Cambustion

AAC

Aerodynamic Aerosol Classifier

Application Note: AAC03v03

Measuring size-resolved particle penetration through face mask materials

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Introduction

During the COVID-19 pandemic, face coverings have been widely worn in public spaces to capture respiratory particles produced by the wearer and reduce spread of infection. The intention is that coverings over the mouth and nose will protect others against the spread of infection by capturing particles produced by the wearer that may carry the virus.

Numerous recent studies have emphasised the possibility of airborne coronavirus transmission (e.g. Zhang et al. (2020)). Both aerosols and droplets can be generated as a continuum of particle sizes during various normal respiratory activities including coughing, talking and singing.

It is therefore of interest to investigate the particle size-resolved filtration properties of various face mask materials across a wide particle size range. A suitable instrument for achieving this is the Aerodynamic Aerosol Classifier (AAC; Fig. 1), which can select particle sizes between 25 nm and >5 μm.

The AAC transmits particles of a selected aerodynamic diameter by balancing opposing centrifugal and drag forces, (the centrifugal force being generated by a rotating cylinder) allowing the selected particles to be carried by the sheath flow to the outlet. This principle of aerosol selection or classification is independent of the charge state and produces a truly monodisperse aerosol, with a high transmission efficiency limited only by diffusion and impaction losses.

The AAC principle is described in further detail here: http://www.cambustion.com/products/aac/animation

Figure 1: The AAC

Size-resolved particle penetration

Various face covering samples were mounted and sealed in a 47mm filter holder. These coverings included washable cloth face masks consisting of woven fabrics, disposable surgical masks consisting of non-woven fabrics and disposable filtering half masks (with examples conforming to the FFP1 and FFP2 classes specified in EN 149).

AAC-classified particle penetration was measured using the methodology of Payne et al (2018). As shown below (Fig. 2), the sample was placed downstream of the AAC which was run at a series of setpoints that automatically calculate rotational speeds and sheath flows to select particle aerodynamic diameters. Dioctyl sebacate (DOS) oil was selected as the challenge aerosol because of its low vapour pressure (i.e. its resistance to evaporation at ambient temperature) and because it forms particles of known spherical morphology and density.

Particle penetration tests were conducted for filter face velocities corresponding to 160 lpm flow through the entire mask, which is specified in EN 149 to represent **exhalation** flow in steady-state breathing resistance tests.

A constant 10:1 sheath:sample flow ratio was maintained for particle size selection. At reference classifier conditions (0°C and 1.013 bar(a)), the AAC can classify aerodynamic particle diameters from 32 nm to 3 μm at low flow (0.3/3.0 lpm sample/sheath flow) and from 202 nm to 6.8 μm at high flow (1.5/15 lpm sample/sheath flow). The lower size limit of the AAC is sensitive to particle diffusion and the maximum obtainable rotational speed (this can be extended down to 25 nm if the sheath flow is reduced by approximately 25% at the maximum speed, which broadens the transfer function). The maximum selected aerodynamic diameter for most measurements was 2 μm, which is close to the upper size limit of the Condensation Particle Counter (CPC) model used to measure particle number concentration. For the cloth mask samples, additional measurements were made up to 5 μm using a Palas Welas 1000 Optical Particle Counter (OPC) as the particle detector.

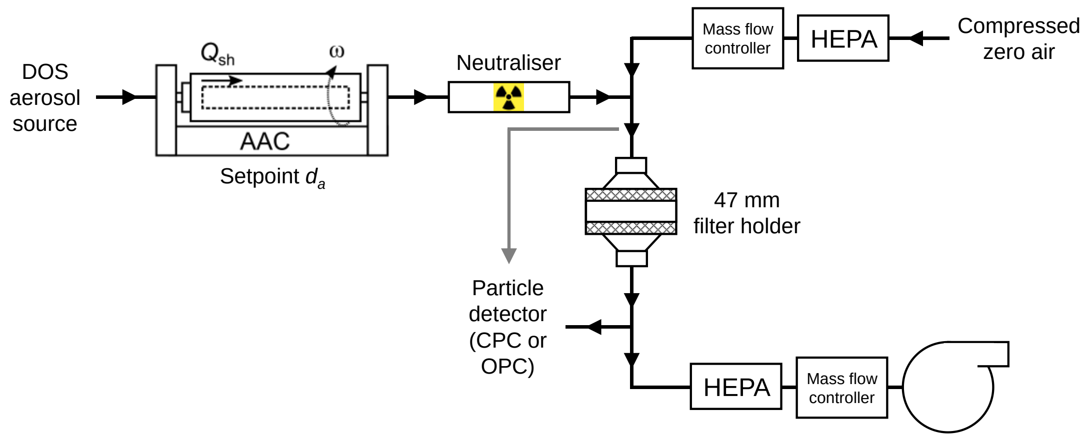

Figure 2: Schematic for measuring size-resolved particle penetration

Measurements adhered to the short-term particle penetration test outlined in Clause 8.2 in ISO 16900-3 but for monodisperse aerosol. After a stabilisation time of 3 minutes, logging of filter penetration is initiated (at 1 concentration reading per second) and the short-term penetration value is the average taken over the following 30 seconds.

ISO 29463-3 requires that a neutraliser is installed downstream of the classifier (historically a Differential Mobility Analyser, DMA) so that an equilibrium charge distribution is prescribed on the aerosol incident on the filter sample. Therefore the AAC output was passed through a Krypton-85 neutraliser. The challenge aerosol then mixes with HEPA-filtered make-up air (to establish the correct filter face velocity), which is supplied by a compressed zero air cylinder.

Particle number concentration upstream of the filter was recorded by bypassing the filter holder. The penetration at each particle size was calculated as the ratio of down- to upstream concentrations measured alternately, with a blank correction applied for particle losses in the empty filter holder. In all cases, the CPC was operating in single count mode or the OPC was operating below its coincidence correction threshold; to ensure this, dilution of DOS aerosol upstream of the AAC was provided by a modified version of the rotary disk diluter used in the Cambustion DMS500.

Results

Penetration measurements for AAC-classified DOS particles between 50 nm and 5 μm are plotted in Fig. 3 for samples cut from six commercially available face coverings. For each penetration value the error bars represent a two-sided 95% confidence interval, which was calculated in accordance with the specifications for particle counting statistics in Clause 7 of ISO 29463-2 (based on the Poisson distribution).

For the range of flows tested in this study, the particle aerodynamic diameter with the highest penetration through the filter materials was generally a few hundred nm. Capture of smaller particles is mostly influenced by diffusion (and mobility diameter), whereas capture of larger particles is mostly influenced by interception and impaction, for which aerodynamic diameter is the most useful measure of particle size.

The impact of interception increases as particle size approaches the fibre width. Comprehensive assessment of woven materials is reliant on the ability to classify particles up to 5 μm, since it is only at this larger size range where filtration efficiency for the cloth coverings approaches 90%. In these samples the particles interact with highly ordered yarns (bundles of fibres) rather than individual fibres, which limits the influence of the interception mechanism.

In contrast, the FFP1 and FFP2 respirators tested in this study comprise matrices of randomly oriented fibres, meaning tortuous air paths and high particle collection. Particle capture is also likely enhanced by loading of static charges in these filter media. While the surgical masks are not electret media and the fibre density is lower, the amorphous matrix of fibres promotes interaction between particles and individual fibres, leading to collection of >90% of 2 μm particles.

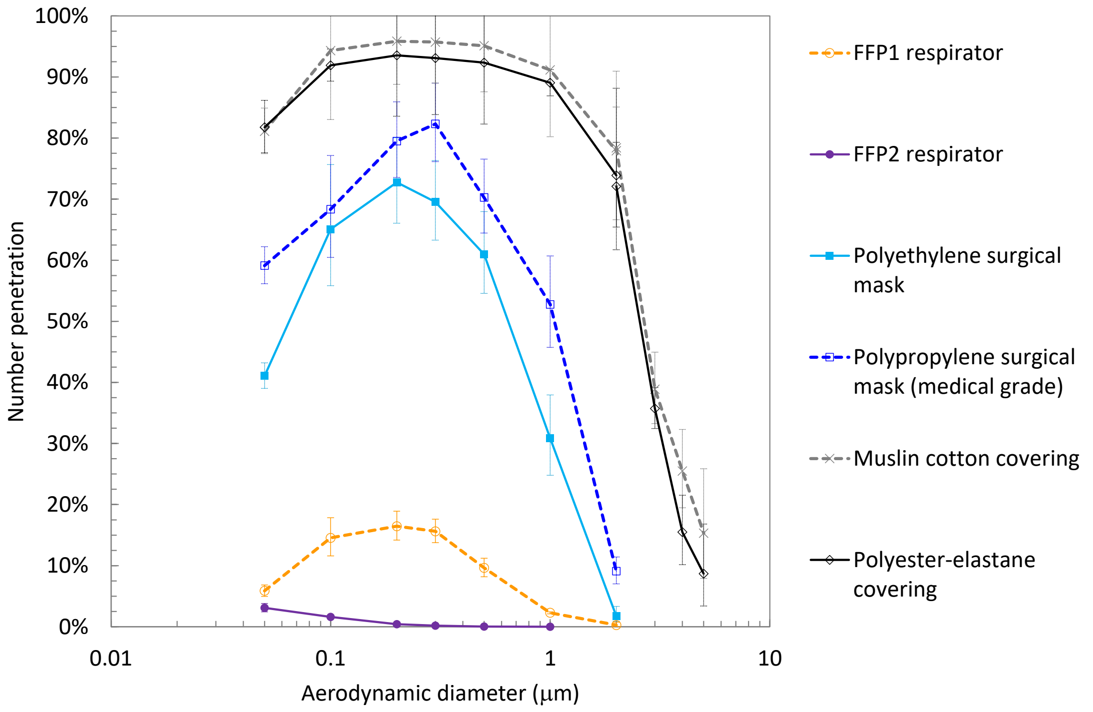

Figure 3: Number penetration of AAC-classified DOS particles through various face mask materials at 160 lpm equivalent through the entire mask

Note: since these tests involve particle penetration of material samples sealed by an o-ring in a housing, the results are not representative of an entire face covering with air leakage around the edges.

Further reading

AAC: www.cambustion.com/products/aac
Publications: http://www.cambustion.com/publications/pubinst/AAC

Note regarding standards

A variety of standards are used to measure and classify mask performance, with different challenge aerosols, test procedures and performance criteria. Manufacturers may select from the different standards for validation of their products, so packaging and availability in different geographical areas may vary.

FFP1/FFP2 categorises masks according to EN 149:2001+A1:2009 (European Union)

N95 categorises masks according to NIOSH-42CFR84 (United States of America)

KN95 categorises masks according to GB2626-2006 (People’s Republic of China)

Publications referred to in the text

- CEN. (2009). EN 149:2001+A1:2009 Respiratory protective devices - Filtering half masks to protect against particles - Requirements, testing, marking.
- ISO. (2011). Part 2: Aerosol production, measuring equipment and particle-counting statistics. In ISO 29463:2011 High-efficiency filters and filter media for removing particles in air.
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- Payne, S. D., Irwin, M., Johnson, T. J., & Symonds, J. P. (2018). A New Methodology for Measuring Filtration Efficiency as a Function of Particle Aerodynamic Diameter Using a Monodisperse Aerosol Source. FILTECH. Cologne, Germany. https://www.researchgate.net/publication/334896027_A_New_Methodology_for_Measuring_Filtration_Efficiency_as_a_Function_of_Particle_Aerodynamic_Diameter_Using_a_Monodisperse_Aerosol_Source
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