Aerodynamic Aerosol Classifier (AAC)

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Cambridge Particle Meeting 2013

Cambridge, UK, May 24, 2013

Objectives and outline

- Developing a new instrument to classify aerosol particles according to the aerodynamic diameter.

Outline:

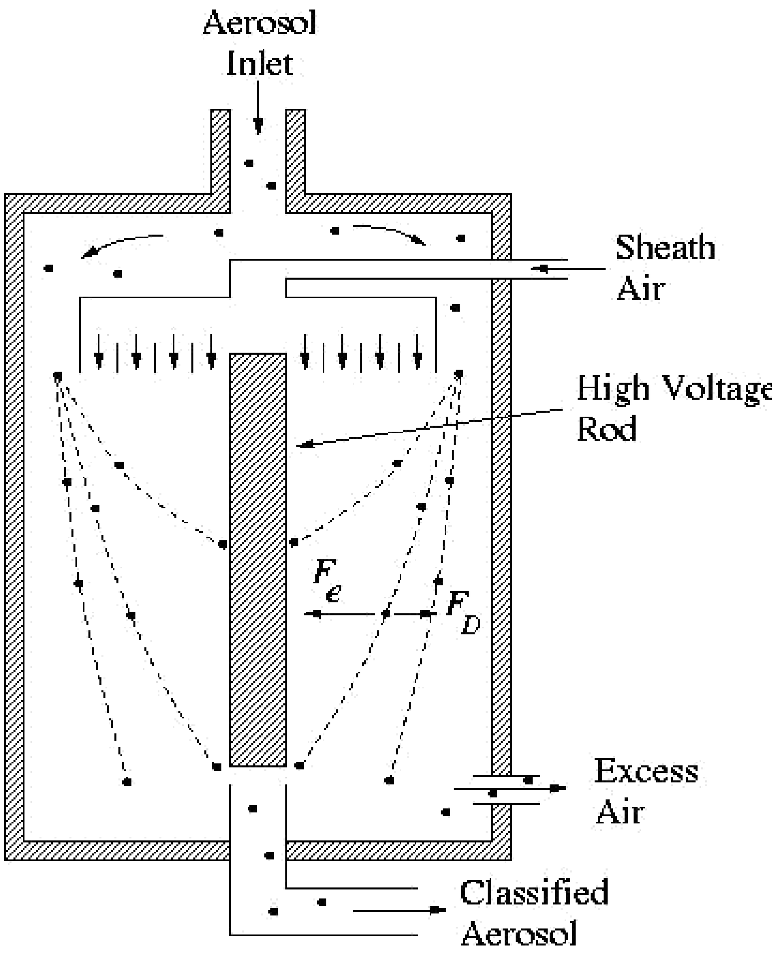
1. Two non-diffusion models
2. Two diffusion models
3. Validation Experiments
4. Application: Mass, shape factor and effective density of soot particles using tandem AAC-DMA.

DMA

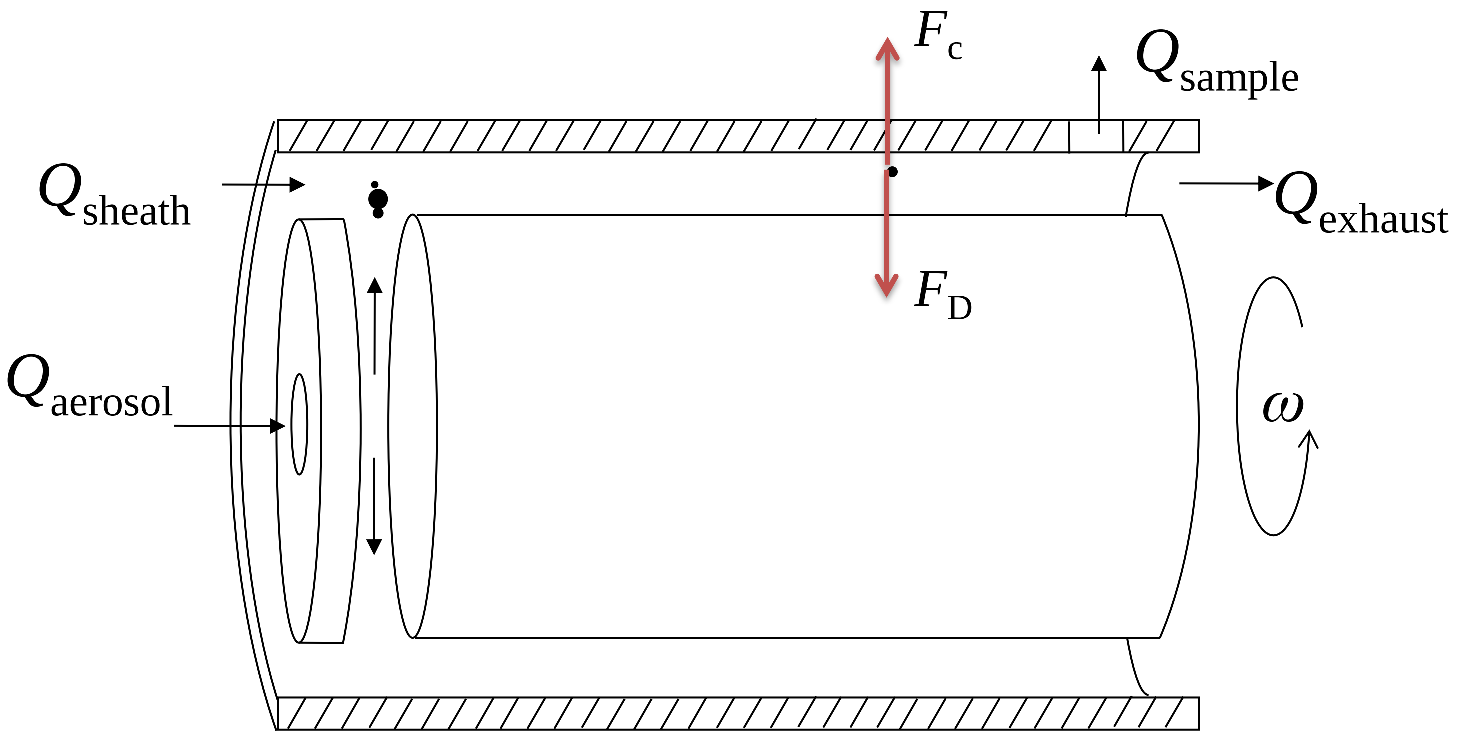
Differential Mobility Analyzer

Particles are classified using electrostatic and drag forces.

Particles are classified by electrical mobility (size).



Concept



- Two co-axial cylinders rotating at the same rotational speed
- Classify different particle size by changing the rotational speed ω

Advantages

– Classification **Without Charging** the Particles

AAC gives a truly monodisperse size

(DMA, CPMA or APM may classify larger particles with two or more charges)

– **Classifies** particle based on **Aerodynamic diameter**

Cascade impactors make a cut off

APS measures the particle size based on Aerodynamic diameter

Non-diffusion Models

Limiting Trajectory model

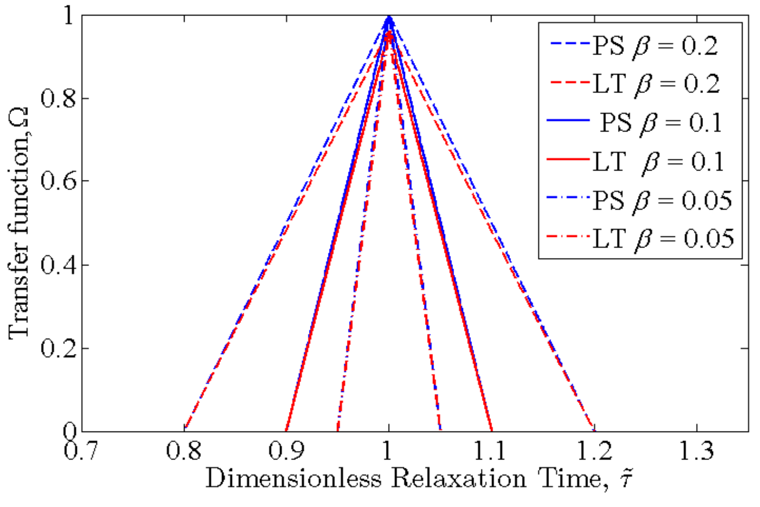
Wang and Flagan (1990) for DMA

Particle Streamline model

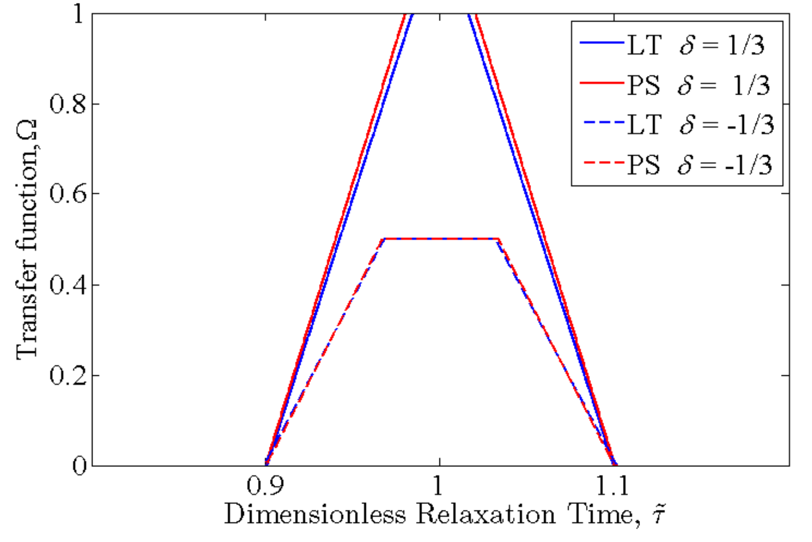
Knutson and Whitby (1975) for DMA

Transfer Function

Balanced flow

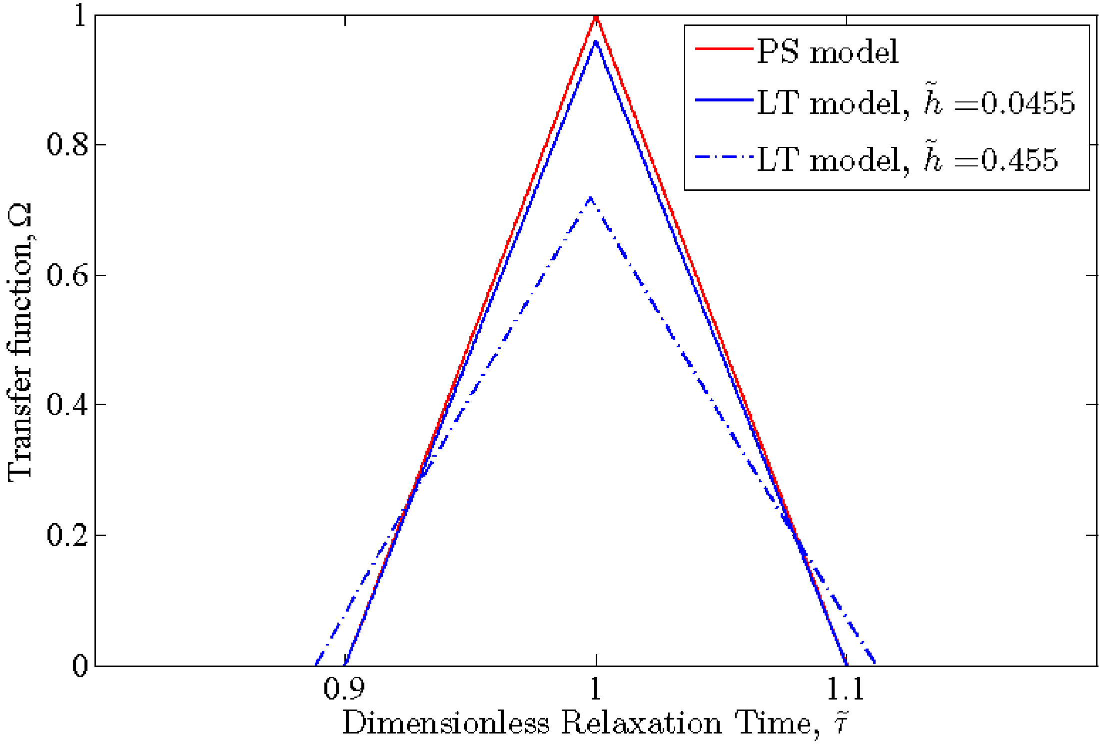


Unbalanced flow



$$\tilde{\tau} = \frac{\tau}{\tau^*}$$

Large gap



$$\tilde{\tau}_{\text{LT}} \approx \tilde{\tau}_{\text{PS}}$$

Diffusion models

Convective Diffusion model

Solving Convective Diffusion equation applying BC

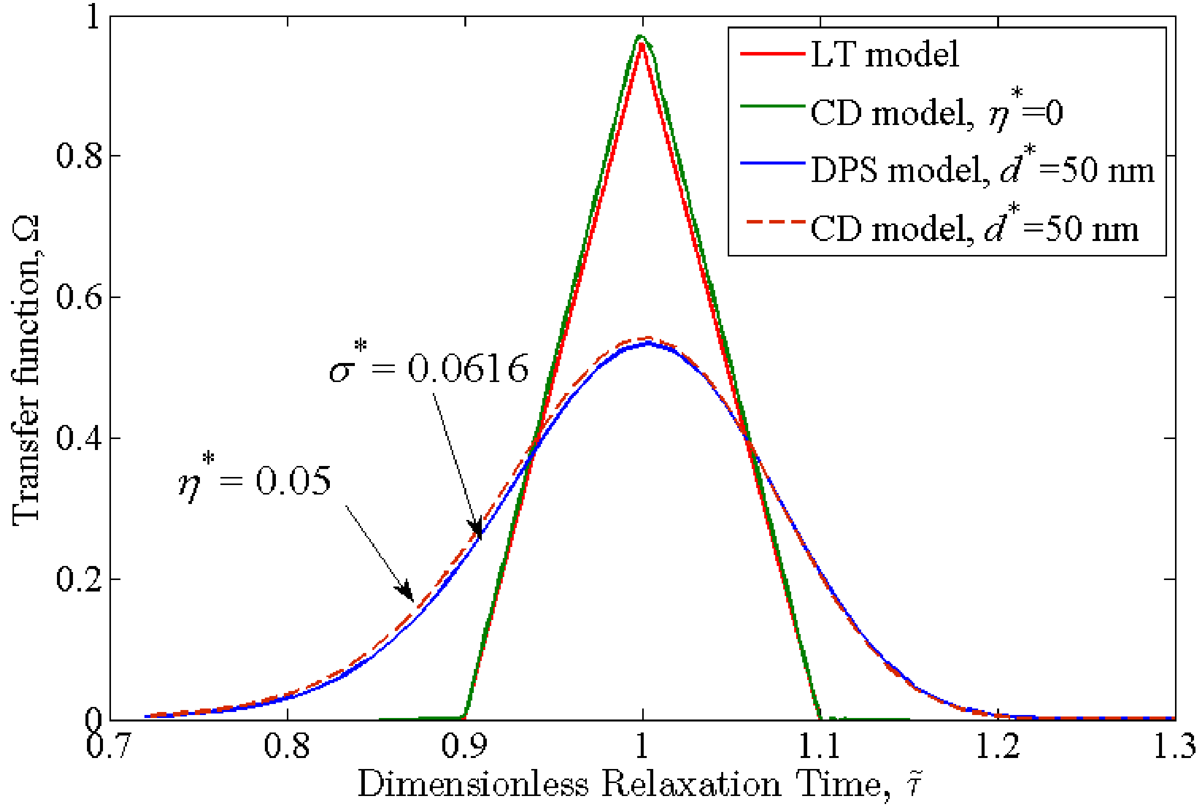
Similar to J. Olfert (2005) for CPMA

Diffusing Particle streamline

Diffusion spreads particles in a Gaussian profile about the corresponding non-diffusing particle streamline

Similar to Stolzenburg (1988) for DMA

Diffusion models

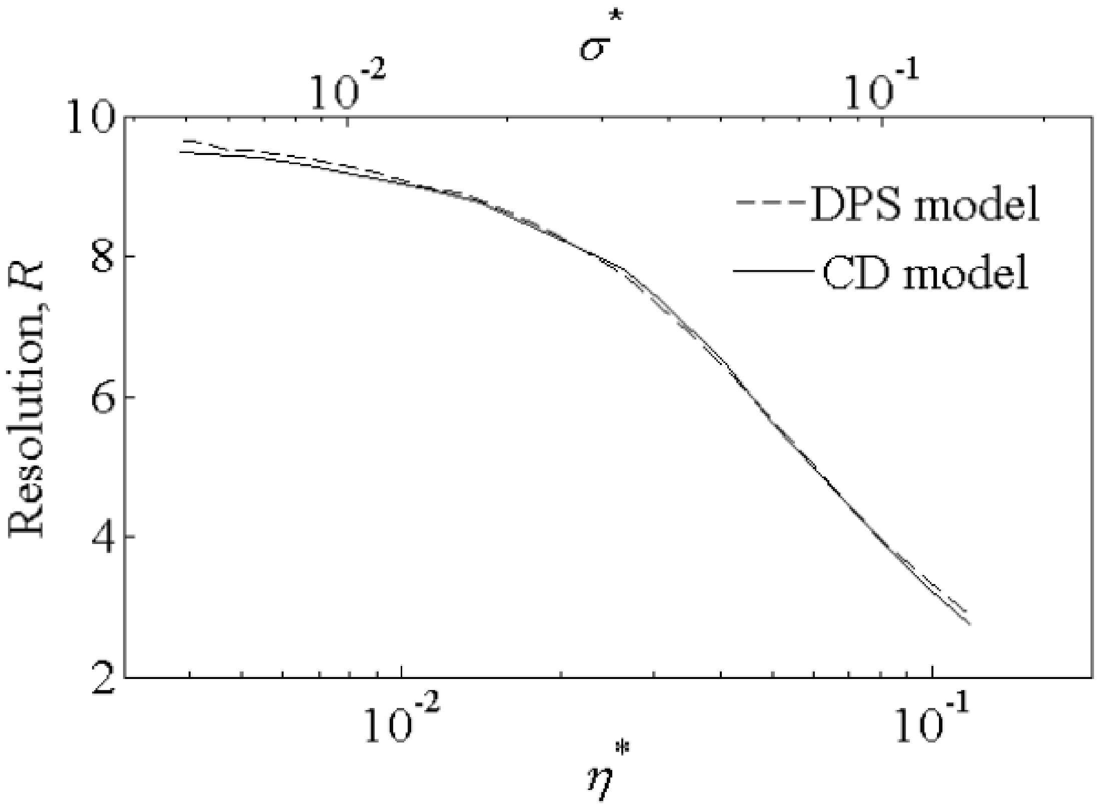


DPS model CD model

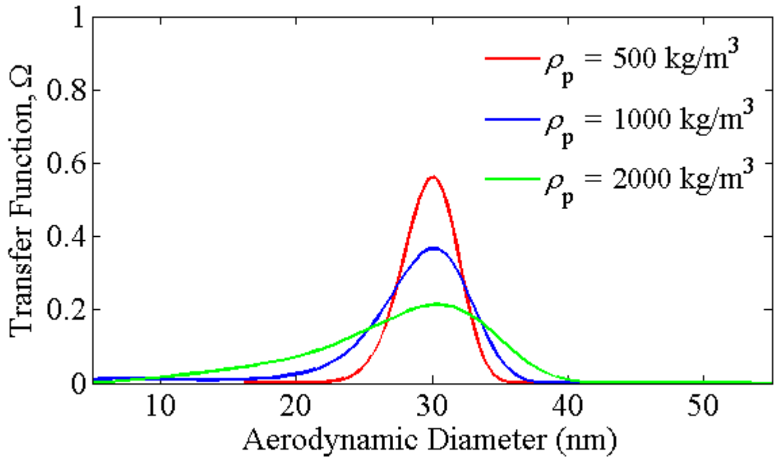
$$\sigma = 1.23\,\eta.$$

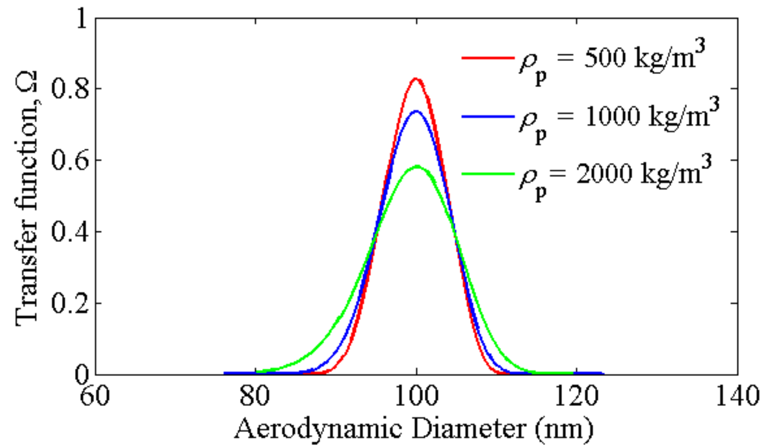
$$\tilde{\tau}_{\mathrm{LT}} \approx \tilde{\tau}_{\mathrm{PS}} \approx \zeta$$

Resolution



Effect of density



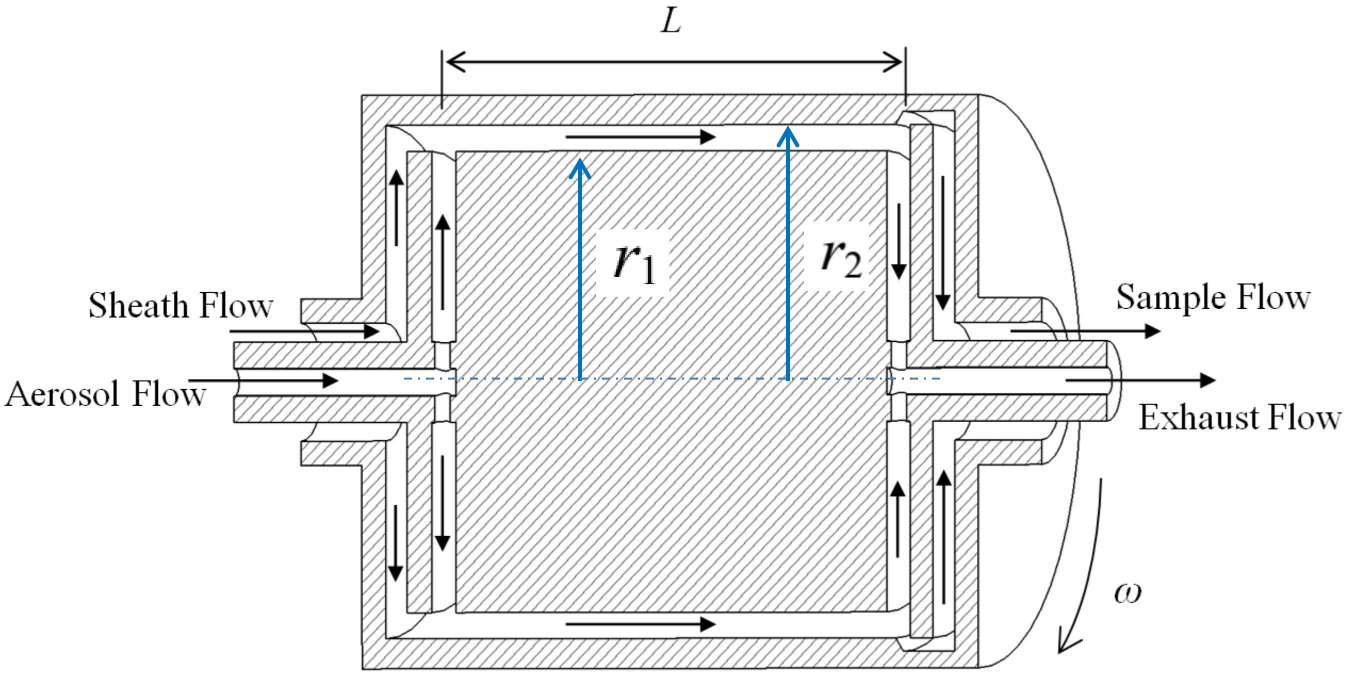


$$d_{mo} = d_{ae}\sqrt{\frac{\rho_0 C_c(d_{ae})}{\rho_p C_c(d_{mo})}},$$

Stokes-Einstein equation ($D=kTB$)

Design

Property	Value
r_2 (mm)	45
r_1 (mm)	43
L (mm)	210
Q_{sh} (L/min)	3
Q_a (L/min)	0.3
Q_s (L/min)	0.3
Temperature (^{0}C)	20
Pressure (atm)	1



For more details please see:

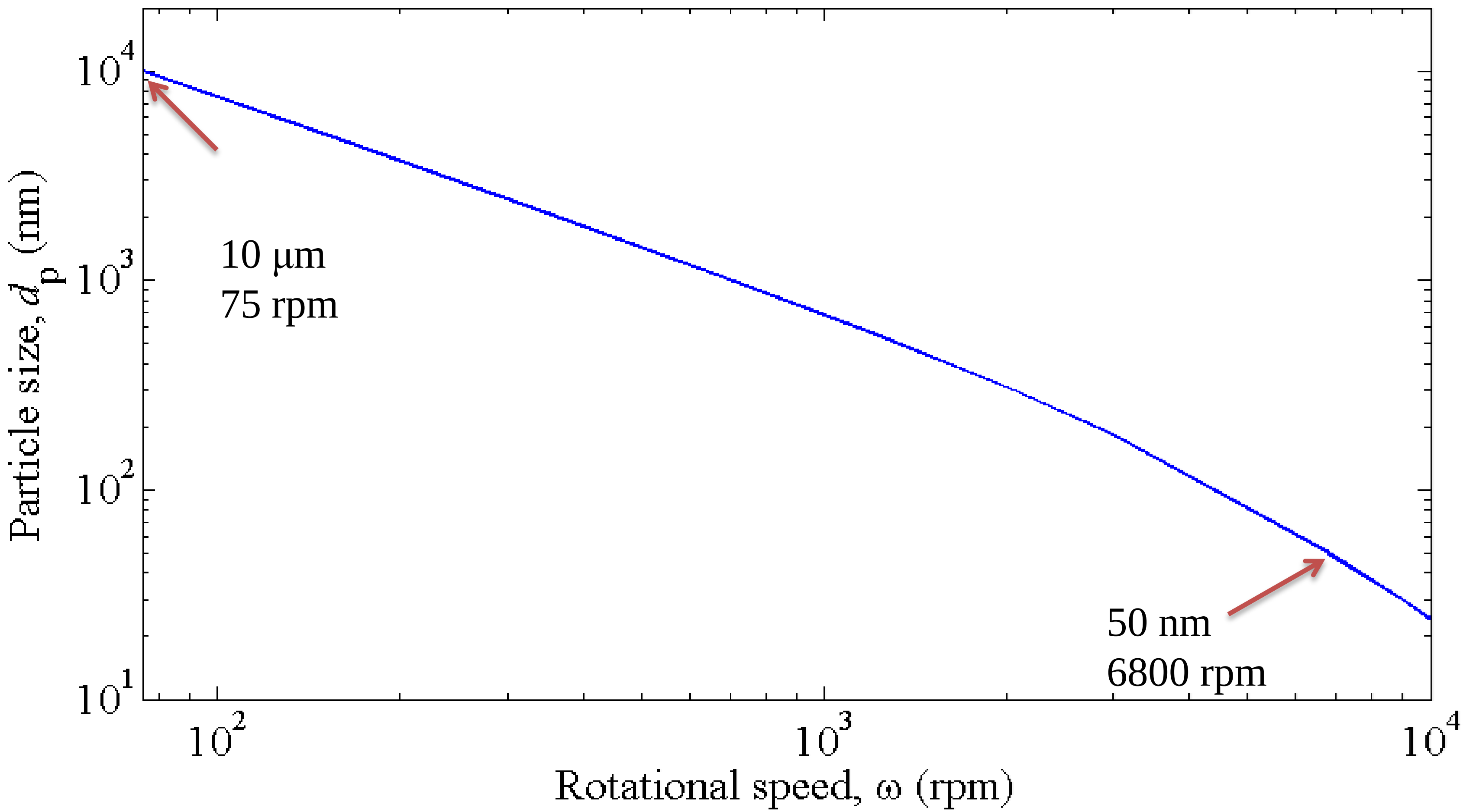
An Instrument for the Classification of Aerosols by Particle Relaxation Time: Theoretical Models of the Aerodynamic Aerosol Classifier,

Aerosol Science and Technology (2013)

F. Tavakoli & J. S. Olfert

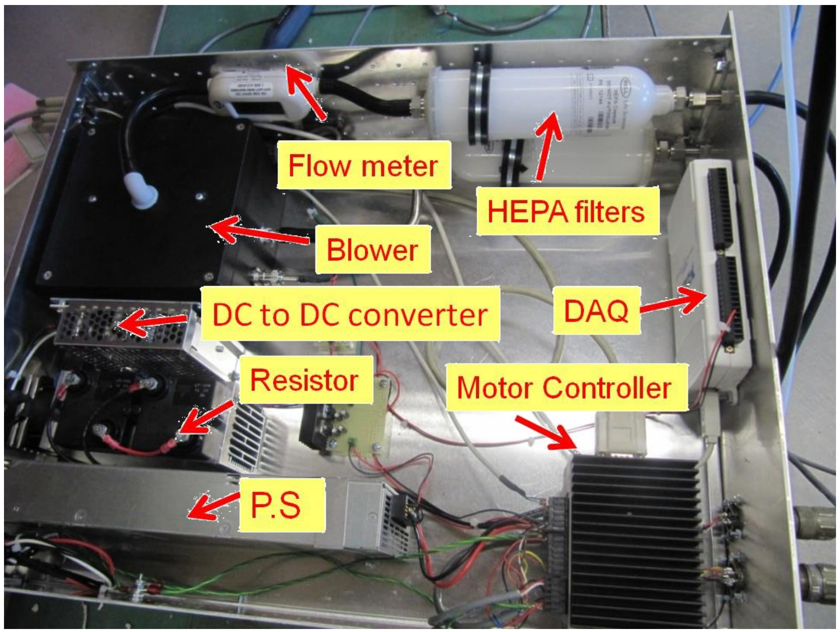
DOI:10.1080/02786826.2013.80276

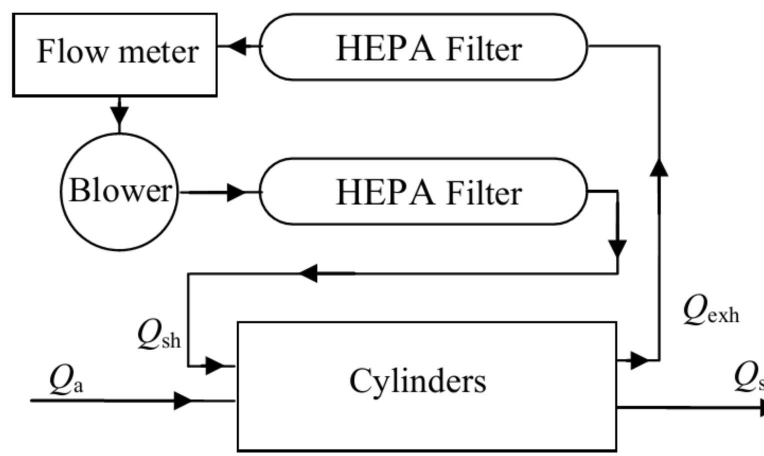
Design



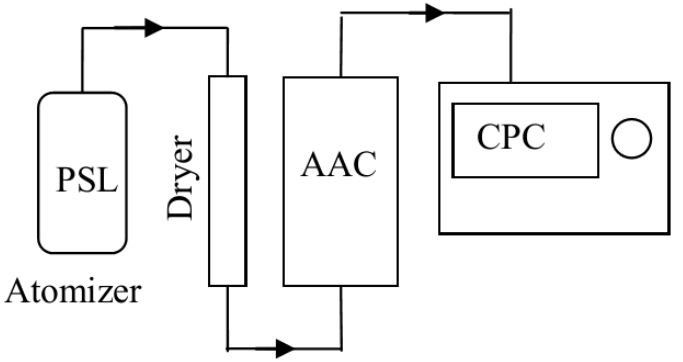
10^4
10^3
10^2
10^1
Particle size, d_p (nm)
10 µm
75 rpm
50 nm
6800 rpm
10^2
10^3
10^4
Rotational speed, ω (rpm)

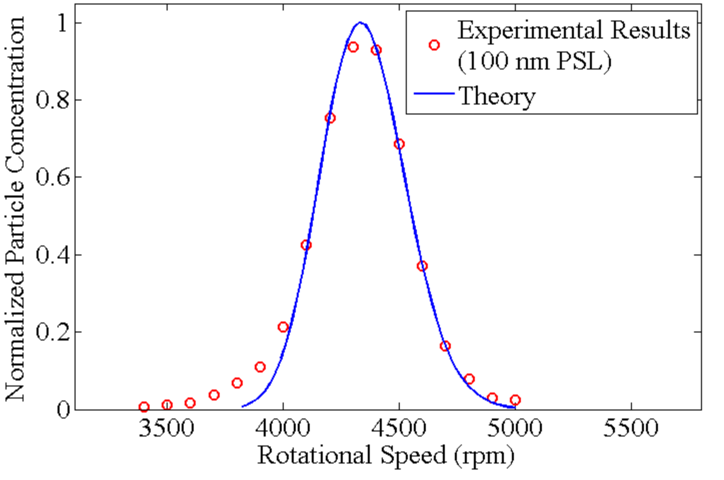
Flow diagram





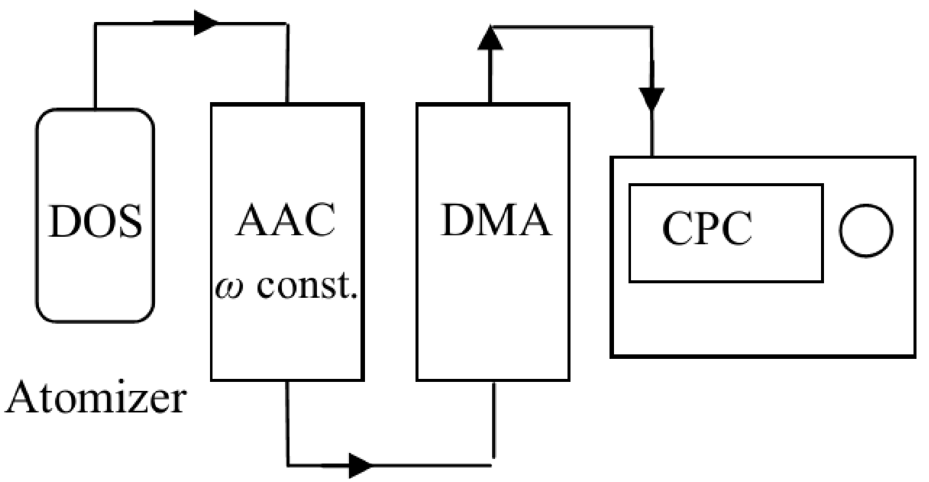
Setup I - PSL

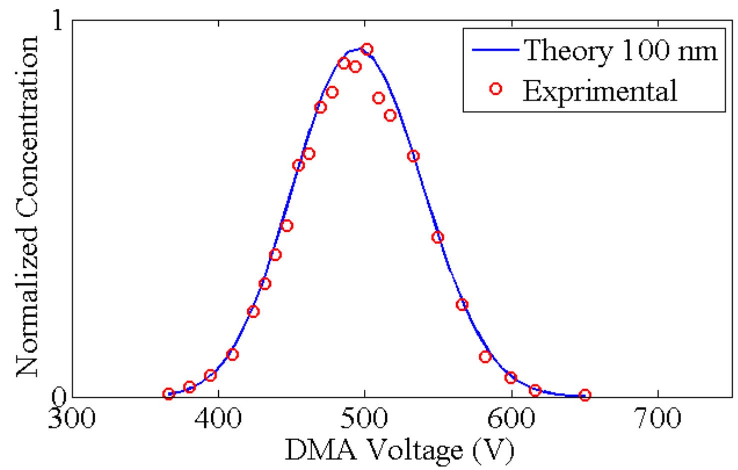




$$N_i(\omega_i) = \int \eta_{\mathrm{AAC}}\, n_{\mathrm{PSL}}(d_{\mathrm{ae}})\, \Omega_{\mathrm{AAC}}(d^*_{\mathrm{ae},i}, d_{\mathrm{ae}})\, dd_{\mathrm{ae}}$$

Setup II - DOS

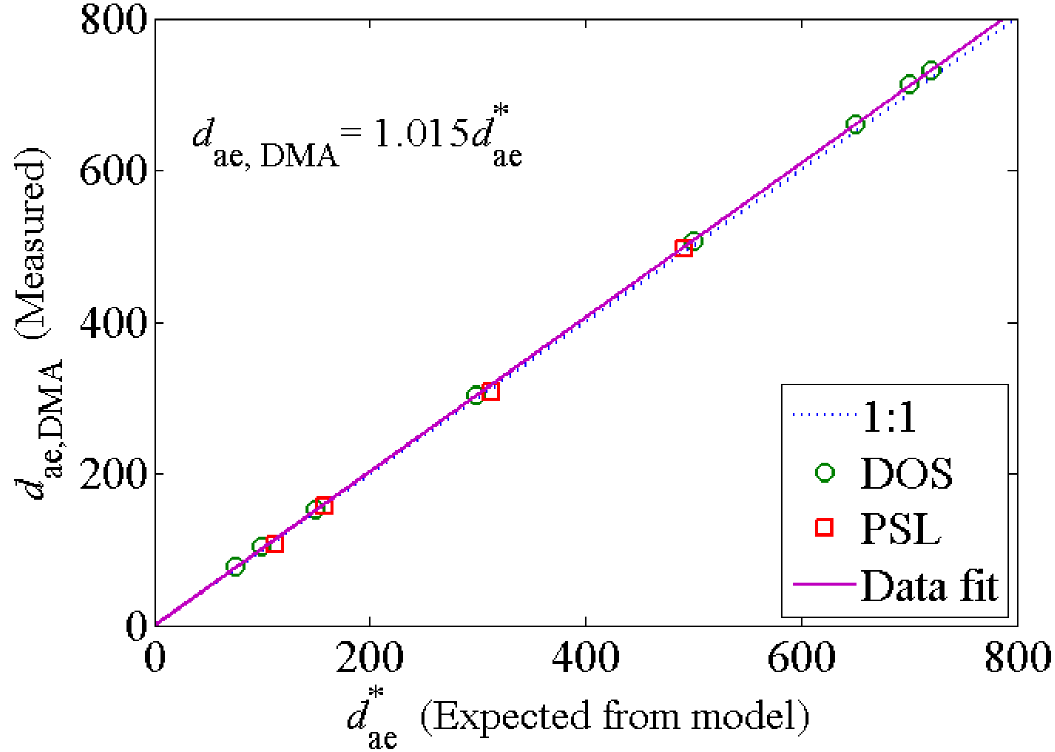




$$N_i(V_i) = \int \left[\iint \eta_{\mathrm{AAC}} n_{\mathrm{DOS}}(d_{\mathrm{ae}}) \Omega_{\mathrm{AAC}}(d^*_{\mathrm{ae}}, d_{\mathrm{ae}}) dd_{\mathrm{ae}} \right] \times \eta_{\mathrm{DMA}} \Omega_{\mathrm{DMA}}\left(d^*_{\mathrm{mo},i}, d_{\mathrm{mo}}\right) dd_{\mathrm{mo}}$$

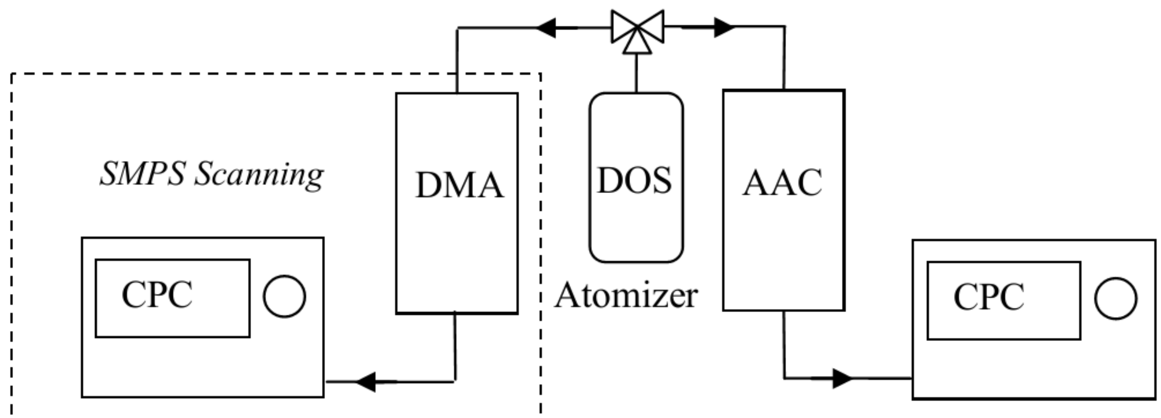
Effective length
(correction for the transfer function location)

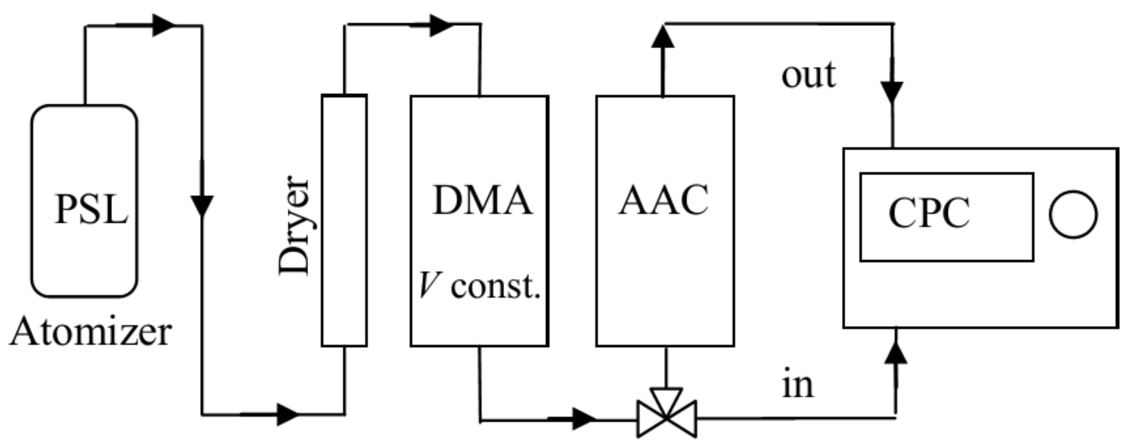
The aerodynamic diameter classified by AAC is consistently larger than the expected value. The data are quite linear, so we can use a linear correction (1.5% shorter length)



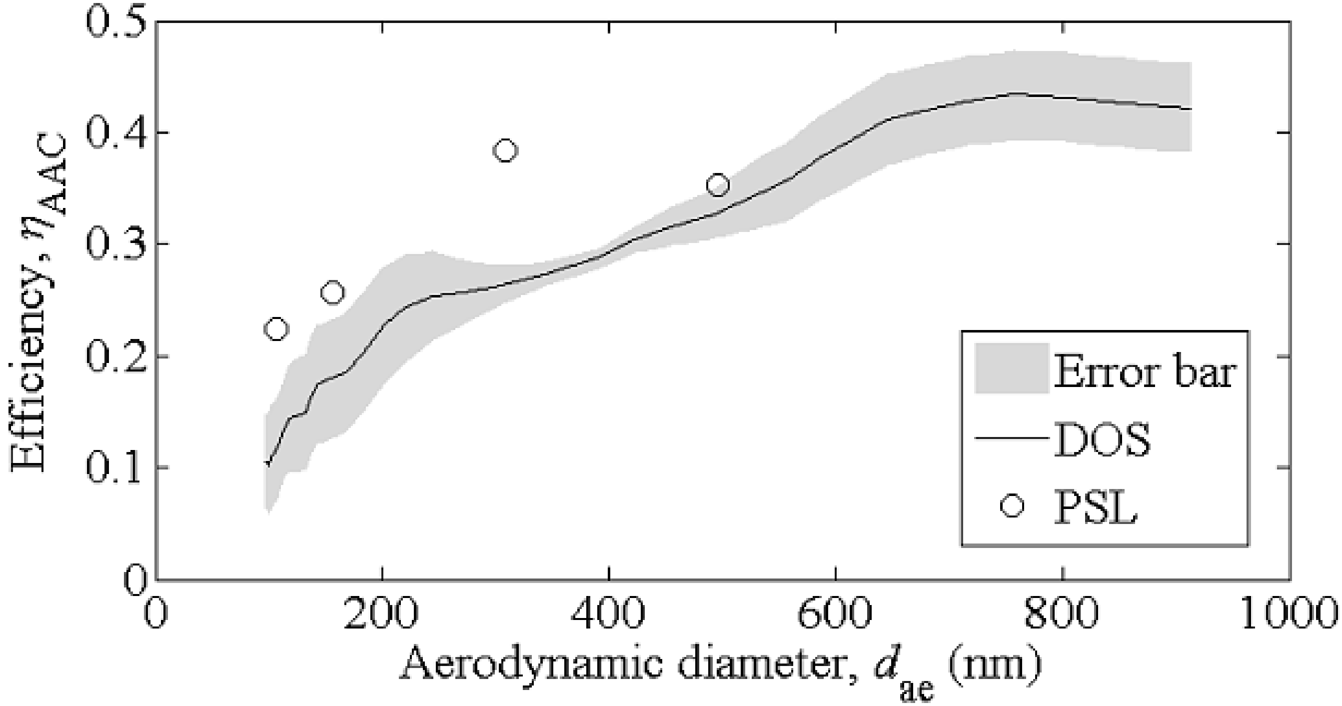
$$L_{eff} = L \,/\, 1.015 = 206.8 \text{ mm}$$

Set up III & IV
calculate the efficiency



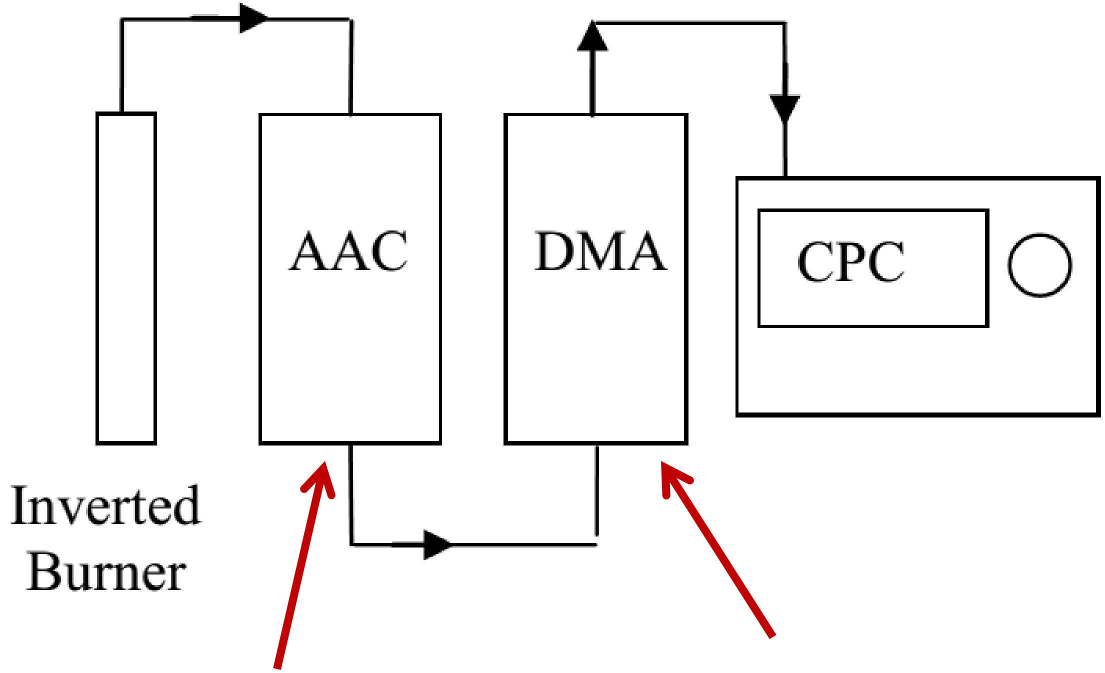


AAC efficiency



Applications

Soot particle from a inverted burner



(Particle Relaxation time)
Aerodynamic diameter

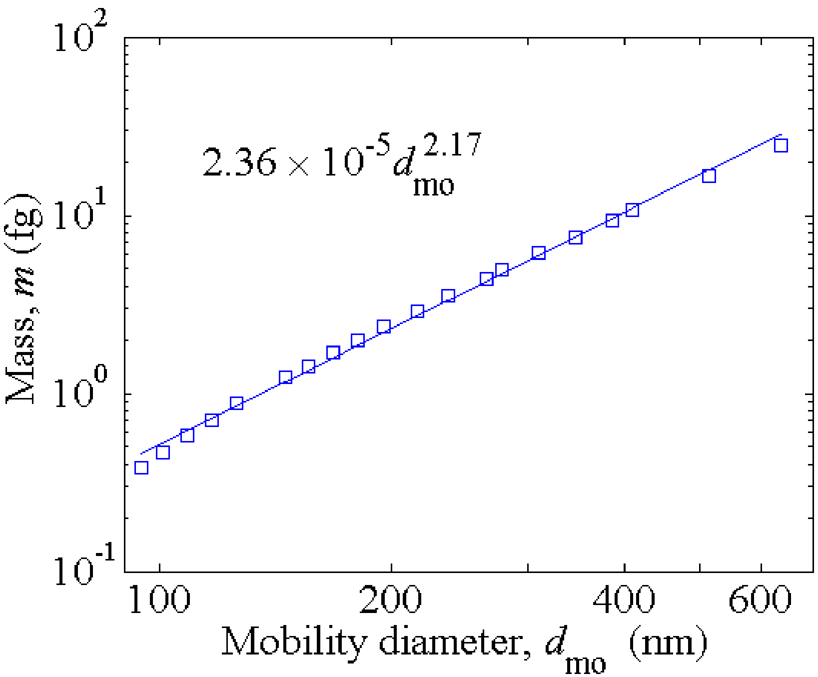
(Particle Mobility)
Mobility diameter

Soot particle from a inverted burner

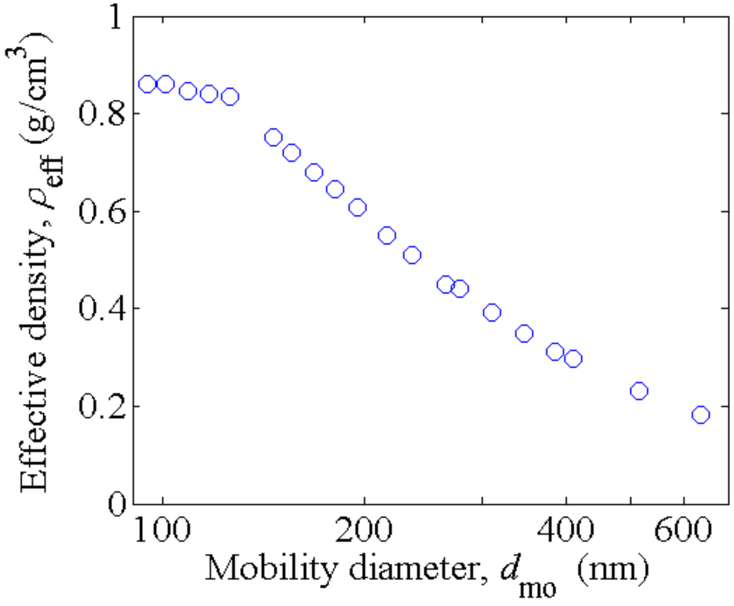
$$\tau = mB$$

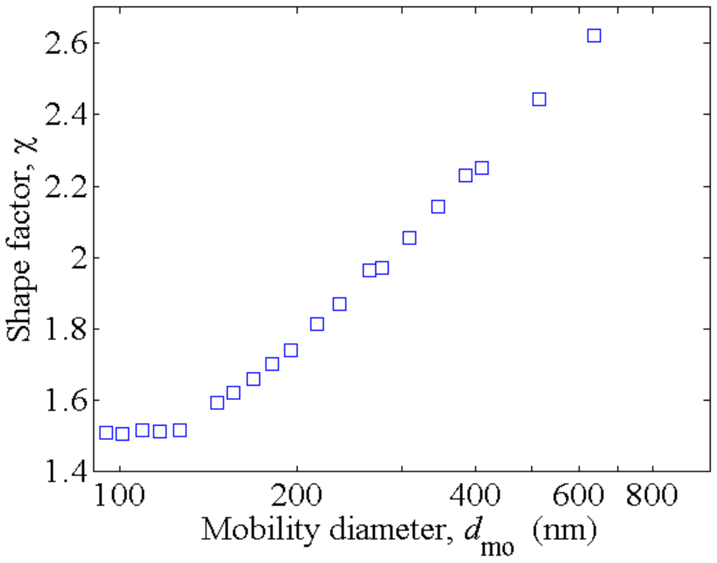
AAC DMA

Mass-mobility exponent



Soot particle from a inverted burner





Conclusion

- AAC classifies particles by their aerodynamic diameter effectively
- Experimental results agree well with theory
- Combination of AAC and DMA can be used to calculate other properties such as mass, effective density, and shape factor.

Thank you!

Questions/Comments?