Size Classification Without Charging – Characterization Of The New Aerodynamic Aerosol Classifier

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An introduction to the AAC (at AAC!)

The Aerodynamic Aerosol Classifier solves two problems in Aerosol Science:

1. How do I select a monodisperse size classified aerosol without multiple / zero charging artefacts?

2. How do I select a monodisperse aerosol based upon Aerodynamic Diameter?
True monodisperse aerosol using AAC

DMA produces *multiple peaks*

**DESIRE**

**REALITY**

![Graph showing concentration vs. particle diameter](image-url)

Concentration

Particle diameter

Concentration

Particle diameter

- 1+
- 2+
- 3+
True monodisperse aerosol using AAC

The AAC produces a truly monodisperse aerosol
Classification by Aerodynamic Diameter

Rather than just determining the sizes of particles in an aerosol stream, it is often desirable to be able to classify them for further online analysis.

Impactor – “low pass”

Virtual Impactor – “high pass”

“Band pass”

Aerodynamic Diameter
AAC Principle

Go to https://www.cambustion.com/products/aac/animation to see animation
Efficiency compared to Neutraliser + DMA

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Total Transmission Efficiency

- AAC
- Neutralizer + DMA

Mobility Diameter, $d_p$ (nm)
Selection of Sheath Flow and Speed

Relaxation time, \( \tau \), of an aerosol particle is analogous to a characteristic acceleration time for a car, e.g. its “0-60” mph time (Hinds, 1999; pp 111-116)
- i.e. the time taken to adjust to a new condition of forces

\[
\tau \equiv mB = \frac{C_c(d_{ae})\rho_0 d_{ae}^2}{18\mu} = \frac{2Q_{sh}}{\pi \omega^2 (r_i + r_o)^2 L}
\]

Cunningham slip

mass

mobility

for (balanced) AAC sheath flow \( Q_{sh} \), rotational speed \( \omega \), classifier inner and outer radii \( r_i \) and \( r_o \) and length \( L \), gas viscosity \( \mu \) and unit density \( \rho_0 \)

Resolution parameter \( (R) \), as for a DMA, is \( Q_{sh}/Q_{aerosol} \)

Required resolution sets \( Q_{sh} \), then solve for \( \omega \) for a given \( d_{ae} \)

AAC “History”

• First prototype, Alberta / Cambustion (2010–14)

• Second prototypes, Cambustion / Alberta (2015–16)

• Production instruments, Cambustion (2017–)

25 nm – 5 μm+ size range
→ 7000 rpm, 15 lpm sheath
Step scanning function
Connects to a wide range of CPCs
Monodisperse output

DOS → AAC → TSI SMPS

AAC $d_{ae}$ setpoint converted to mobility diameter $d_{m}$, SMPS charge correction on (AIM)

- $d_{ae} = 50.0$ nm
  - $d_{m,AAC} = 54.2$ nm
  - $d_{m,SMPS} = 57.7$ nm

- $d_{ae} = 75.0$ nm
  - $d_{m,AAC} = 81.0$ nm
  - $d_{m,SMPS} = 83.4$ nm

- $d_{ae} = 100$ nm
  - $d_{m,AAC} = 107$ nm
  - $d_{m,SMPS} = 108$ nm

- $d_{ae} = 200$ nm
  - $d_{m,AAC} = 213$ nm
  - $d_{m,SMPS} = 208$ nm

- $d_{ae} = 400$ nm
  - $d_{m,AAC} = 420$ nm
  - $d_{m,SMPS} = 397$ nm

- $d_{ae} = 600$ nm
  - $d_{m,AAC} = 627$ nm
  - $d_{m,SMPS} = 536$ nm

SMPS charge correction not completely effective

SMPS charge correction breaks down when distribution truncated
Monodisperse output summary

\[ y = 1.077x - 9.081 \]

\[ R^2 = 0.9999 \]

4 \( \mu \)m DOS particles, PALAS Welas spectrum of AAC output
**Step Scanning Inversion**

By applying methods used by Stolzenburg and McMurry (2008) on the DMA, it can be shown* that

\[
\frac{dN}{d \log d_{ae}} \bigg|_{i} \approx \frac{\ln(10) \cdot N_i}{\eta_i \cdot \frac{d \log d_{ae}}{d \log \tau} \bigg|_{i} \cdot \beta_i}
\]

where

\[\beta^* = \left(1 + \frac{1}{\beta}\right) \cdot \ln(1 + \beta) - \left(1 - \frac{1}{\beta}\right) \cdot \ln(1 - \beta)\]

\[\beta = \frac{1}{R_t} = \frac{Q_{aerosol}}{Q_{sheath}}\]

And by differentiating

\[\tau \equiv \frac{C_c(d_{ae}) \rho_0 d_{ae}^2}{18 \mu}\]

\[
\frac{d \log (d_{ae})}{d \log (\tau)} =
\]

\[C_c(d_{ae}) \cdot d_{ae} \cdot \left[2 \cdot d_{ae} + 2.34 \cdot \lambda + 1.05 \cdot \lambda \cdot \exp \left(-0.39 \cdot \frac{d_{ae}}{\lambda}\right) \cdot \left(1 - \frac{0.39 \cdot d_{ae}}{\lambda}\right)\right]^{-1}\]

\[\omega\] is varied over a scan, downstream CPC logged and inverted to give

\[
\frac{dN}{d \log d_{ae}} \text{ vs } d_{ae}
\]

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*T.J. Johnson et al., in preparation
Size Accuracy

Aerosol sources:
Duke Scientific & JSR Polystyrene Latex Spheres
Aerosolised with:
• TSI electrospray (<100 nm)
• BGI Collison nebulizer (>100 nm)
**Classification Performance – Tandem AACs**

### Transmission Efficiency ($\lambda_\omega$)

Scales area under transfer function
- Ideal behaviour $\Rightarrow 1.0$
- $<1.0 \Rightarrow$ losses, $>1.0 \Rightarrow$ gains

### Transfer Function Width Factor ($\mu_\omega$)

Scales FWHM
- Ideal behaviour $\Rightarrow 1.0$
- $<1.0 \Rightarrow$ broader, $>1.0 \Rightarrow$ narrower

$\lambda_\omega$ and $\mu_\omega$ determined by scanning the monodisperse output of one AAC with another AAC, then performing a deconvolution.

\[ N_2(\tau_2^*) = \frac{\int \eta_i(d_{a,2}) \cdot \Omega_{NI,1}(\tau_1,\tau_1^*,\beta_1,\lambda_{\Omega,1},\mu_{\Omega,1}) \cdot \Omega_{NI,2}(\tau_2,\tau_2^*,\tau_{\text{agree}},\beta_2,\lambda_{\Omega,2},\mu_{\Omega,2}) \cdot dN_i}{\int \eta_i(d_{a,1}) \cdot \Omega_{NI,1}(\tau_1,\tau_1^*,\beta_1,\lambda_{\Omega,1},\mu_{\Omega,1}) \cdot dN_i} \]
Transmission Efficiency & Broadening Results

Resolution (R) = 10: LF (“low” flow): $\frac{Q_a}{Q_{sh}} = 0.3/3$ LPM, HF (high flow): $\frac{Q_a}{Q_{sh}} = 1.5/15$ LPM

1. AAC reaches 0.8/0.9 = 89% of max transmission away from diffusion loss regime – small particle losses consistent with diffusional loss
2. AAC “losses” much lower than neutraliser + DMA system across all sizes
3. AAC transfer function approx twice as broad as expected – this probably due to imperfect flow distribution, especially as rotating

T.J. Johnson et al., in preparation
Step-scan comparison with SMPS

- DOS nebulized by constant output atomizer
- Both SMPS multiple-charge correction, and empirical AAC losses/broadening correction based on tandem experiments were used. AAC data converted to mobility metric.
- High degree of agreement between corrected AAC and SMPS/CPC measurements (CMD, GSD and $N_{total}$ agreement of -0.8%, 1.2% and 1.4% respectively)
Step-scan comparison with ELPI

DOS nebulized by constant output atomizer

Particle Aerodynamic Diameter, $D_{ae}$ (nm) vs. Aerodynamic Spectral Density, $dN/d\log d_{ae}$ (cm$^{-3}$)
Conclusions

- AAC provides a means to select a monodisperse aerosol without charging it – removing multiple charging effects, and mitigating particle loss due to charging efficiency.
- AAC provides a means to select a monodisperse aerosol by aerodynamic diameter
- Production instrument has a size range 25 nm – 5 μm+
- Production instrument accuracy and transmission efficiency excellent
- Production instrument broadening more than expected – but still comparable resolution to a DMA
- Can currently be stepped scan to yield a size spectrum
References


Any questions?

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Booth #13 at AAC

www.cambustion.com/aac