Apparatus for the Test of Fire Detectors in Dusty Environments

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Abstract

Optical smoke detectors are designed to detect small concentrations of smoke to ensure a fast and reliable detection of arising fires. Unfortunately the complex task of avoiding false alarms is not completely addressed. In contrast to the well standardized methods for the evaluation of the detection capability of a smoke detector, there is a lack of reproducible and representative test methods concerning the false alarm susceptibility with regard to nuisance aerosols.

A recent study says that about 10 % of false alarms are caused by dust. For this reason this paper presents a new approach for the test of optical smoke detectors regarding their susceptibility to false alarms due to the nuisance aerosol dust. The presented test apparatus is a very helpful and important tool for developers as well as for system designers having a quantitative decision criterion to find the optimal detector for a specific scenario.

Keywords: Fire detection, false alarm susceptibility, dust properties, test method, non-fire sensitivity

Introduction

Many false alarms are caused by construction works in the surrounding of optical smoke detectors. A recent study shows that about 10 % of false alarms are caused by dust [1]. Unfortunately the developer of smoke detectors has no representative test methods to quantify improvements and to point out the dust resistance of new developments. For this reason a test apparatus for the test of optical smoke detectors regarding their susceptibility to false alarms due to the nuisance aerosol dust has been developed.

Test dust for non-fire sensitivity testing

To solve the complex problem of false alarms caused by dust it was necessary to understand the very different dust properties such as the particle size distribution and relevant rise rates of dust concentration. For this reason several dust sources have been analyzed during an extended field campaign [2]. Relevant for the design of a test procedure is the choice of test dust type. The analysis of the measured particle size distributions revealed that DMT Dolomite 90 with its standardized grain size distribution is a good solution [2][3]. Fig. 1a shows the volume fraction of the DMT Dolomite 90 test dust. Dolomite is a vacuum cleaner test dust in accordance with DIN IEC 60312. Compared to the four grades of test dusts specified in ISO 12103-1 [4], Dolomite 90 as test dust is a quartz-free material and is not hazardous to health. Dolomite 90 test dust consists of particles in the same range as the ISO test dusts. It covers the whole dust range of "ISO ultrafine" (A1, about 3.5 % smaller than 1 µm) and "ISO fine" (A2) [5].

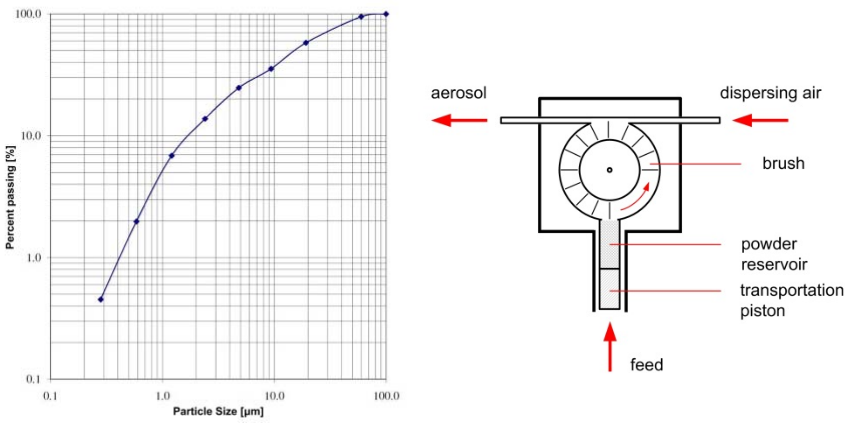

Fig. 1. (a) Volume fraction (%) of Dolomite 90 test dust [3]; (b) Palas powder disperser RBG 1000 [7].

Feeding such dust types manually into a test apparatus typically leads to a hardly reproducible particle density distribution as many particles stick to each other giving a higher density of larger particles [6]. For this reason the Palas RBG 1000 powder disperser was used for reproducible dust supply. The dust powder has to be filled into a cylindrical reservoir and is transported onto a rotating brush. Dispersing air streams over the brush and pulls the powder out of the brush. Dosing is performed using the precisely controlled feed rate of the feed piston [7]. The schematic of the Palas powder disperser RBG 1000 is shown in Fig. 1.

Test apparatus for the evaluation of the behavior of smoke detectors in non-fire situations

The presented test apparatus is a consistent further development and re-design of a first test duct as described in [8] and [9]. The compact design of the new test duct provides a portable device with a very small volume (about 40 l) and little weight. The test apparatus set-up has been developed in the form of a closed duct with a rectangular profile similar to the EN54 test duct. The duct consists of two concentric 150 mm high stainless steel rings with a diameter of 300 mm and 600 mm respectively, resulting in a mean path length of about 1.8 m and a cross-section of 150 mm × 150 mm (see Fig. 2 and Fig. 3). The linear connection between the left and right semi-circles is about 180 mm. The flow velocity between 0.2 m/s and 1 m/s is generated by an encapsulated motor with a mounted airscrew.

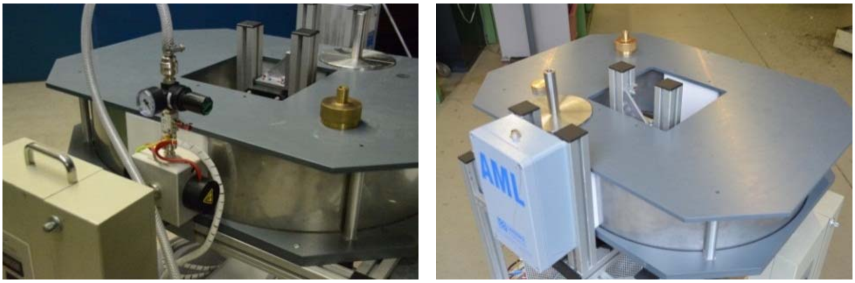

Fig. 2. Different views of the developed test duct.

Fig. 3. View inside the developed test duct.

Due to the small cross-section and the need for very precise extinction measurement, the obscuration meter Lorenz AML [10] had to be adapted. All surfaces are made of stainless steel and all metal parts are grounded to prevent electrostatic charges. A bipolar corona discharger is used to neutralize the charge of the generated dust and to reduce the dust accumulation at the channel walls. Due to the small volume another deciding factor was the development of a reproducible and in a wide range adjustable slow and precise aerosol feeding.

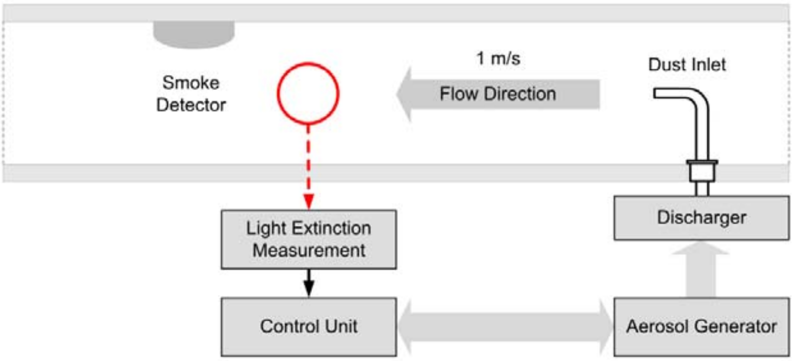

Fig. 4. Diagram of the dust supply.

The visualization and data conversion is done by LabView-based software as well as the controlling and timing of the aerosol generator. The diagram of the dust supply is shown in Fig. 4. The detector is mounted at the duct ceiling, as required by manufacturers. A turnable socket holder enables the measurement of the directionality property of smoke detectors.

Aging process inside the test apparatus

Finding a typical slope for the rise of the dust concentration in the test apparatus the mean increase of the aerosol concentration in the dust scenarios has been calculated [2]. The resulting curve of all performed tests of the extinction m_{Ext} [dB/m] is proportional to the number of particles n multiplied with the extinction cross-section C_{Ext}. Thus a linear increase of m_{Ext} is expected if the dust production is constant.

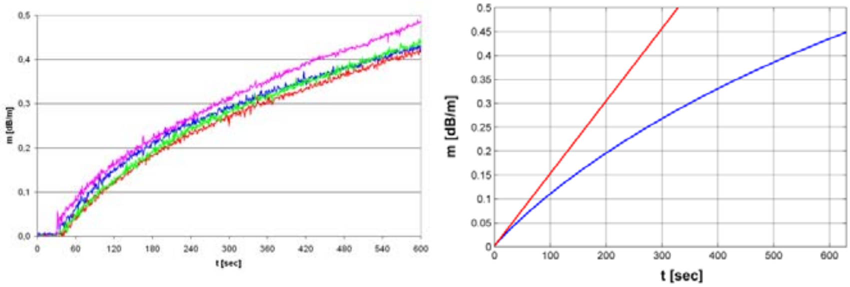

Fig. 5. (a) Measured dust density of four tests; (b) Theoretical slope and simulation of particle aging inside the test apparatus.

The non-linear trend of m_{Ext} seen in Fig. 5a can be explained by the aging of the aerosol, i.e. the sedimentation. This effect could also be reproduced with the developed test apparatus, where a constant dust supply is provided. Simulations of the optical extinction were performed, where the effect of sedimentation has been considered. The resulting curve, shown in Fig. 5b, confirms that sedimentation is the major reason for the non-linear increase of the extinction. In order to linearize the increase of the optical extinction m_{Ext} a controlled dust supply was implemented. Although sedimentation is a natural phenomenon also seen in the test campaign [2] it is interesting to once measure the evolution of the particle size distribution within the test apparatus during a dust test.

Proposal draft for determining the response behavior of optical smoke detectors

Following EN54 tests measuring the directionality or the response behavior of a smoke detector the increase of the aerosol concentration has to be within the limits [11], typically about 0.06 dB m^{-1} min^{-1}:

$$0.015 \leq \Delta m / \Delta t \leq 0.1 \quad (dB\ m^{-1}\ min^{-1}) \qquad \text{(Eq. 1)}$$

The achieved linearity of the dust concentration in the test apparatus is a precondition for performing dust tests in a similar manner as smoke tests according to EN54. The increase of the dust concentration could be within the following limits to simulate a slowly increasing pollution:

$$0.05 \leq \Delta m / \Delta t \leq 0.07 \quad (dB\ m^{-1}\ min^{-1}) \qquad \text{(Eq. 2)}$$

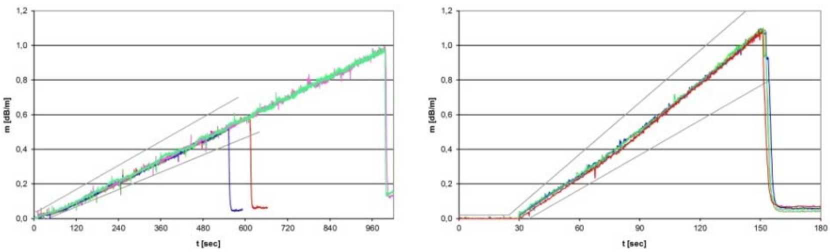

Fig. 6. Measured dust density of several tests: (a) slowly increasing dust exposure; (b) fast increasing dust exposure.

Construction works close to an optical smoke detector may cause a fast increasing dust exposure [2]. In addition to the slow increase of the dust concentration a second test is reasonable, as the measuring campaign showed a much faster increase of the dust density compared with the EN54 values. A possible second slew rate is proposed to be within the following limits:

$$0.4 \leq \Delta m / \Delta t \leq 0.6 \quad (dB\ m^{-1}\ min^{-1}) \qquad \text{(Eq. 3)}$$

Measured dust density of several tests as well as the limits of a slowly and a fast increasing dust exposure is shown in Fig. 6.

Impact of the static particle discharge on the measuring results

The comparison of measured extinction values m [dB/m] after exhausting the test apparatus without and with static particle discharge as a function of the different dust slew rates is shown in Table 1. The presence of measurable extinction values is caused by dust accumulation on the opposite-facing windows in the extinction path. The installation of the static particle discharge unit is a good solution to reduce the remaining values.

Table 1. Comparison of *m* [dB/m] after exhausting the test apparatus without and with static particle discharge.

Slowly increasing dust exposure - $0.05 \leq \Delta m / \Delta t \leq 0.07$ [dB m^{-1} min^{-1}]			
m [dB/m]	t [sec]	m [dB/m] after exhaust, without static particle discharge	m [dB/m] after exhaust, with static particle discharge
1 dB/m	≈ 17 min	≈ 0.4 dB/m	≈ 0.15 dB/m
Fast increasing dust exposure - $0.4 \leq \Delta m / \Delta t \leq 0.6$ [dB m^{-1} min^{-1}]			
1 dB/m	≈ 2 min	≈ 0.1 dB/m	≈ 0.05 dB/m
2 dB/m	≈ 4 min	≈ 0.4 dB/m	≈ 0.16 dB/m

In this context the comparison with the EN54-7 n-heptane fire (TF5) is very interesting. The maximum smoke concentration of about 2.1 dB/m is reached about 4 minutes after igniting a TF5. In the smoke-free air of the fire laboratory the extinction measuring device still displays a value of about 0.34 dB/m respectively ≈ 16.4 % of the maximum value after exhausting. A fast increasing dust concentration in the developed test apparatus leads also to a maximum extinction value of 2 dB/m after about 4 minutes. Several tests have shown that values in the range from 0.11 dB/m to 0.31 dB/m (respectively 5.4 % to 14.8 % of the maximum extinction) could be measured after exhausting the dust test apparatus. So the deposit of dust on opposite-facing windows is in the same range (and lower) than after the test fire TF5 and can be considered as an acceptable value.

Airborne applications

In airborne applications false alarms can be very costly, as they may force a pilot to an emergency landing at the next airport. Due to the high safety standards in aviation, any fire in the cargo compartment of an airplane has to be detected within only 60 seconds. This leads to highly sensitive smoke detectors with low alarm thresholds, but it unfortunately also implicates a high number of false alarms. Due to the fact that dust is the major source of false alarms in airborne applications the developed test apparatus became a test standard for optical smoke detectors in aircraft applications. The main topics of the developed test apparatus have been adopted by the Aerospace Standard AS 8036 [12]. The goal is that no alarm shall occur as a result of normal dust present at the detectors' location, nor from dust that normally accumulates within the detector. This standard specifies minimum performance standards for optical smoke detectors intended for use in protecting aircraft cargo compartments, galleys, electronic equipment bays and other similar installations.

Conclusion and outlook

The development of a test apparatus for the evaluation of the behavior of smoke detectors in non-fire situations is a first step to provide a helpful tool for developers as well as system designers. In contrast to the well standardized methods for the evaluation of the detection capability of an optical smoke detector, there is a lack of reproducible and representative test methods concerning the false alarm susceptibility. Until now, the developer has no possibility to verify new developments. This gap may be filled by the development of an apparatus for the test of fire detectors in dusty environments. The developed apparatus became a test standard for optical smoke detectors in airborne applications.

The analysis of dust properties caused by construction works in comparison with standardized test dusts showed that Dolomit 90 as test dust is a good solution. The test apparatus gives a qualitative statement on the sensitivity of the tested detector regarding the nuisance aerosol dust. This will allow analyzing the efficiency of new detector designs by manufacturers.

In case of the boundary condition (23 ± 5) °C and (55 ± 15) % relative humidity, tests have shown sufficiently linear and reproducible data. For the use of different dust types (e.g. ISO Ultrafine dust [4][12]) the control software for the dust supply has to be adapted.

Acknowledgements

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