Non-fire Sensitivity Testing of Optical Smoke Detectors

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Abstract

With the increasing use of smoke alarms also the number of false alarms increases. The consequences of false alarms should not be underestimated, as they may cause several costs to the operator, not only in buildings (e.g. cause the interruption of the production line) but especially in airborne applications if a false alarm force a pilot to an emergency landing at the next airport. For this reason the department of Communication Systems of the University Duisburg-Essen has developed three new test devices for nuisance tests of optical smoke detectors.

The new test devices are very helpful and important tools for developers as well as for system designers giving the possibility of performing reproducible and well characterized dust tests. They will find its application in the field of detector development, and detector calibration giving a quantitative decision criterion to find the optimal detector for a specific scenario. The paper describes the technical construction and the function of the developed test equipment as well as some measuring results.

Keywords: fire detection, false alarm susceptibility, dust, water fog

Introduction

Optical smoke detectors are designed to detect even small concentrations of smoke to ensure a fast and reliable detection of arising fires in order to protect and save lives as well as to keep damages as low as possible. There is a long tradition of testing the behaviour of optical smoke detectors. The European Standard EN54 defines a series of tests to prove and certify the functionality of smoke detectors, i.e. to prove that the detector is able to detect a fire in a prescribed period of time or up to a defined smoke concentration.

Unfortunately the complex task of testing and comparing the false alarm susceptibility of detectors is almost not addressed in the EN testing procedures. A recent German study shows that about 10 % of false alarms are caused by dust and another 10 % are caused by water steam. With the aim of reproducible non-fire testing procedures for smoke detectors several dust, water fog and steam sources have been analysed during a big field campaign [1]. The focus of the field campaign was on the dust properties caused by construction works in the surrounding of an installed smoke detector. The typical size distributions of water droplets in common false alarm scenarios as e.g. showering were analysed finding parameters for new test methods.

As a result of the study two test devices were developed, allowing a qualitative statement on the sensitivity of the tested detector regarding nuisance aerosols like dust and water fog with reproducible results. This is a new approach for the test of smoke detectors regarding their susceptibility to false alarms due to both nuisance aerosols.

Test apparatus for dust tests

The test apparatus (see Fig. 1) consists of a test duct, a powder disperser (Palas RBG 1000), and an obscuration meter (Lorenz AML) [2]. Manufactured from stainless steel, the test duct consists of two concentric rings and a cross-section of 150 mm × 150 mm. The mean path length is about 1.7 m. The flow velocity is 1 m/s.

Dust accumulating on the glass surface of the extinction measuring device is much lower when discharging the dust particles and grounding all duct components [3]. For this reason, the powder disperser is combined with a bipolar corona discharger (Palas CD 2000) to neutralize the charge of the generated dust and to reduce the dust accumulation at the channel walls.

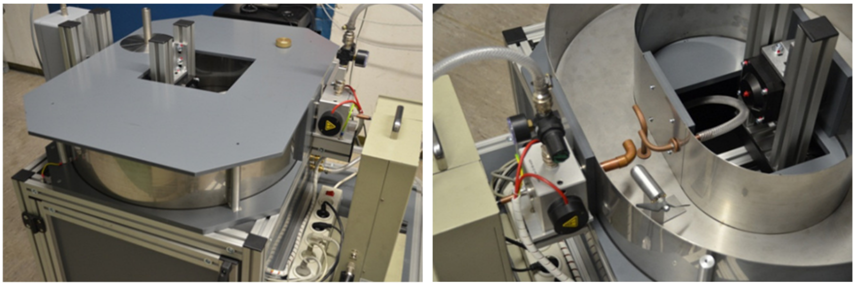

Fig. 1. Duct type test apparatus for dust tests.

Relevant for the design of a test procedure is the choice of test dust. The analysis of the measured particle size distributions caused by construction works in the surrounding of an installed smoke detector (particle sizes in the range 14 µm to 97 µm) revealed that the DMT Dolomite 90 quartz-free test dust with its standardized grain size distribution is a good solution [4]. DMT 90 covers the whole dust range of “ISO ultrafine” test dust (A1) and “ISO fine” test dust (A2).

In this context, comparison with the TF5 (EN54) soot accumulation properties is very interesting. The smoke concentration increases up to *m* ≈ 2.1 dB/m within 4 min. After exhausting the fire lab *m* ≈ 0.34 dB/m was measured, according to ≈ 16.4 % from the maximum value. A dust test with the fast increasing dust concentration increases up to 2 dB/m within the same time. After exhausting the dust particles, values in a range from 0.11 dB/m to 0.31 dB/m (according to 5.4 % to 14.8 %) were measured. Dust accumulation on the glass surface of the extinction measuring device is less than soot accumulation after a TF5 and for that reason absolutely acceptable.

Controlled and reproducible dust dispersion is performed by the powder disperser combined with the discharger controlled by LabView. On the basis of the guidelines for measurements performed in the EN54 smoke tunnel (paraffin oil tests) for response value measurements the rate of increase of dust aerosol density was set in the range $0.015 \leq \Delta m / \Delta t \leq 0.1$ (dB m^{-1} min^{-1}). To simulate a slowly increasing aerosol concentration typically the linear increase of the dust concentration is about 0.06 dB m^{-1} min^{-1}. On the other hand, construction works close to an optical smoke detector may cause a fast increasing dust exposure. For this reason a linear increase of about 0.5 dB m^{-1} min^{-1} was chosen as a second test.

In a big field study the response behaviour of 40 optical smoke detectors was analyzed. The detectors were acquired on the market including cheap smoke alarms as well as more expensive line type detectors. Table 1 shows some examples of the evaluation and comparison of the measured RTV (Response Threshold Value) at an alarm measured in the dust test apparatus (slow and fast increasing dust concentration) in comparison with measurements in the EN54 smoke tunnel. In addition to the RTV the deviation from the mean value is specified.

Table 1. Extinction *m* [dB/m] at an alarm depending on the detector.

		Measured extinction value m [dB/m] at an alarm			Deviation from the mean value	
		m_{min}	m_{mean}	m_{max}	- dB/m	+ dB/m
Detector 1	slow ramp	0,101	0,109	0,127	-0,008	0,018
	fast ramp	0,203	0,224	0,243	-0,021	0,019
	paraffin oil	0,148	0,153	0,157	-0,005	0,004
Detector 2	slow ramp	0,120	0,126	0,133	-0,006	0,007
	fast ramp	0,208	0,252	0,356	-0,044	0,104
	paraffin oil	0,165	0,179	0,188	-0,014	0,009
Detector 3	slow ramp	0,114	0,121	0,143	-0,007	0,022
	fast ramp	0,224	0,271	0,313	-0,047	0,042
	paraffin oil	0,161	0,169	0,179	-0,008	0,010

The evaluation criteria for the test results of measurements with dust include a comparison with the test results of measurements performed in an EN54 smoke tunnel. The expected RTV fluctuations are caused by the detector chamber as well as by the test apparatus. Consequently, more than one measurement for each detector is used for the determination of one RTV value.

Fig. 2 shows a more detailed view on the test results. The RTV *m* [dB/m] is normalized by the mean value of 10 measurements for three detectors performing the slowly increasing dust exposure (a) and the fast increasing dust exposure (b) in comparison with paraffin oil tests (c).

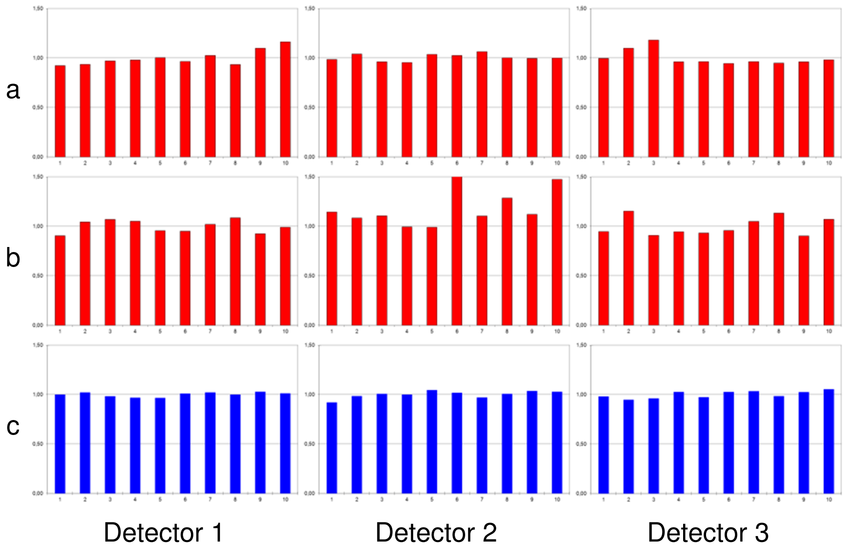

Fig. 2. RTV *m* [dB/m] of detector 1 - 3 normalized by the mean value of 10 measurements.

New features of the dust test apparatus

For cigarette tests in the dust test apparatus the discharger and the aerosol generator are replaced by a small box with an automatic smoker. A small fan keeps the cigarette burning and a chopped pump blows the cigarette smoke into the test apparatus. The control unit is necessary for a reproducible and linear increasing smoke concentration within the test apparatus.

In addition to the extension for cigarette tests, the test apparatus for dust tests can also be extended by a burning chamber. This allows the combination of downscaled fire tests with dust tests to check the reliability of smoke detection in dusty environments [5][6].

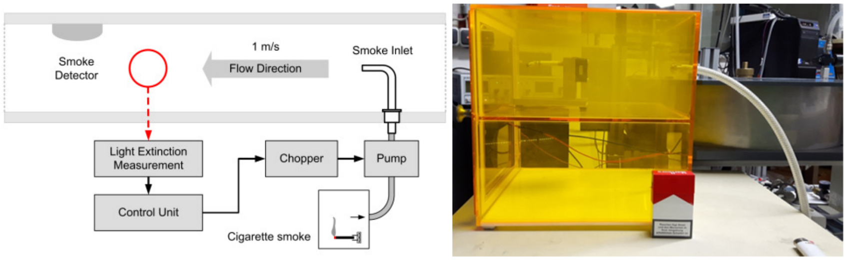

Fig. 3. Test equipment for cigarette tests.

Test apparatus for water fog tests

The new duct type test device for water fog tests is shown in Fig. 4. The dimensions of the duct are similar to the test duct for dust tests. Fig. 5 shows the principle with all important parts. A high-end airbrush (controlled by a servo motor in combination with a valve) works as the aerosol generator. Due to the system's modular structure of the new design, the test apparatus can be used for water fog tests as well as for dust tests. This is an enormous advantage compared to the old design described in [7]. A fast and simple replacement of the components is easy to perform. The discharger has to be replaced by the airbrush and the air stream laminarisation unit has to be added.

The aerosol generation works with demineralized water but without heating up the air inside the duct and the device under test [7]. Therefore the detectors response to the aerosol can be addressed independently from the condensation effect on the optics.

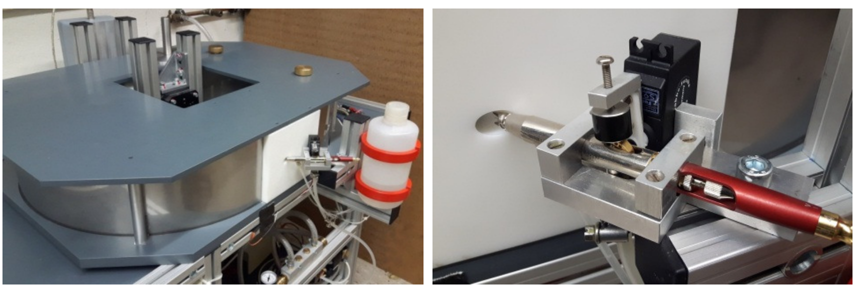

Fig. 4. Duct type test apparatus for water fog tests.

In high humidity environments evaporation and saturation processes play an important role for the life time of water droplets and are mainly determined by temperature and relative humidity [3][7]. The life time of droplets increases at higher humidity and temperature values and thus has a strong influence on the control. This climatic control is implemented and providing constant start conditions for each test, e.g. a relative humidity about 80 % to 90 %. The tests are performed with a reproducible, linear increase of the water fog concentration of about 0.5 dB m^{-1} min^{-1}.

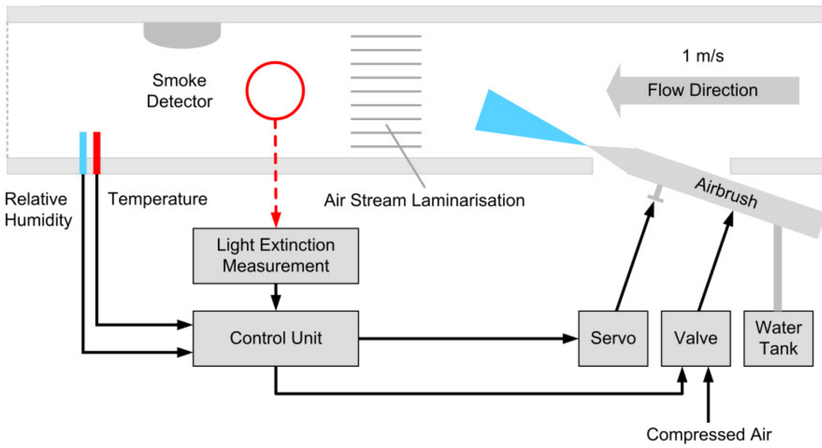

Fig. 5. Duct type test apparatus for water fog tests.

Fig. 6 shows the RTV *m* [dB/m] normalized to the mean value of 10 measurements for three detectors performing water fog tests (a) in comparison with paraffin oil tests (b).

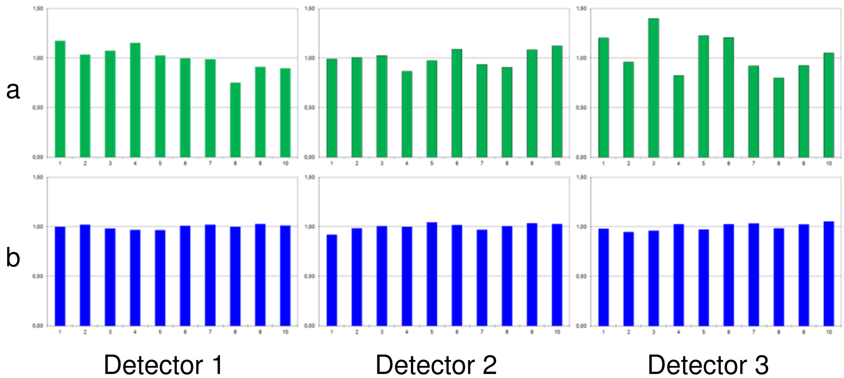

Fig. 6. RTV (Response Threshold Value) *m* [dB/m] of detector 1 - 3 normalized to the mean value of 10 measurements.

Evaluation of the test results (dust and water fog)

To get an impression about the behaviour of smoke alarms in dusty and foggy environments as well as the repeatability of the test procedure, all 40 optical smoke detectors were tested 10 times. Table 2 shows the test results with dust and water fog in comparison with paraffin oil tests for 3 smoke detectors.

In order to keep the number of tests as low as possible it needs a method to estimate the minimal number of test-repetitions for a representative result. A single measurement is insufficient due to expected fluctuations of the RTV.

Here a rule was worked out, that the changes of the resulting median value of three consecutive RTV measurements should be lower than 5 % (see Eq.1 and Eq.2). To keep the impact of possible measuring errors and outliers as low as possible the RTV-median value was used for calculation. The evaluation of the performed measurements is currently done offline.

$$\frac{|(m_{med,(n-2)} - m_{med,(n-1)})|}{m_{med,(n-1)}} < 0.05 \quad \text{(Eq.1)}$$

$$\frac{|(m_{med,(n-1)} - m_{med,n})|}{m_{med,n}} < 0.05 \quad \text{(Eq.2)}$$

Table 2. Comparison of the RTV *m* [dB/m] of detector 1 - 3 for up to 10 consecutive measurements.

Detector 1										
Measurement	1	2	3	4	5	6	7	8	9	10
Paraffin oil	0,153	0,156	0,150	0,148	0,148	0,154	0,156	0,153	0,157	0,155
Dust ramp 1	0,101	0,102	0,106	0,107	0,110	0,106	0,112	0,102	0,120	0,127
Dust ramp 2	0,203	0,234	0,239	0,235	0,214	0,213	0,228	0,243	0,207	0,222
Water fog	0,884	0,779	0,808	0,866	0,772	0,749	0,743	0,565	0,685	0,674
Detector 2										
Measurement	1	2	3	4	5	6	7	8	9	10
Paraffin oil	0,165	0,176	0,181	0,179	0,188	0,182	0,174	0,180	0,186	0,184
Dust ramp 1	0,124	0,130	0,121	0,120	0,130	0,129	0,133	0,126	0,125	0,125
Dust ramp 2	0,240	0,228	0,232	0.209	0,208	0,356	0,232	0,270	0,235	0,310
Water fog	1,699	1,724	1,761	1,487	1,671	1,869	1,604	1,557	1,859	1,926
Detector 3										
Measurement	1	2	3	4	5	6	7	8	9	10
Paraffin oil	0,166	0,161	0,162	0,174	0,165	0,174	0,175	0,167	0,173	0,179
Dust ramp 1	0,120	0,133	0,143	0,116	0,116	0,114	0,117	0,115	0,116	0,119
Dust ramp 2	0,257	0,313	0,246	0,256	0,252	0,259	0,284	0,307	0,244	0,290
Water fog	1,929	1,540	2,246	1,323	1,968	1,937	1,477	1,283	1,486	1,686

As an example, the number of necessary measurements for dust and water fog for the evaluation of the RTV of 3 smoke detectors is shown in Table 3. The evaluation of all performed EN54 paraffin oil tests shows that the calculated median RTV value of the tested smoke detectors is ± 5 % of the overall median value after 3 measurements.

The calculated median RTV value of smoke detectors 1 and 2 is ± 7 % of the overall median value after 3 measurements. In most cases 3 measurements are enough to fulfil the termination condition. Smoke detector 3 is an exception. 5 measurements are necessary for dust ramp 2 and 7 measurements for the water fog test to fulfil the termination condition.

Table 3. Number of necessary measurements for dust, water fog, and paraffin oil tests for the evaluation of the RTV.

	Number of tests until the termination condition occurs	Calculated mean value [dB/m]	Total number of performed measurements	Mean value of all measurements [dB/m]
Detector 1				
Paraffin oil	3	0,153	10	0,155
Dust ramp 1	3	0,105	10	0,105
Dust ramp 2	3	0,193	10	0,204
Water fog	3	0,832	10	0,782
Detector 2				
Paraffin oil	3	0,176	10	0,181
Dust ramp 1	3	0,121	10	0,124
Dust ramp 2	3	0,211	10	0,226
Water fog	3	1,799	10	1,779
Detector 3				
Paraffin oil	3	0,166	10	0,171
Dust ramp 1	3	0,131	10	0,117
Dust ramp 2	5	0,242	10	0,248
Water fog	7	1,978	10	1,686

Test apparatus for spray tests

In some applications, sprays (e.g. insecticide and deodorant in aviation) may cause false alarms in addition to dust and water fog as nuisance aerosol. In order to solve this problem a special spray tunnel was developed as well as a test procedure for both aerosols. The test apparatus is an open duct with a length of about 0.9 m and a width at the widest point (cross-section) of 42 cm x 42 cm. The shape of the test apparatus for spray tests has been adapted to the spraying angle of different sprays. Fig. 7 and Fig. 8 show the test apparatus for water fog tests.

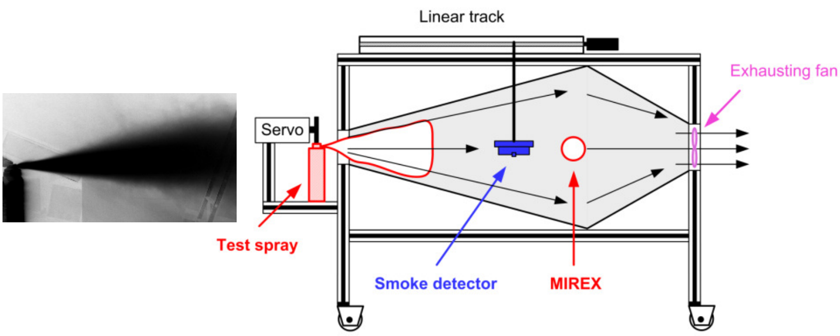

Fig. 7. Test apparatus for spray tests.

The spray interval / pause time is controlled by a servo and LabView and can be adapted to reach the required mean reference light obscuration. Fig. 9 shows the time response of two spray test as an example of the aerosol concentration *m* [dB/m] in the measuring zone measured by the MIREX smoke measuring device.

Fig. 8. Test apparatus for spray tests.

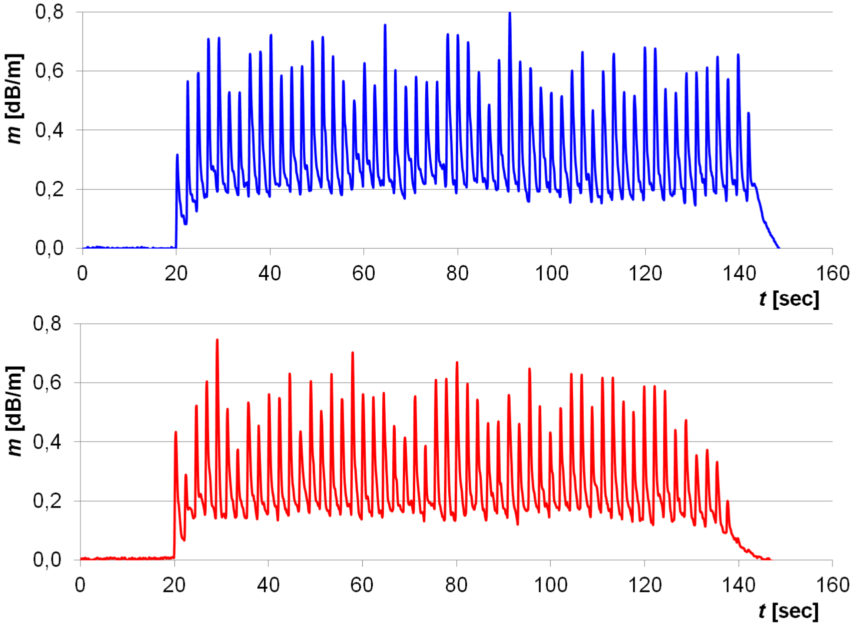

Fig. 9. Time response of two spray tests.

Conclusion

The department of Communication Systems of the University Duisburg-Essen has developed three new test devices for nuisance tests. The test devices for dust and water fog tests allow reproducible measurements with a linear increase of the dust resp. water fog concentration. It is possible to extend the dust test apparatus for cigarette smoke tests as well as for the combination of smoke and dust.

The test devices are very helpful and important tools for developers as well as for system designers giving the possibility of performing reproducible and well characterized dust tests. They will find its application in the field of detector development, detector calibration giving a quantitative decision criterion to find the optimal detector for a specific scenario. The main topics of the developed test devices for dust and spray tests have been adopted by the Aerospace Standard AS 8036 [8].

References

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