Characterization of Nuisance Aerosols for scattered-light Smoke Detection

Aleksandar Duric, Martin Sepiol, Christian A. Bruun, Armend Zendeli, Thomas Attinger, Christian Spagno, Ulrich Kuhn-Matysiak
Siemens Schweiz AG, Zug, Switzerland

Abstract

False alarms have been the subject of increased debate within the fire safety community and standardization groups around the globe. Results from both the field [1] and Siemens internal investigations support previous findings [2], which identified the most common nuisance aerosols for commercial (non-residential) smoke detectors to be steam (cooking, showering or industrial sources) and, to a lesser extent, dust (industrial sources, construction works, as well as house dust). In 2016, the first test for robustness against cooking nuisances has been introduced in the UL268 7th edition standard for multi-criteria smoke detectors. In view of this development, the properties of common nuisance aerosols and their effects on scattered-light smoke detectors were investigated in laboratory conditions.

Within the scope of this work, aspects of nuisance scenarios, reproduced under laboratory conditions, have been investigated. They include the selection of a suitable test setup, the influence of environmental conditions, the characteristics of aerosol propagation within the laboratory, the aerosol entry into the detector, and the sensing of the aerosol by the detector. The findings show that the challenge in developing a fire detection technology with active distinguishing between fire and non-fire aerosols lies not only in picking the optimal light scattering configuration but also in choosing test procedures, which reflect field applications and have sufficient stability. Both aspects require attention when developing standardized tests.

Keywords: nuisance aerosol, smoke detector, light scattering

Introduction

A recent study on fire alarm statistics in selected European countries [1] showed that, on average, only one in ten fire alarms is caused by a real fire. The remainder are false alarms. Although it is oftentimes difficult to determine the cause of a false alarm, non-fire aerosols, such as steam or dust, or environmental factors, such as electromagnetic interference, likely represent the most common trigger. These so called deceptive (or unwanted) alarms account for almost one third of evaluated events [1]. Improving a fire sensor's stability and selectivity, that is, its capacity to actively distinguish between fire and deceptive phenomena, is therefore a vital contribution to the overall reduction of false alarms and to the strengthening of confidence in fire detection as a life safety mechanism.

Laboratory setup

To elucidate different aspects of nuisance scenarios and their impact on the performance of fire detectors, experiments were conducted in a climate-controlled fire test laboratory. The room is a Siemens custom design test facility with dimensions of 3x3x3 m and temperature control to within ±2 K, between -30 °C and +70 °C. The laboratory further accommodates reference sensors for probing aerosol and environmental characteristics.

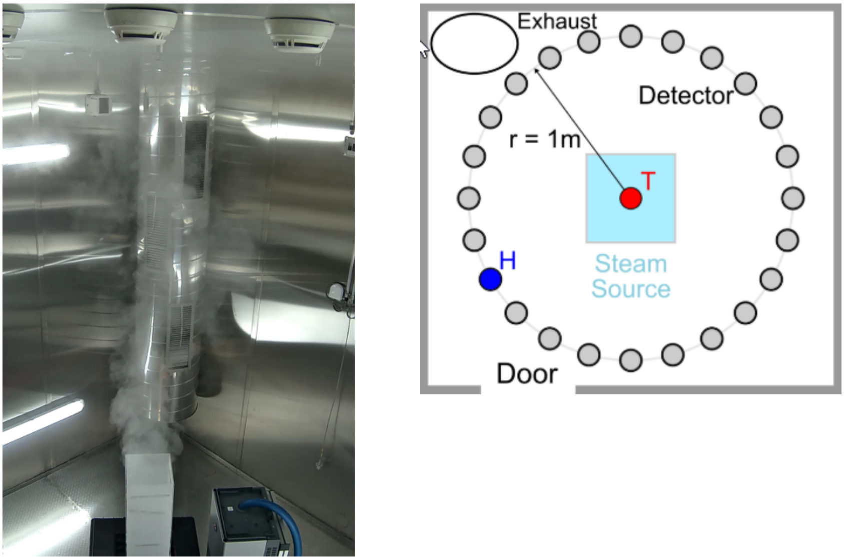

Fig. 1. Left: Test lab photo during a steam test. Right: schematic of the ceiling setup, H = humidity sensor, T = temperature sensor, circles denote detector positions on 1m-circle. Schematic not to scale.

Throughout the experiments, the optical scattering properties of the nuisance aerosols were measured using a multi-angle scattering chamber (MASC) instrument [3]. The MASC signals were analysed and compared to signals from common scattered-light configurations in smoke detectors.

Steam test

The steam test has been designed to expose smoke detectors to levels of steam typically encountered close to a shower or cooking area.

It is conducted in the climate-controlled fire test laboratory described in the section above. Over the past two years, the test has been fine-tuned and put to use in numerous test campaigns aimed at testing a detector's resilience to steam. A commercial humidifier Carel Heater Steam UR013 HL103 (FA Carel Industries, Italy) is used as a steam source and a rectangular chimney of 80 cm length for straightening the steam flow towards the ceiling. Ambient parameters such as temperature and relative humidity are recorded throughout a test run. Additionally, the density of condensation nuclei in the laboratory air is sampled at the beginning of each trial using a condensation particle counter (CPC Grimm 5403) covering a size range of 4.5 nm to ~3 μm. Experience from past test campaigns shows that 2 to 3 reproducible runs at room temperature can be conducted each day on the same detector setup. The cycle time is limited by the time it takes for the laboratory to dry and reach acceptable starting conditions.

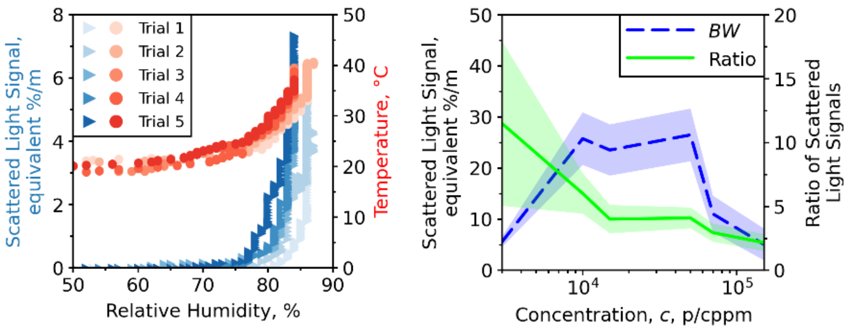

Fig. 2. Left: temperature (red) and scattered light signal of conventional smoke detectors (blue) vs. relative humidity in the room over a range of 5 tests over 5 consecutive days; right: light scattering signal and ratio of light scattering signals Ratio = BW/FW (BW and FW are backward and forward scattering signals, respectively) in the alarm range of smoke detectors vs. particle concentration prior to steam exposure (shaded area = 1σ).

Graph on the left-hand side in Fig. 2 shows the development of temperature and detector scattering signal over a range of steam tests, versus relative humidity increase after steam release. The temperature increase of 20 K under constant ambient conditions is repeatable and coincides with the increase of scattering signal. Such an increase can be observed in real field conditions during steam development and makes this nuisance challenging for multi-criteria detectors using optical and thermal sensors.

The room size and the steam path from source to the detector will determine actual temperature and humidity increase, hence particular care needs to be taken when this test is performed at small scale.

Controlling the concentration of ultrafine particles in the test room, which act as condensation nuclei, was crucial for reproducible steam tests. This means that besides temperature and humidity, air quality in the lab and the seasonal variation of particle concentration needs to be considered when conducting steam test. Prior to steam generation, soot particles were produced by a short activation of Bunsen burner and evenly distributed in the room using a fan, and then sampled by CPC. At most tested particle concentrations, except at the highest ones, the scattered light signals were not elevated prior to steam exposure, indicating that the majority of particles were small and not detected by smoke detectors. Right hand-side graph in Fig. 2 shows the effects of particle concentration on the scattered light signals. The steam density, quantified by the scattered light intensities, increases with particle concentration.

At the lower end of particle concentration ~3 k#/cm^3 the detector signals due to steam were insufficient to trigger alarm and the test was not reproducible. On the opposite side, towards large particle concentrations the ratio of light scattering signals during steam exposure decreased, indicating that the aerosol properties changed towards smoke-like aerosol. For the subsequent analysis, the experiments were conducted at ~10 k#/cm^3, which is in the range of normal city air [4].

To investigate the development of scattered light signals within the optical chamber of smoke detectors during steam tests, a miniature camera module NanEye (FA ams AG, Austria) was placed inside the optical chamber and synchronized with the scattered light measurement (see Fig. 3 below).

Condensation signal on the lens surface is used as an indication for the level of condensation inside the optical measurement chamber. It is assumed that as condensation on the lens surface increases, the background signal in the chamber will also increase, as the surface scattering properties of the chamber walls change. From the synchronized condensation and detector scattering signals as well as from the analysis of video recordings, the contribution of steam aerosol and condensation to the scattering signals, i.e. to the detector alarm can be evaluated. Typical time range where alarm of single scattering detectors occurs in these trials is marked orange in Fig. 3., (lower left) indicating that both the steam aerosol and the condensation (less than 50 % of lens surface covered by condensation) in the optical chamber contribute to the scattering signal.

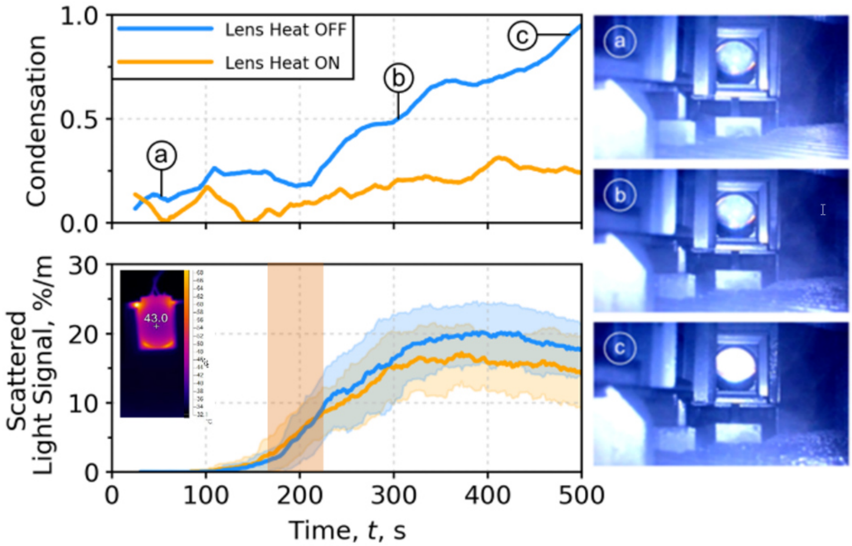

Fig. 3. Data from a scattered-light smoke detector, subjected to a steam test at room temperature (21.5 °C). The photographs in the right column of the figure were taken with an endoscope camera, placed inside the detector's optical measurement chamber, and pointing towards the lens in front of the photoelectric sensor that measures the scattered light. The images show the condensation buildup within the measurement chamber, with "a" being the state at the beginning of the test, "b" being the state at approximately 50 % condensation, and "c" being the state close to maximum condensation. The level of condensation on the surface of the lens, plotted in the top left graph, is determined by the amount of light reflected from it. The graph on the bottom left shows the corresponding smoke detector signal (forward-scattered light). In the lower left graph, the IR image of heated lens is embedded.

By heating the lens to 43 °C using a wire wrapped around the lens, the influence of lens condensation can be studied. Comparison of scattering signals with lens heating switched on and off shows that the condensation in the alarm range does not influence significantly both the scattering signal and its variance, indicated by the shaded area (1σ) in the lower plot in Fig 3. The signal variance is attributed to the steam clouds traveling through the optical chamber. Increased lens condensation (states "b" and "c" in Fig. 3) affects its collimating function. The average scattering signal with lens heating switched off is therefore slightly larger as the lens collects more background chamber signal, which is also increased due to the condensation layer on the chamber walls.

Dust tests

While it was possible to investigate most nuisance sources in the fire test laboratory, dust exposure scenarios were emulated using either a dust channel or a box with swirled dust to avoid dust contamination of the laboratory and its exhaust system. However, testing in such confined spaces poses additional challenges. In the case of dust, unwanted particle size filtering and the associated distortion of the particle size distribution significantly influences the detector response.

This situation was investigated by measuring angularly resolved polarized scattering signals using the MASC instrument [3].

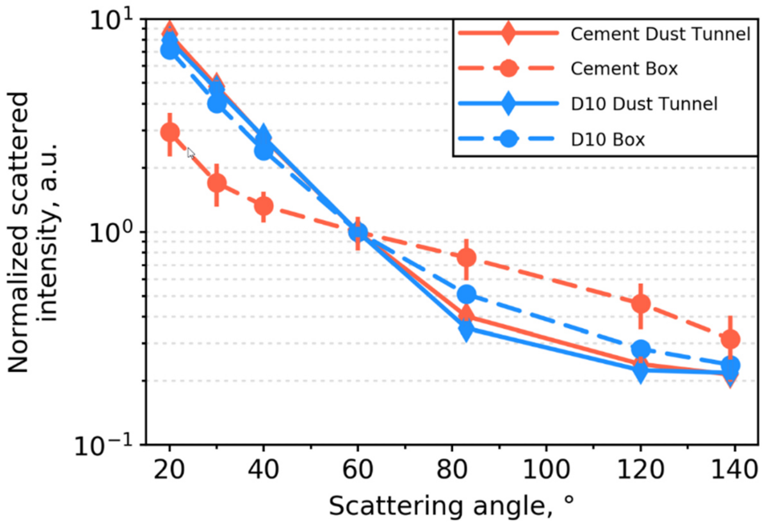

Fig. 4. MASC scattered-light intensity measurements for D10 and cement dust at parallel polarization and a wavelength of 846 nm, normalized to the value at 60°.

These measurements are shown in Fig 4. For two dust types (Dolomite 10 and cement) and two different dust application methods. In the first application method, dust is circulated with 1 m/s in a tunnel and continuously sampled by MASC. This method produced a rather stable angular distribution of scattering signals (solid lines) with small difference between the two dust types. We attribute this effect to the rather high air velocity and geometry of the dust tunnel (~5 m long with 4 bends), which allows for large particles to settle down and having impacting effects on them at the bends (100 µm particles have settling time of ~1 s per meter). This stable particle distribution corresponds more to dust suspended in air over longer time periods and at lower air velocities.

In another application method the cement and D10 dust were swirled in a square box with a volume of ~0.1 m^3 for a short period of time and immediately sampled by MASC. The scattering signals exhibit a more flattened angular distribution (dashed lines) indicating a different particle size distribution, in case of cement more sharply increasing towards small angles, possibly due to the presence of large particles.

D10 particles were differently affected by the application processes. Smaller dependence of D10 scattering signals on the application method can be attributed to its particle size distribution being practically limited to 10 µm (settling time ~2 min per meter [5]).

Although the trial reproducibility (the length of error bars represents one geometrical standard deviation) in the case of swirled cement is significantly less than in the dust tunnel, the difference between scattering signals for swirled particles in a box and particles circulated in a tunnel can be clearly observed. The former case resembles a detector being very close to the dust source or single or periodic events of dust release, e.g. switching on the ventilation in dusty industrial environment. To our experience this is also a relevant nuisance source for commercial detectors.

Conclusions

In this work, two of numerous nuisance scenarios reproduced under laboratory conditions are presented. Steam and dust are considered most relevant nuisance aerosols for commercial fire detectors, which are used in vast number of different applications, from rather clean office environment to hostile environments like dusty industrial areas. A performant fire detector is expected to cover all required applications without false alarms.

Maintaining well controlled ambient conditions, including the concentration of ultrafine particles, a good reproducibility of the steam test was achieved, making it suitable for routine performance testing of fire detectors. Beside scattered light signals a reproducible temperature increase of 20 K makes this test challenging for multi-criteria detectors. Contribution of condensation effects in the smoke chamber to the scattering signals during steam trials was investigated and compared to the contribution of steam aerosol. It was found out that in the range of alarm for today's detectors, they both contribute to similar extent. Condensation on the optical elements (e.g. lens) does not change the scattering signals and the overall detector response significantly.

Effects of dust on the scattering signal shown to be dependent on the dust type and the application method (circulated in a tunnel or swirled in a box). In contrary to D10 dust, angular distribution of scattering signals for cement dust significantly depends on the application method most likely due to its particle size distribution extending towards large particles. To our experience, both dust application methods resemble realistic field cases and should be considered in performance testing.

Acknowledgements

The authors would like to thank Prof. Markus Loepfe from FHNW in Windisch for his scientific advice during this work.

References

[1] S. Festag et al., *“False Alarm Study: False Alarm Data Collection and Analysis from Fire Detection and Fire Alarm Systems in Selected European Countries*”, ISBN 978-3-503-18100-1, June 2018.

[2] W. Krüll, et al., *“Non-fire Sensitivity Testing of Optical Smoke Detectors”*, AUBE'17/SUPDET2017, September 2017.

[3] J. Robertz et al., *“Portable instrument for online investigations of optical properties of airborne particles”*, AUBE'17/SUPDET2017, September 2017.

[4] https://www.umweltbundesamt.at/fileadmin/site/publikationen /rep0656.pdf, 02.2021.

[5] W. C. Hinds, “Aerosol Technology”, 2nd edition, ISBN 0-471-19410-7, 1999.