Cambustion

AAC

Aerodynamic Aerosol Classifier

Application Note: AAC04v01

Using the Aerodynamic Aerosol Classifier (AAC) as a low-pass separator

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Introduction

Figure 1: The AAC.

The Aerodynamic Aerosol Classifier (AAC; Fig. 1) is designed to transmit particles of a selected aerodynamic diameter in the range 25 nm to >5 µm. This is achieved by the passing the polydisperse aerosol through a rotating cylinder (the *classifier*), such that the particles are subject to opposing centrifugal and drag forces and only those of the selected size will follow the correct trajectory and exit through the sample (monodisperse) outlet. Particles larger than the setpoint will impact the outer wall of the classifier before reaching the outlet, whereas particles smaller than the setpoint will not reach the sample outlet and will exit through the sheath (excess flow) outlet. The sheath flow exiting the classifier is then passed through a HEPA filter to remove the unwanted particles and then recirculated. This process – presented by Tavakoli and Olfert (2013) – is summarised in Figure 2 and an animation is available at the link: https://www.cambustion.com/products/aac/animation.

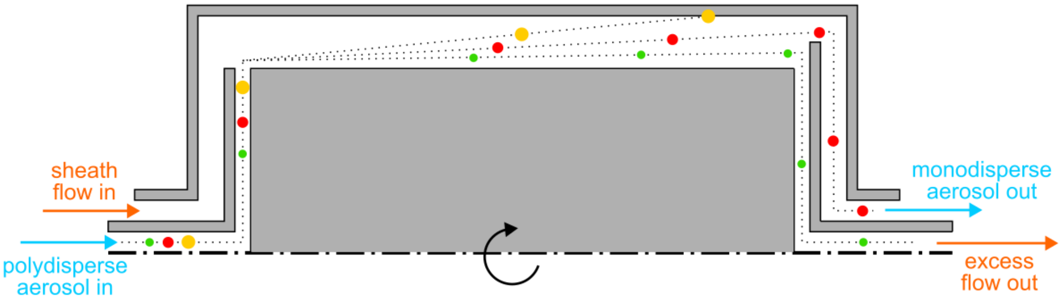

Figure 2: Operating principle of the AAC.

While particles larger than the setpoint are lost in the AAC classifier, those smaller than the setpoint remain suspended and, upon exiting the classifier, can be considered a useful aerosol. It is therefore of interest to investigate the use of the AAC as a low-pass filter by recovering the sheath aerosol.

Impactors are a common type of low-pass filter used in aerosol science, but the application of the AAC presented here presents advantages, such as online adjustment of the cut-off size, as well as in the steepness of the transmission curve at the cut off.

Hardware modification

Existing AACs can be easily modified to allow use as a low-pass filter, making this application of particular interest. The safety of the instrument remains unaltered as it is sufficient to disconnect one pipe at the back of the instrument, without interfering with any of the systems within the lid or the electronics box.

The sheath flow exiting the classifier goes under the baseplate and then enters the electronics box through transparent pipes located at the back of the instrument. HEPA filters and a blower are located in the electronics box and control the flow, before sending it up to the baseplate once again, where the clean sheath is brought to the classifier inlet.

In order to use the AAC as a low-pass filter, the sheath exiting the classifier must be recovered before it enters the electronics box by disconnecting the tube indicated in Figure 3. The blower located in the AAC will continue to operate normally and generate the sheath input to the classifier at the setpoint entered in software, but it will now be necessary to draw the correct amount of flow out of the classifier.

As the AAC is designed to have balanced flows (sample in = sample out; sheath in = sheath out), this must remain the case in this new application, and the standard flow rate limits apply to the sample and sheath flows.

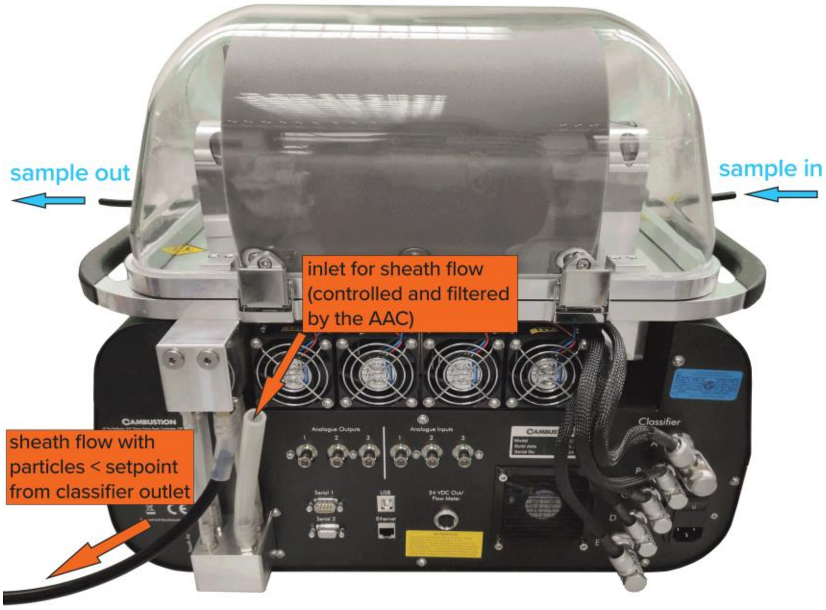

Figure 3: AAC hardware modification required. The rear-most large clear pipe at the back of the AAC must be disconnected. The bottom connection must be left open as the sheath in is controlled by the AAC. The sheath out must be drawn from the top connection, ensuring that the total flow drawn matches the sheath flow set in the AAC software. The sample out must also be drawn to the desired flow rate, such that the sample in flow is free to balance as in normal AAC operation.

Experimental setup for performance evaluation

Due to the standard flow rates ranges of the sample (0.3-1.5 lpm) and sheath (2-15 lpm), when used as a low-pass separator the AAC will dilute the aerosol as well as filtering out the particles larger than the setpoint.

To minimise the dilution, it is necessary to use low sheath/sample ratios, which correspond to a low resolution (i.e., there is a trade-off between the steepness of the cut-off and the dilution). However, as the AAC is designed for monodisperse classification at extremely high resolution, “low” resolution still offers good sharpness for a low-pass separator.

The dilution-corrected transmission efficiency was investigated using the experimental setups shown in Figure 4, which use a second, standard AAC to either scan the output of the low-pass AAC (Fig. 4a) or produce a monodisperse challenge aerosol (Fig. 4b). Different combinations of sample and sheath flow rates were tested in order to identify suitable operating settings.

Dioctyl sebacate (DOS) oil was selected as the challenge aerosol because it forms spherical particles of known density and has a low vapour pressure (i.e., it is resistant to evaporation at ambient temperature).

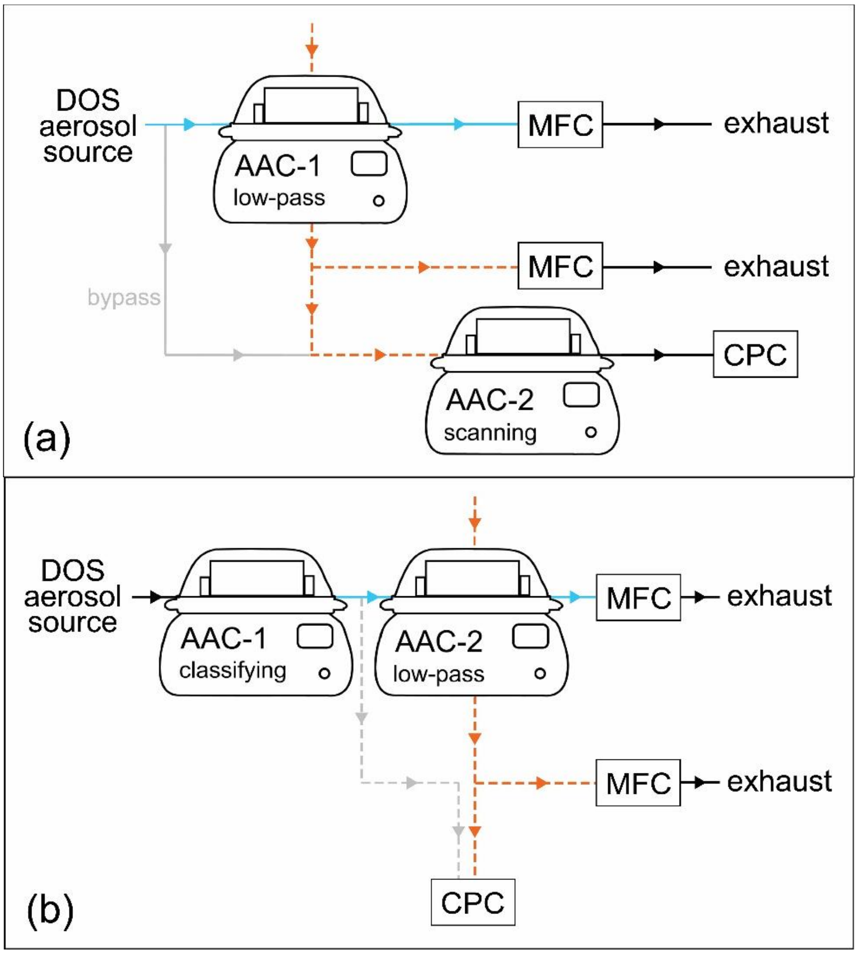

Figure 4: Experimental setup for the determination of the transmission efficiency of the AAC as a low-pass separator – (a) scanning the polydisperse output of the low-pass separator, (b) transmission of a monodisperse challenge aerosol.

Results

Tests with a polydisperse challenge aerosol showed that when using 1.5 lpm of sample and 4.0 lpm of sheath the transmission is excellent between 200 nm and 2 µm (> 90%). Scaling down the sample and sheath flow rate while maintaining a similar ratio does not show significant differences in transmission, but a slight improvement is visible in the cut-off sharpness when going from a sheath:sample ratio of 3 to 4 (Fig. 5).

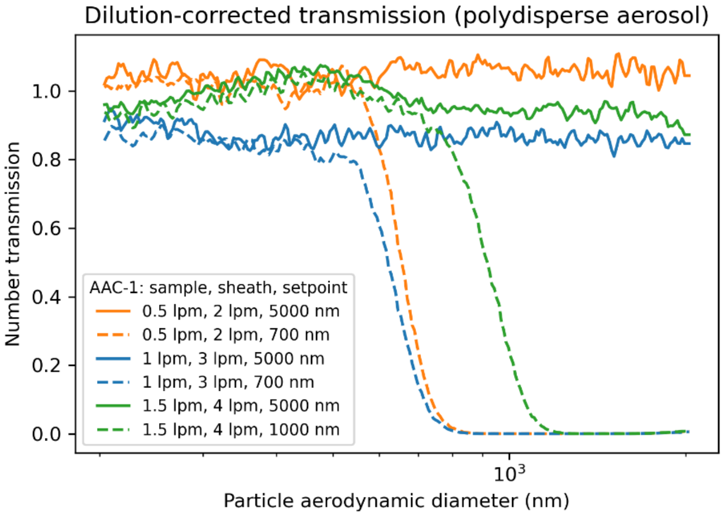

Figure 5: Transmission and cut-off sharpness for different combinations of sample and sheath flow rates with low dilution.

Above about 2 µm the transmission of particles in the sheath starts to drop, with impaction losses dominating: while the sample outlet was designed to ensure high transmission at all sizes, the sheath was not intended to be recovered and hence shows limitations. Increasing the sheath flow rate at constant sample flow does not affect transmission of small particles (i.e., no effect on diffusional losses), but causes impaction losses to become important at lower sizes (Fig. 6).

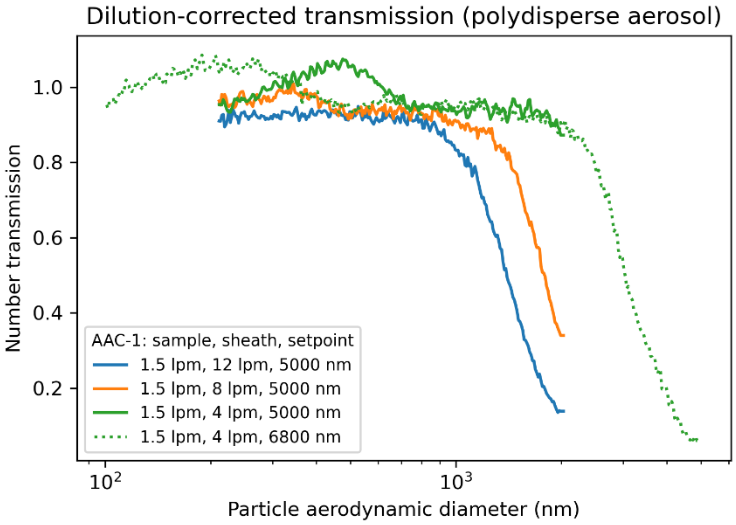

Figure 6: Transmission of polydisperse aerosol at different sheath flows.

For inlet aerosol concentrations of 10^7 – 10^8 particles/cm^3, the transmission dropped to about 40% and showed more variability with particle size – possibly due to the coagulation of the liquid test aerosol.

Further tests carried out with monodisperse aerosols when running the low-pass separator at 1.5 lpm sample and 4.0 lpm sheath confirmed the uniform behaviour of particles between 200 nm and 2 µm.

In Figure 7, the transmission curves of aerosols down to 200 nm all show similar slopes and match the setpoint of the low-pass AAC. As expected, the number of particles transmitted at setpoints above the aerosol size is close to the total number indicated by the CPC when in bypass (~90%).

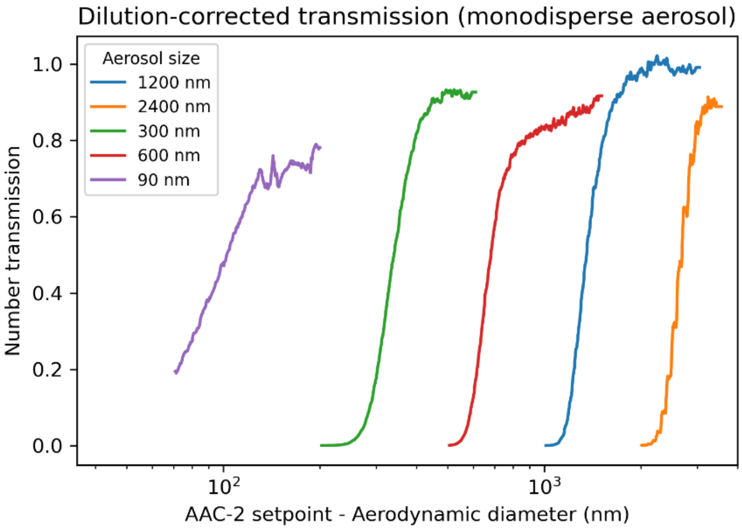

Figure 7: Transmission of monodisperse aerosols - AAC-2 scanning.

At 90 nm the effect of diffusion becomes more noticeable. This both means that some particles are still present in the sheath at or below the AAC setpoint, and that the maximum transmission when above the setpoint is lower (~80%). These two issues become more significant as size decreases.

Manually adjusting the setpoint of AAC-2 enables taking transmission and bypass measurements in close succession, while averaging the concentrations over a few seconds. This method should allow a more precise determination of the transmission as compared to scanning and yielded in a plateau transmission of ~95% for particles of aerodynamic diameter ≥200 nm. As already seen while scanning, the transmission starts to drop for smaller particles (Fig. 8).

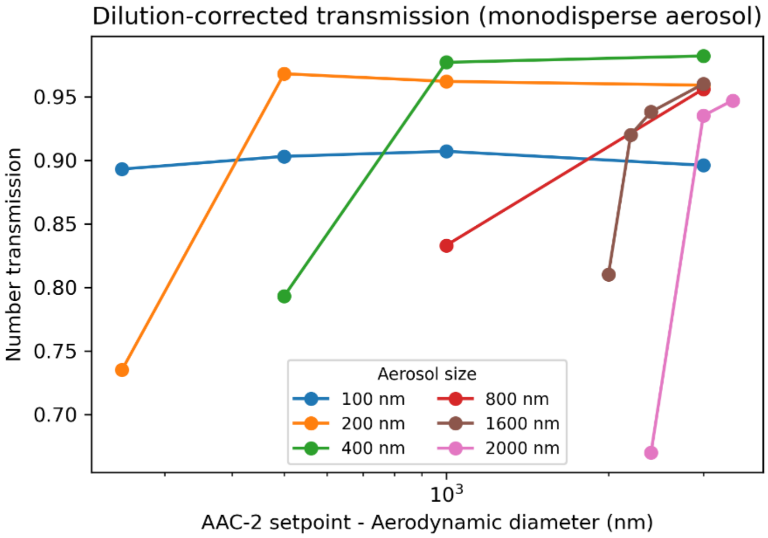

Figure 8: Transmission of monodisperse aerosol - AAC-2 setpoint stepped manually.

Conclusions

Existing AACs can be easily converted into a low-pass separator by disconnecting a pipe at the back of the instrument to recover the sheath (which contains all the particles smaller than the setpoint) at the exit of the classifier.

The performance of the AAC as a separator was investigated using polydisperse and monodisperse aerosols. Having corrected for the dilution, transmission was close to 100% and independent of size between 200 nm and 2 µm. The shape of outlet aerosol size distribution is therefore controlled by the setpoint of the AAC.

The dilution is set by the sheath:sample flow ratio and determines the sharpness of the cut-off. For the AAC to correctly size-select, the thickness of the sheath that the particles need to cross in the classifier gap must be sufficiently large (see Fig. 2). This translates into a minimum dilution factor (~3) being applied in this application.

In particular, the use of 1.5 lpm of sample and 4.0 lpm of sheath presents a good operating condition thanks to a combination of low dilution, consistent transmission, and reasonably steep cut-off.

Further reading

AAC: www.cambustion/products/aac

Publications referred to in the text

Tavakoli, F. and Olfert, J. S. (2013) Aerosol Science and Technology 47, 916-926.