Density and Mass Mobility Exponent Determination with the CPMA

Introduction

The Cambustion Centrifugal Particle Mass Analyzer (CPMA) is an aerosol classification instrument, which allows selection of pre-charged ultrafine aerosol particles *directly according to their mass:charge ratio*.

It may be considered an equivalent instrument for particle mass to the Differential Mobility Analyzer (DMA), which allows selection of particles according to their electrical mobility (drag:charge ratio).

The CPMA is used with an external pre-charger, which may be of the radioactive, X-ray or corona types.

The CPMA uses a balance between electrostatic and centrifugal forces to select particles of a given mass:charge ratio.

Novel features ensure a higher throughput of particles of the selected mass:charge ratio, compared with earlier instruments such as the Kanomax Aerosol Particle Mass analyzer (APM). [Ehara *et al.* (1996)]

The CPMA principle is described in detail in this animation:
http://www.cambustion.com/products/cpma/animation

Density and Mass Mobility Exponent Determination

Key applications for the CPMA are determination of the density of particles, and determination of the relationship between mass and size for particles.
In both applications, the CPMA is used in tandem with a DMA, with a detector to monitor the output of the CPMA. An optional second detector (monitoring the concentration at the inlet of the CPMA) may be used to compensate for any fluctuations in the aerosol concentration.

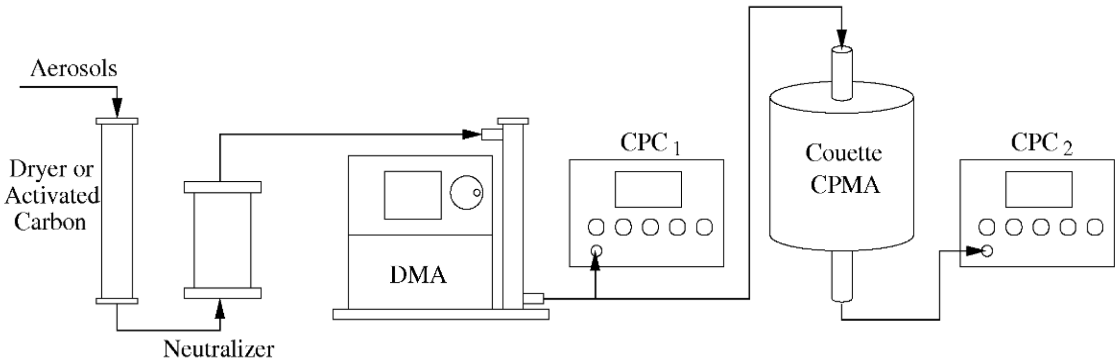
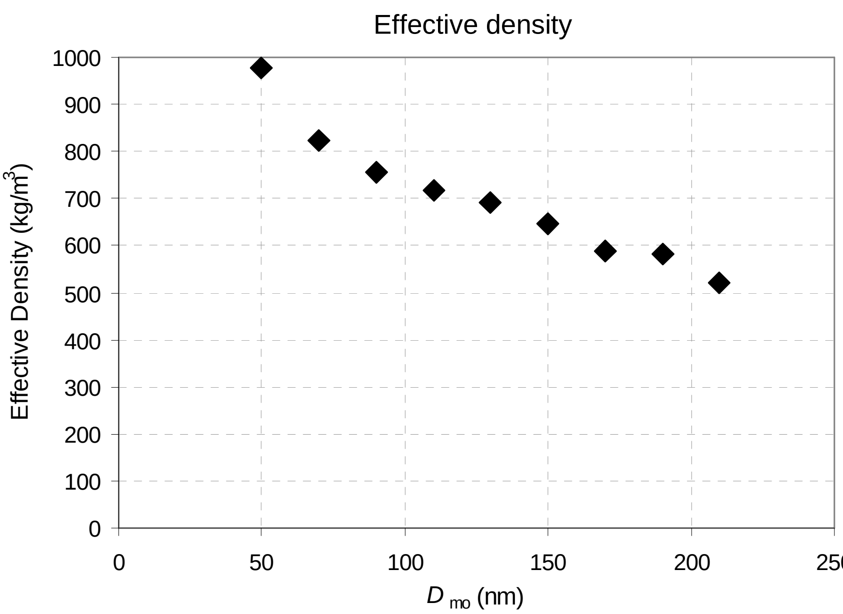


Diagram courtesy of J. Olfert

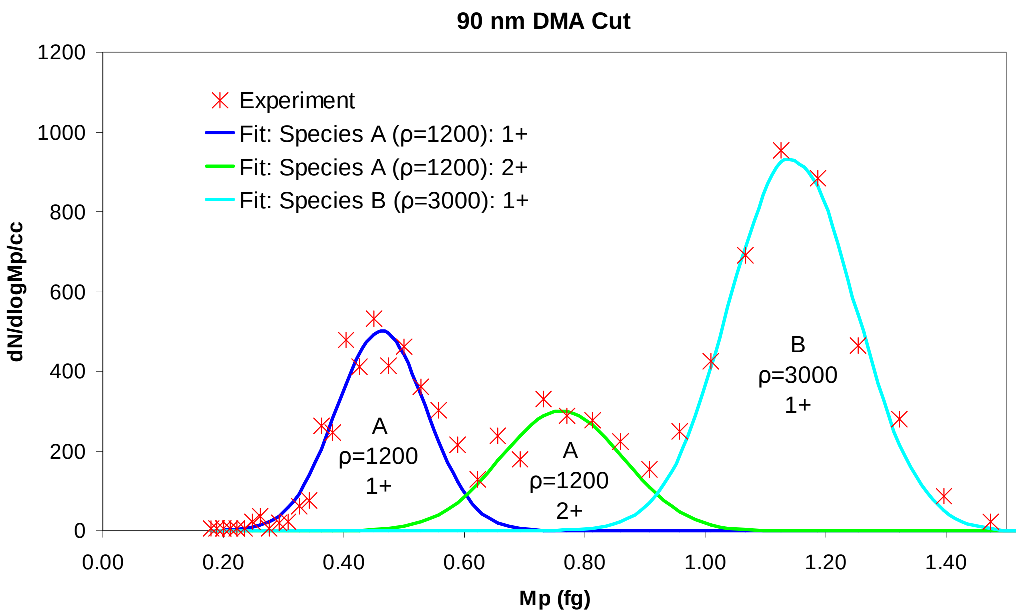
The dryer in the above diagram is used to dry wet aerosols, e.g. those generated in a nebuliser, and the (bipolar) neutraliser (charger) is often integral to the DMA.
To determine the density of a particle, the DMA is set to pass a certain size of particle. From this, the volume of the particle is calculated, e.g. for a spherical particle, the volume is $\pi d^3/6$.
CPMA is scanned to obtain the mass of the particles which have been selected by the DMA – all the particles emerging from the DMA will have at least one charge already. The density is then simply the mass divided by the volume. If the particles are not spherical, $m/(\pi d^3/6)$ is known as the *effective*

density – the density the particles would have *if* they *were* spherical. The effective density for particles which are not spherical varies with size, for example, the effective density of soot aerosols decreases with size as the packing efficiency of the fractal agglomerate decreases:



The issue of charge correction exists, and this does bias the value of the peak mass at each size point. The mass spectrum will contain multiple peaks, and strictly speaking an off-line de-convolution of the scan data should be performed to obtain the true peak mass, taking into account an appropriate charging model.

However, depending on what level of accuracy is required, this may not be necessary for all applications. The following scan shows an example where there is a combination of multiple charging from the DMA, and a second, more dense species present:



Density Factor (ρ_f) and Fractal Index (f):

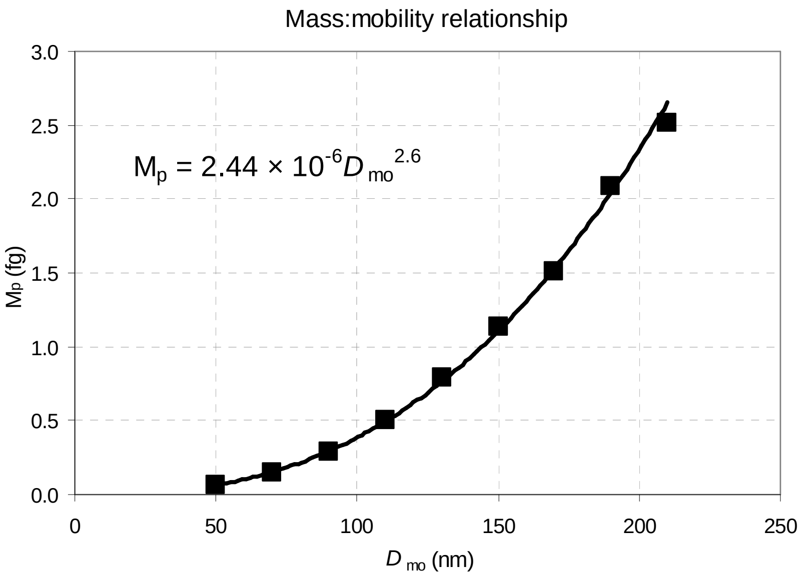
These relate particle mass (M_p) to diameter (D_p) in that:

$$M = \rho_f \times D_p^{\,f}$$

As the CPMA fundamentally measures mass, this relationship is inverted to calculate particle size for a given mass. The user can enter a density factor and fractal index depending upon the quantity used. The default is “unit density” – that of spherical drops of pure water where the density factor is 523.5 kg m^{-3} (= (π/6) × 1000) and the fractal index is 3. It follows from the above relationship that the unit of ρ_f depends on f.

For non-spherical “fractal” particles, f can be non-integer. The CPMA can be used with a DMA to measure f for any aerosol. Strictly speaking, as the DMA measures particle mobility size, this is then known as the mass-mobility exponent, D_{fm} (also known as the “mobility based fractal dimension”). For Diesel soot, D_{fm} can be in the range 2.2 to 2.8].

The same experimental setup as for measuring density can be used to determine this for a given aerosol, and hence infer information about particle morphology. In this case, the peak mass is plotted versus size for each DMA size setting. A power-law best fit line is fitted to the data, of the form $M = \rho_f \times D_p^{\,Dfm}$ and D_{fm} is determined by a power law fit, or as the gradient of a log-log plot:



The mass:mobility relationship of an aerosol may vary with environmental factors such as humidity, as particles undergo changes in both mass and size through hygroscopic growth. The combination of CPMA and DMA allows study of these changes [Vlasenko & Mikhailov, 2013]

Use with a DMS

For aerosols which are transient in nature, it may be desirable to increase the speed of this process. The neutraliser and CPMA may be used *upstream* of a fast response Differential Mobility Spectrometer (DMS). The DMS charger is disabled, and a special calibration for singly charged particles is applied in software.

An analog output of the CPMA is configured to give particle mass and connected to a DMS analog input. The CPMA is step-scanned whilst logging a file on the DMS.

If the DMS lognormal inversion is used, the file will then contain both the mass (as an analogue input) and the mobility size (as the CMD of the lognormal mode).

A mobility-mass chart may be directly plotted without having to “step” the size as with a DMA.

See [Johnson *et al*., 2013.]

Further Reading

Aerosol Precipitator	www.cambustion.com/products/precipitator
CPMA:	www.cambustion.com/products/cpma
UDAC:	www.cambustion.com/products/udac
Publications	http://www.cambustion.com/publications/pubinst/CPMA

Publications referred to in the text

- *Novel method to classify aerosol particles according to their mass-to-charge ratio — Aerosol Particle Mass Analyser.* K. Ehara, C. Hagwood & K.J. Coakley. *Journal of Aerosol Science.* Volume 27, Issue 2, Pages 217–234 (1996)

  http://dx.doi.org/10.1016/0021-8502(95)00562-5

- *Tandem of Differential Mobility Analyzer and Centrifugal Particle Mass Analyzer: application to hygroscopic growth of aerosol particles.* S.S.Vlasenko, E.F.Mikhailov. European Aerosol Conference, (2013)

  http://eac2013.cz/EAC%20abstracta/Instrumentation/Vlasenko-Sergey_Instrumentation_20130228-095742_9415980356.pdf

- *Mass–Mobility Measurements Using a Centrifugal Particle Mass Analyzer and Differential Mobility Spectrometer.* T.J. Johnson, J.P.R. Symonds, J.S. Olfert. *Aerosol Science and Technology*, **47**(11), pages 1215–1225 (2013)

  http://www.tandfonline.com/doi/abs/10.1080/02786826.2013.830692