates are reproducible
✓ Different slew rates can be adjusted
✓ Easy to handle apparatus
Summary and outlook

Test apparatus for dust tests

✓ Several dust sources have been analyzed during a big field campaign
✓ Dolomite test dust DMT 90 as test dust is a good solution
  (particle size < 90 μm)
✓ Simulation of a slowly increasing dust exposure
  of the optical smoke detector is possible
✓ Simulation of a fast increasing dust concentration
✓ The main topics of the developed test apparatus have been
  adopted by the Aerospace Standard AS 8036
Summary and outlook

Test apparatus for fog tests

- The particle size distribution of water steam caused by showering and cooking has been analyzed during a big field campaign.
- An airbrush pistol as source of water steam is a good solution.
- Aerosol concentration slew rates are reproducible.
- The developed test device for water steam tests is a good emulation of the shower scenario.
- It’s a promising first step for designing a new test method.
Publications

• W. Krüll, T. Schultze, R. Tobera & I. Willms
  *Apparatus for the test of fire detectors in dusty environments*
  15th International Conference on Automatic Fire Detection, AUBE '14, Duisburg, Germany, October 2014

• R. Tobera, W. Krüll, T. Schultze & I. Willms
  *Apparatus for the test of fire detectors in high foggy environments*
  15th International Conference on Automatic Fire Detection, AUBE '14, Duisburg, Germany, October 2014

• W. Krüll, T. Schultze, R. Tobera & I. Willms
  *Characterization of dust aerosols in false alarm scenarios*
  15th International Conference on Automatic Fire Detection, AUBE '14, Duisburg, Germany, October 2014

• W. Krüll, T. Schultze, R. Tobera & I. Willms
  *Analysis of dust properties to solve the complex problem of non-fire sensitivity testing of optical smoke detectors*
  9th Asia-Oceania Symposium on Fire Science and Technology, AOSFST, Hefei, China, October 2012.

• W. Krüll, T. Schultze, I. Willms & A. Freiling
  *Developments in Non-Fire Sensitivity Testing of Optical Smoke Detectors - Proposal for a New Test Method*
  10th International Symposium on Fire Science, University of Maryland, College Park, Maryland USA, June 2011

• W. Krüll, T. Schultze, I. Willms & A. Freiling
  *Development of a test installation to determine false alarm susceptibility of smoke detectors*

• W. Krüll, T. Schultze, I. Willms & A. Freiling
  *Test Apparatus for the Evaluation of the Behaviour of Smoke Detectors in non-fire Situations*
  2010 International Symposium on Safety Science and Technology, 2010 ISSST, Hangzhou, China, October 2010

• I. Willms & W. Kruell
  *Developments in Non-Fire Sensitivity Testing*
Thank you for your attention!

http://nts.uni-due.de
Graphical comparison of ISO 12103-1 dust and DMT D90 dust

ISO 12103-1 test dust A1 .. A4 (1)  
DMT D90 test dust (2)

Source:  
1  Powder Technology Incorporated (PTI)  
2  DMT GmbH & Co. KG, Essen, Germany

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