Mass Distribution of Aerosol for Testing Smoke Detectors

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Abstract

The aim of this paper is to carry out a detailed investigation and measurement of the aerosol used to test smoke detectors and smoke alarms to EN and ISO standards. The term 'mass distribution' is used in the definition of the aerosol in EN54-7, and this is discussed together with commonly used measurement techniques. Most smoke tunnels in use by test laboratories use a similar aerosol that meets the requirements of the standards, and they produce very similar results for the response value of optical detectors

The work reported here shows that it is possible to modify the aerosol significantly and for it still to be compliant. The resolution of the measurement can be significant. It is also shown that modifying the mass distribution of the aerosol used will affect the response values measured in tunnel tests. This will become more significant in the future with shorter wavelengths used in optical scatter smoke detectors.

It is suggested there is a need to improve the definition of the aerosol in these standards, and some ideas are presented for consideration.

Keywords: Aerosol, mass distribution, smoke detector testing.

Introduction

Most smoke tunnels in use by test laboratories and manufacturers all use a similar aerosol that meets the requirements of the standards, and they produce very similar results for the response value of optical detectors and smoke alarms. The aim of this paper is to carry out a detailed measurement of the aerosol and to investigate whether the requirements in the EN and ISO standards are sufficient to characterise the aerosol sufficiently to obtain consistent results.

The definition of the aerosol in EN54-7 [1] is as follows:

> "A polydisperse aerosol shall be used as the test aerosol. The maximum of the aerosol mass distribution shall correspond to particle diameters between 0,5 µm and 1 µm… "

The definition in ISO 7240-7 [2] is similar, but stated differently:

> “A polydispersive aerosol shall be used as the test aerosol to measure the response threshold values. The bulk of the particles comprising the aerosol shall have a particle diameter between 0,5 μm and 1 μm…”

It is widely understood that ‘mass distribution‘ refers to the variation of the particle mass in the aerosol with particle diameter. It can be plotted as a histogram with the total mass in each bin plotted against particle diameter. The peak in the distribution can be determined by the particle diameter range of the bar with the greatest height. It is also possible to characterise the aerosol by plotting histograms of numbers of particles in each bin, or the total surface area of the particles in each bin. The mass distribution will naturally have a peak at a larger particle diameter than the surface area or number distribution. In the aerosol used the mass distribution peak is in the region of the wavelength used in optical detectors and the tunnel obscuration meter.

Most means of measuring the distribution of an aerosol produce results that have bins that vary in width across the particle diameter measurement range. They are also commonly plotted with a logarithmic scale on the horizontal particle diameter axis to illustrate variations over a wide range of diameters. The vertical axis of a mass distribution is conveniently plotted as dM/dlogD, which normalises the effect of different bin sizes and the logarithmic horizontal axis. The quantity dM/dlogD for each bin is calculated by:

$$dM/d\log M = M_{tot}/(\log D_U - \log D_L) \qquad (mg/\mu m) \qquad \text{(Eg. 1)}$$

where: M_{tot} = total mass of particles in bin
D_U = diameter of upper boundary of bin
D_L = diameter of lower boundary of bin

The definition used in EN54-7 will be used in this paper as it provides a more specific definition than the wording in ISO 7240-7. In both standards it is recommended that paraffin oil is used to generate the aerosol, and it is assumed that the particles are spherical. The geometric diameter of the particles is therefore equivalent to the aerodynamic diameter [3] which is used directly in many methods of measurement.

Measurement techniques

There are many techniques for counting and measuring particles in an aerosol. The techniques discussed here are:

- <u>Cascade impactor</u>, which uses impaction in several stages to directly measure the mass of particles in different aerodynamic particle diameter ranges. It is the oldest technique, and still in use.

- Optical particle sizer (OPS), which uses optical scatter from individual aerosol particles to estimate particle diameter and produce a diameter/mass distribution. A TSI 3330 instrument was used in this work (see Fig. 1). The concentration limit for reliable measurement is 3000 particles/cm^3, which corresponds to approximately 0.008dB/m in an EN54-7 test tunnel.
- Aerodynamic particle sizer (APS), uses an optical method to measure the time of flight of individual aerosol particles from a known impetus. A TSI 3321 instrument was used in this work (see Fig. 1). The concentration limit for reliable measurement is 1000 particles/cm^3. This instrument was used with a 20:1 diluter to allow it to operate at a wider range of aerosol concentrations.

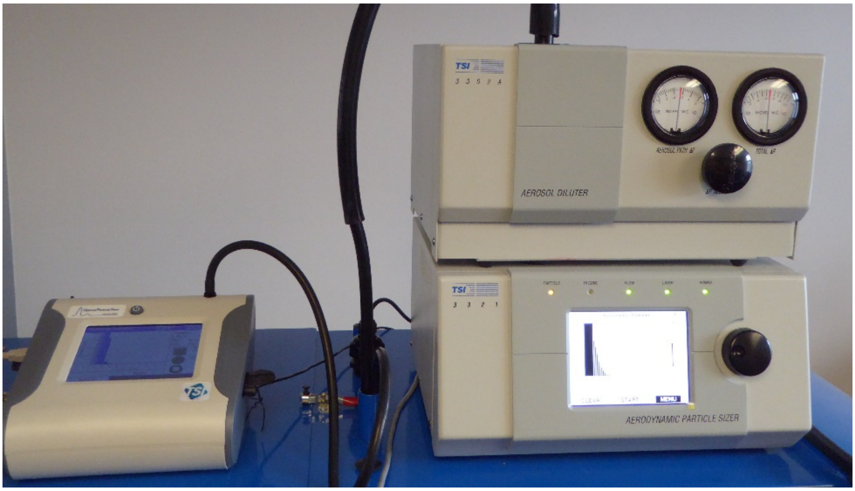

Fig. 1. TSI 3330 OPS instrument (left) and TSI 3321 APS instrument (right) with diluter on top of detector test tunnel.

Measurement of typical aerosols used in EN54 smoke tunnels

The aerosol used in an AW Technology 2800 smoke/heat detector test tunnel was measured using the TSI 3330 OPS and the TSI 3321 APS (Fig. 2). A 10 second run of the aerosol generator was used to allow the measurement to be taken within the operating range of both instruments.

The APS results show a distribution with a peak between 0.5 and 1.0 µm, which is compliant to the requirements of EN54-7. The OPS results show a strong peak above 1.0 µm, which is apparently non-compliant. As the APS instrument measures aerodynamic particle diameter this is a more direct measure of actual particle diameter and can be used to confirm compliance. The difference between the OPS and APS in the distribution in this range is a known artefact of this type of instrument when used to measure liquid aerosols [4], due to strong Mie scattering. It shows that great care in needed in the selection of the measurement technique.

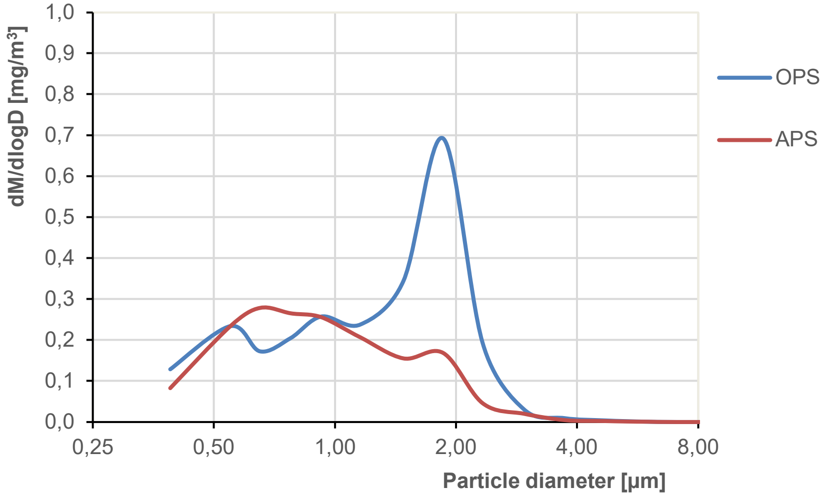

Fig. 2. Mass distribution of aerosol in AW Technology 2800 smoke/heat detector test tunnel.

A series of tests were carried out under a wide range of conditions, and it was found that a good correlation could be obtained between the OPS and the APS mass distributions. It was found that the APS distribution could reliably be calculated from the OPS distribution. This could only be used for the material used in the aerosol used to obtain the correlation in the smoke detector test tunnel.

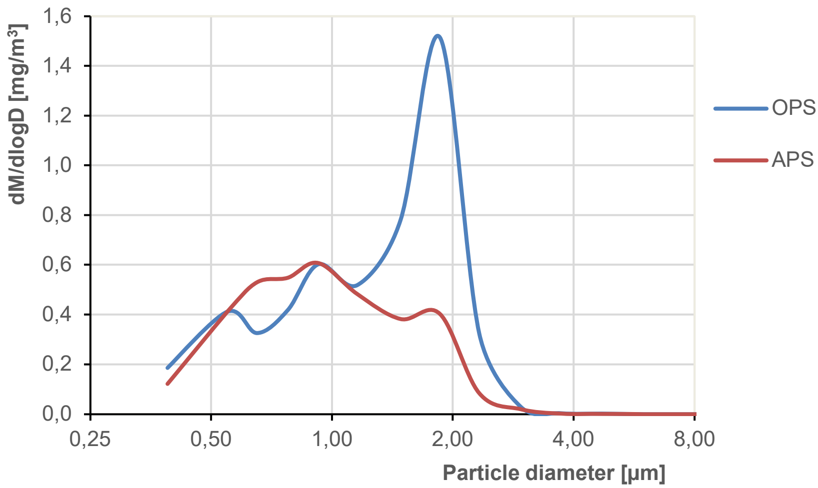

Fig. 3. Mass distribution of aerosol in Lorenz test tunnel with AGW aerosol generator.

The mass distribution of the aerosol in a Lorenz test tunnel with an AGW aerosol generator was also measured using the TSI 3330 OPS and shows a nearly identical distribution (see Fig 3). With the conversion from OPS to APS the mass distribution of the aerosol is also compliant to EN54-7. This indicates that most test laboratories and manufacturers use a very similar aerosol in their measurements.

Some (unpublished) data also indicates that mass distribution measured using a cascade impactor produces results consistent with the TSI 3321 APS. The resolution of this method does however produce wider bin diameters than the optical based techniques.

The peak (APS) between 0.5 and 1.0 µm is only slightly greater than the mass between 1.0 and 2.0 µm. Fig 4 indicates the mass distribution of an aerosol with a peak of equal height at 1.7 µm to that between 0.5 and 1.0 µm. The data is also plotted with the same bin sizes as a typical mass distribution measured with a cascade impactor, and indicates a more definite peak. It is possible to produce similar aerosol with a larger peak in the APS results between 1.0 and 2.0 µm that would not be visible with the lower resolution method.

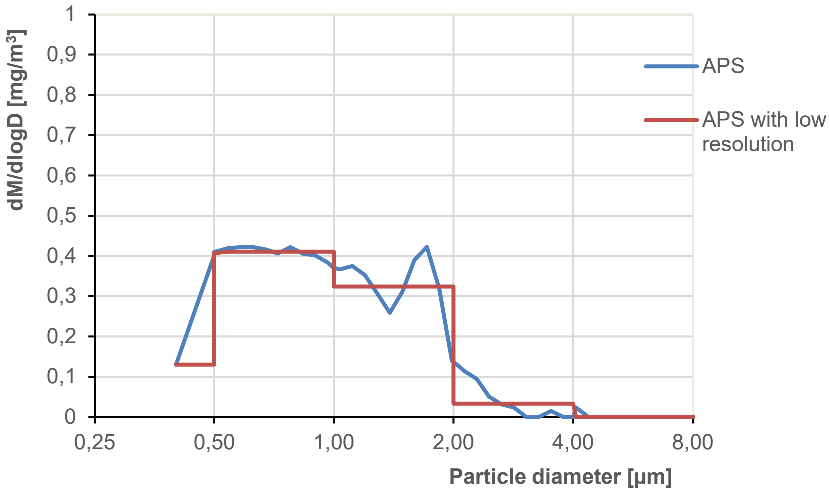

Fig. 4. Mass distribution of aerosol plotted with two different resolutions.

Variations in mass distribution

It is possible to modify the particle mass distribution using an impactor of different sizes to produce a range of distributions as shown in Fig 5. The impactor dimension shown is the distance between the output nozzle and an impactor plate. A smaller distance will have a greater effect on reducing the number of larger particles. In each case the distribution is compliant to EN54-7, but the proportion of larger particles above 1 µm is quite different.

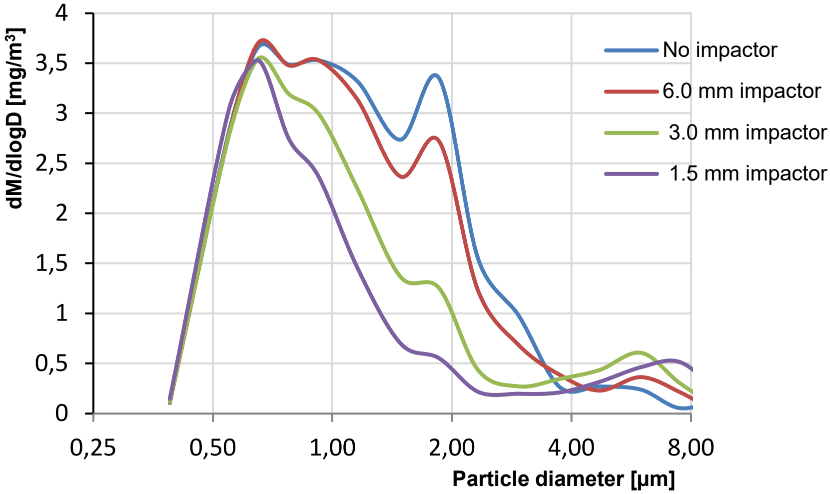

Fig. 5. Mass distribution of aerosol with different impactors.

If the aerosol is left in the tunnel for a period of time, without being refreshed, then the mass distribution can also vary significantly as shown in Fig. 6. The effect of time is not normally significant over a typical test lasting approximately 5 minutes, during which the aerosol is added continuously. It can be seen to have a similar effect to that of the impactors in reducing the proportion of larger particles. From the Stokes settling equation [3] the terminal velocity of 2 µm paraffin particles is 0.4 m/h and is more than 10 times the terminal velocity of 0.5 µm particles. The observed changes in mass distribution is most likely to be dominated by gravitational settling.

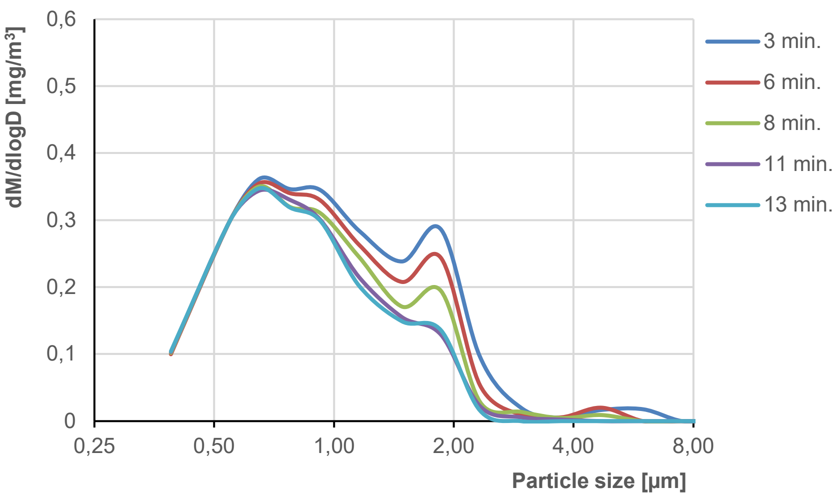

Fig. 6. Mass distribution of aerosol after aging in tunnel.

Effect of distribution of the response value of optical detectors

The effect of the changes in mass distribution on the measured response value of a typical optical scatter smoke detector (Apollo series 65) was measured with the different impactors discussed above. The mass distribution was characterised by the ratio between the total mass of particles between 0.5 and 1.0 µm, divided by the total mass between 1.0 and 2.0 µm.

As shown in Fig. 7 the response value decreases as the relative height of the peak between 0.5 and 1.0 um increases. For small changes in mass distribution the effect is small, and this is because the wavelength of the radiation used in the detector is similar to that used in the tunnel obscuration meter.

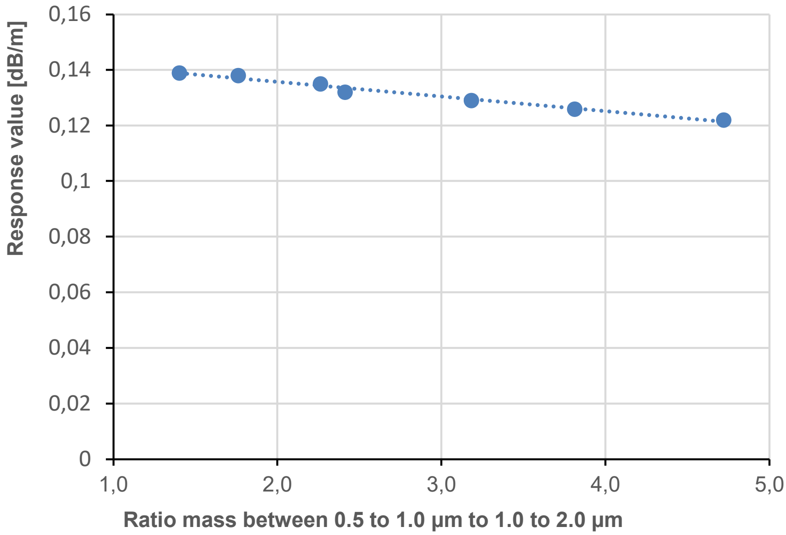

Fig. 7. Effect aerosol mass distribution on detector response value.

For optical detectors that operate at shorter wavelengths the effect is expected to be much larger. This means that defining the aerosol mass distribution is likely to become more important in the future. However, it does also mean that the aerosol could be monitored in real time using two wavelength optical instruments. Further work will include experimental investigations with novel instruments and theoretical analysis using Mie scatter.

Conclusions

When measuring an aerosol mass distribution it is important to use the correct equipment, as even good quality instruments can give misleading results. The OPS instrument does not give an accurate indication of the mass distribution of the paraffin aerosol in the region of interest, but it is possible to calibrate its readings against the APS to give good results for a particular aerosol material. This is a practical way to use the OPS for assessment of the mass distribution and compliance of the aerosol.

The resolution with respect to the particle diameter will vary according to the method of measurement. A cascade impactor has a low resolution which may not reveal peaks in the mass distribution outside of 0.5 μm and 1.0 μm, which can be seen by the OPS and APS. The resolution of the distribution needs to be defined to enable comparison between different techniques.

The definition of a peak in the mass distribution between of 0.5 μm and 1.0 μm is not sufficient to define the aerosol to give comparable results when used for testing optical smoke detectors. A better definition would be useful to maintain consistency of results. This could include:

- stating that the mass distribution is based on aerodynamic particle sizing,
- including a more precisely specified range of the mass distribution. This could be in terms of the height of the peak between 0.5 um and 1.0 um as described above. Alternatively, the mean of the particle diameters weighted by mass could be used. It should allow the mass distribution of aerosol currently in general use,
- a requirement for the resolution of the measurement of mass distribution,
- indicating that the mass distribution could be measured using Optical Particle Sizers that have been cross correlated against calibrated Aerodynamic Particle Sizers.

Acknowlegement

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References

[1] EN 54-7:2018, Fire detection and fire alarm systems – Part 7: Smoke detectors - Point detectors using scattered light, transmitted light or ionization.

[2] ISO 7240-7:2018 Fire detection and alarm systems - Part 7: Point-type smoke detectors using scattered light, transmitted light or ionization.

[3] Hinds W.C., Aerosol Technology, Properties, Behavior and Measurement of Airborne Particles, Wiley–Interscience, 1999.

[4] Zarrath A. et al., Comparison of a New Optical Particle Sizer to Reference Sizing Instruments for Urban Aerosol Monitoring, European Aerosol Conference 21, Manchester, UK.