DMS500 sizing, resolution & time response

Introduction

The Scanning Mobility Particle Sizer (SMPS) has long been established to measure mobility based size spectra. The SMPS using a Differential Mobility Analyser (DMA) to select particles by size and using a Condensation Particle Counter (CPC) as a detector, inherently requires scanning operation, preventing real time measurements with such techniques.

Alternative measurement techniques which produce electrical mobility spectra still classify the particles according to electrical mobility, and then use parallel electrometer detectors to simultaneously derive the calculated concentration across the measurement range. In the DMS500 this allows real-time measurement of particles in the 5 – 1,500 nm range (or 5 – 2,500 nm for the 2.5 micron version of the instrument).

The scanning nature and bipolar charging regime of the SMPS does offer advantages in terms of resolution and sizing accuracy over fast response instruments with unipolar chargers. However, this application note describes the theory, technology and calibration techniques unique to Cambustion fast particle sizing instruments which ensures they can achieve sufficient resolution to resolve multiple aerosol modes and sizing accuracy to within a good tolerance over the whole specified size range, as well as a fast time response to rapidly changing aerosols.

Theoretical Background

Instruments such as the DMS500 follow on from many years of research principally in the University of Tartu in Estonia latterly under Professor Tammet. Initial usage for such instruments was in atmospheric work. This research is summarised in [1]. These instruments operated over a wide size range with no assumptions in the data processing about the number of modes present.

The Cambustion DMS instrument incorporates a further key improvement in this technique to allow resolution of large particles. The upper size limit of measurement by electrical mobility with diffusion charging is caused by the difference in the dependence of particle mobility on diameter in the free molecular and continuum regimes. Above the mean free path of the gas, in the Stokes regime, mobility is approximately inversely proportional to diameter while the mean charge per particle is approximately proportional to diameter. This results in a mobility invariant with diameter, which means that as the particle size approaches this limit the resolution gets rather poor. In the DMS500, the classifier operating pressure is reduced to 250 mbar, which increases the gas mean free path and allows good resolution up to 1 micron, or higher at lower operating pressures. This principle has been presented in [2].

The unipolar charging process for these instruments inevitably produces a charge distribution which is pseudo-continuous for larger particles and therefore significantly broadens the response compared with equilibrium charge used in an instrument like the SMPS. To minimise these effects, the charging ion density.residence time product in the DMS charger is maximised and the charger is designed to minimise the variability in the residence time. Regardless of this, it is necessary to account for the broadening when processing the raw signals from the instrument by deconvolution with the instrument kernel functions, as also required for impactor measurements. Such a deconvolution process assumes no constraint on the number of modes in the size distribution, but is just limited by the broadening of the instrument. This process and the effect on resolution of multiple modes was discussed in [3].

Subsequently, we have developed an additional processing technique which does look for discrete aerosol modes: this technique offers improved sensitivity and convenience of data analysis when there is prior knowledge that only a number of modes are of interest. This is described in [4]. However, this always operates in conjunction with the unconstrained deconvolution above, and itself is designed to

detect one, two or three modes. For more details on the lognormal inversion see http://www.cambustion.com/sites/default/files/applications/DMS/dms06v03.pdf

Many aerosol instruments rely on the accuracy of the charging model used to describe their chargers. The DMS500 is no exception. However, each and every DMS500 is traceably calibrated using real aerosols (both spherical lab aerosols, and soot agglomerates) before leaving Cambustion. This ensures that sizing and concentration accuracy is much better than other instruments with corona chargers which rely on fixed, theoretical models alone.

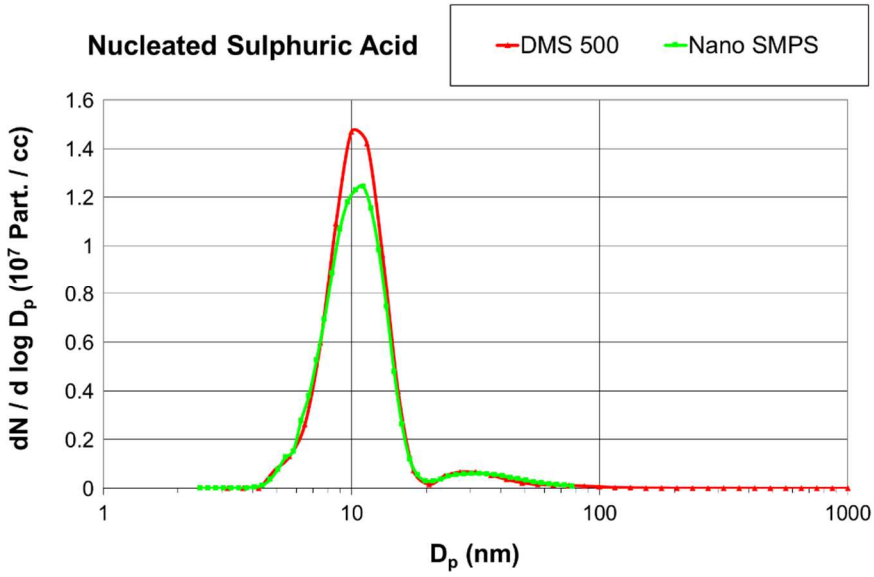
For more information on DMS500 calibration see http://www.cambustion.com/sites/default/files/instruments/DMS500/dms_calibrationv3.pdf and also ref [5].

Experimental Summary

- A sizing comparison is made between a TSI SMPS and a DMS500 using a bimodal sulphuric acid aerosol, representative of a real world aerosol
- A sizing comparison is also made between data from a TSI SMPS and that from a DMS500 using two monomodal aerosols selected with DMAs
- A resolution test is performed by moving those two aerosols in size to show when they are spectrally resolved
- Sizing data using polystyrene latex spheres is presented which shows that the DMS500 can correctly size aerosols over the entire specified size range
- Finally a time response test demonstrates that the DMS500 is genuinely capable of resolving transient aerosol features on a sub 200ms time scale, with data rates of 10 Hz.

SMPS and DMS comparison with Bimodal Aerosol

A sulphuric acid re-nucleation rig was used to generate a bimodal aerosol representative of a real-world aerosol – for full details see [6] from where these data are taken. DMS500 spectrum is shown against that from a TSI SMPS, where a nano-DMA is used.

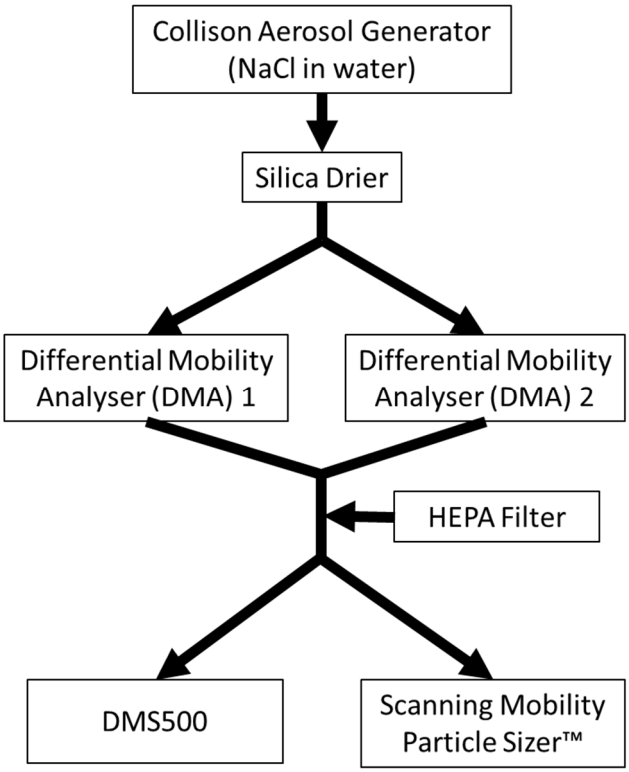


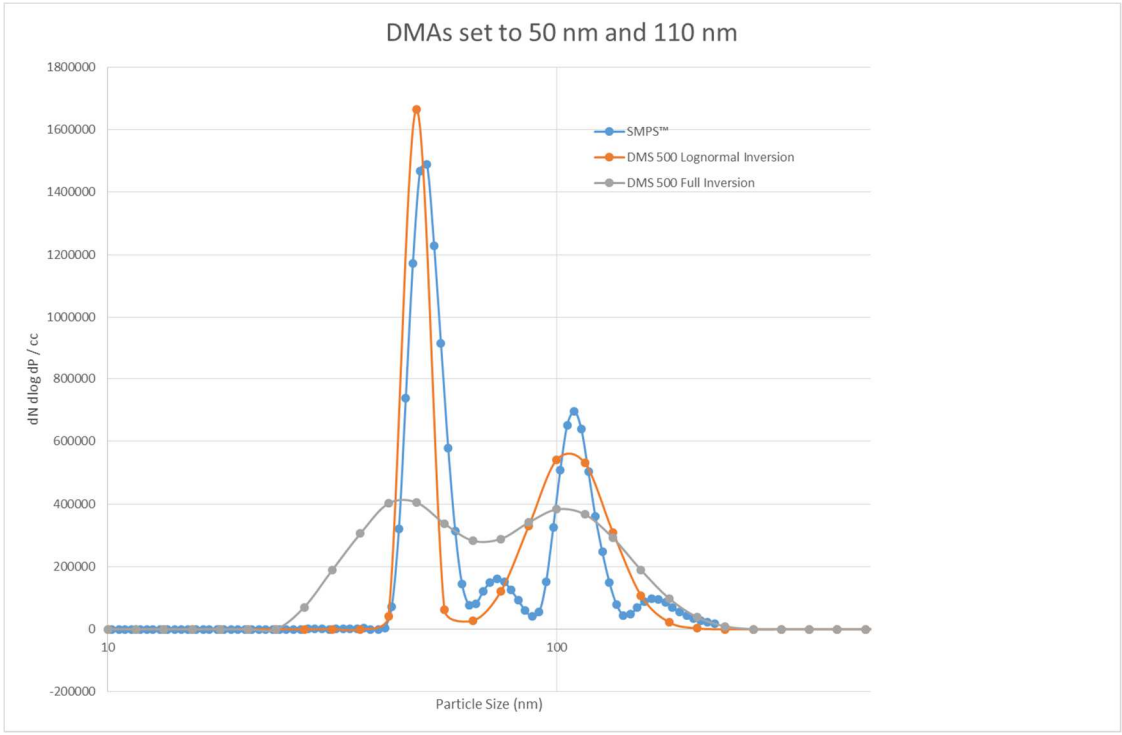
The work in [6] also addresses the sampling of volatile aerosols with the DMS500, and see also http://www.cambustion.com/sites/default/files/applications/DMS/dms02v01.pdf

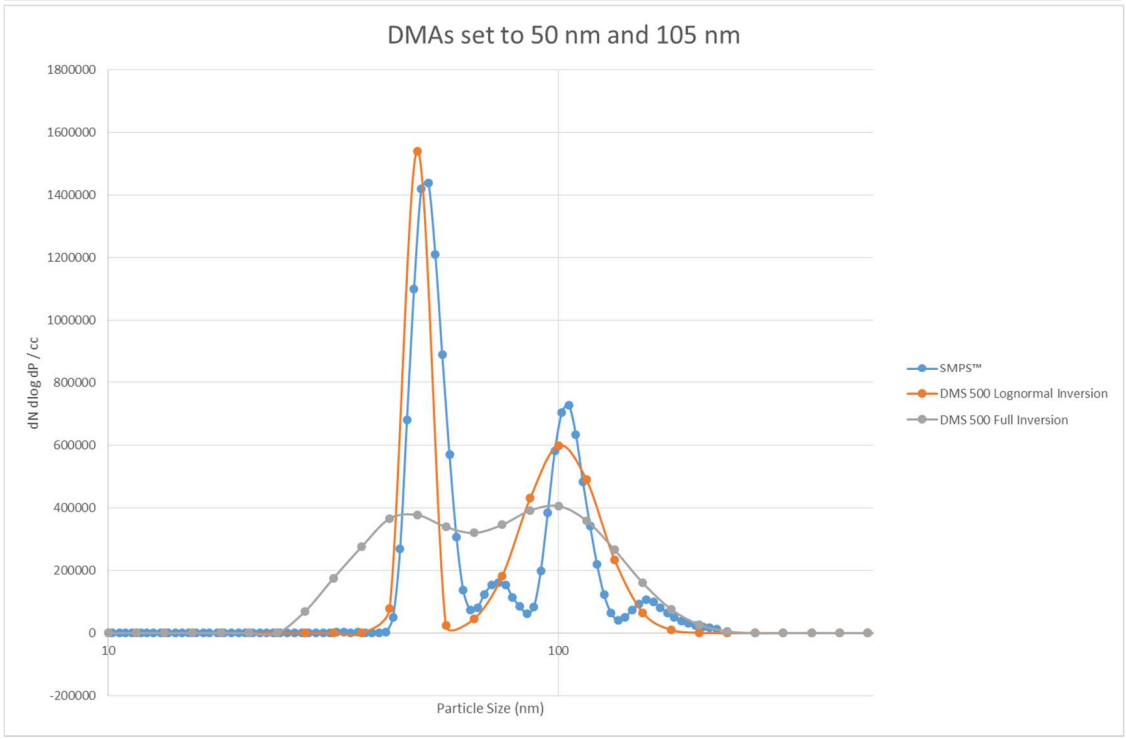
Twin DMA and SMPS Experiment

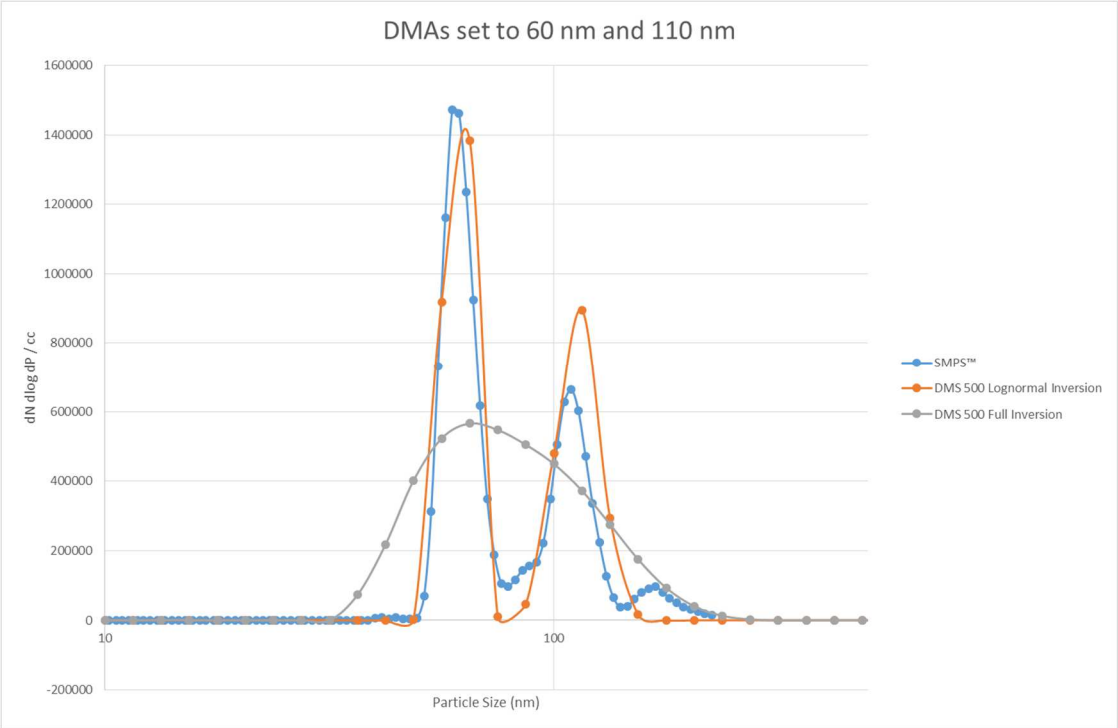
Two TSI 3081 DMAs were used to simultaneously size select dried NaCl particles produced by a Collison nebuliser and silica gel drier. The output from the two DMAs, which could be set to different mobility diameters, was combined and sent to both a DMS500 and the SMPS.

The DMAs were operated at a sheath flow rate of 10 litres per minute, and a sample flow rate of approximately 1.5 litres per minute. This produces aerosols with a rather narrow GSD compared with many real-world aerosols.




DMAs set to 50 nm and 110 nm
1800000
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
-200000
dN dlog dP / cc
10
100
Particle Size (nm)
SMPS™
DMS 500 Lognormal Inversion
DMS 500 Full Inversion


DMAs set to 50 nm and 105 nm
1800000
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
-200000
dN dlog dP / cc
10
100
Particle Size (nm)
SMPS™
DMS 500 Lognormal Inversion
DMS 500 Full Inversion



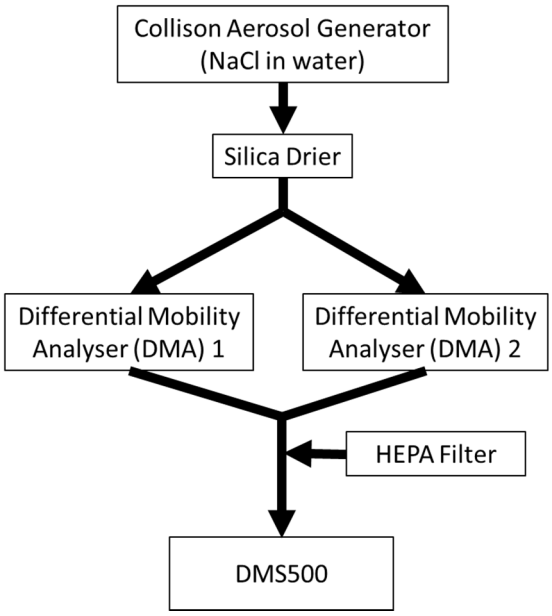
In each case, both the full spectral and bimodal lognormal inversions of the DMS500 are shown. The lognormal inversion is capable of much higher resolution than the full inversion, and the DMA modes are resolved to be almost as narrow as the SMPS can. The full unconstrained inversion does indeed show less resolution than the SMPS, but is still capable of resolving multiple peaks per decade of size range.

Furthermore, the size accuracy of both inversion methods is shown to agree well with the SMPS. At first glance, the full inversion does not appear to agree with the SMPS is concentration terms all that well. However, it is really just the peak height in dN/dlogDp which does not match. The integrated area under the peaks, which represents the aerosol concentration, is very similar for all three data series on each graph, it's just that the decreased resolution of the full DMS inversion results in a wider, lower peak with the same area as the narrower, taller peaks of the lognormal inversion and the SMPS.

Note that the two smaller peaks present in each case are the +2 charge particles selected by the DMAs – these are not resolved by either inversion method used by the DMS

Twin DMA Experiment

Due to the scanning nature of the SMPS, real-time comparison between the DMS500 and SMPS is not possible. However, since the DMAs settings can be changed rapidly, the opportunity exists to study dynamic sizing by the DMS500.



A video of the DMS500 User Interface shows the transitions in measured particle size:

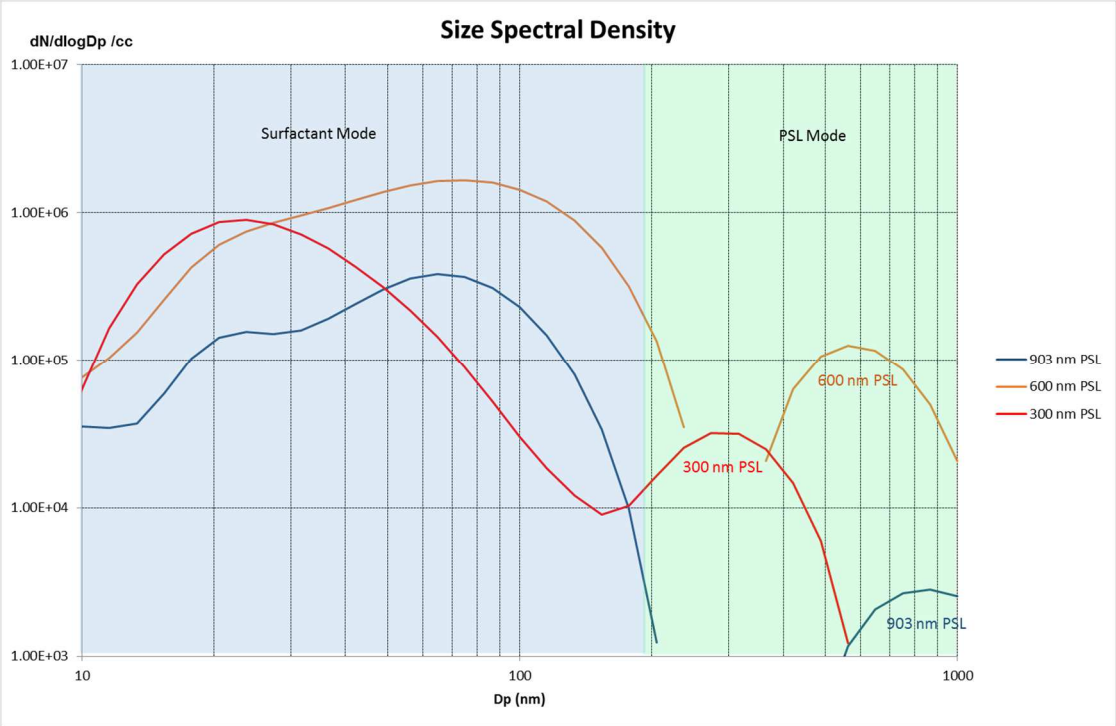
www.cambustion.com/sites/default/files/instruments/DMS500/DMS500 Accuracy and Resolution.mp4

One DMA remains set to a fixed mobility (50nm) while the other DMA settings are changed. Initially the second DMA is changed in a single step to a larger size. The second part of the video shows the second DMA being changed in steps of 10nm.

The ability of the DMS500 to correctly resolve the two distributions is demonstrated, although as with other instruments of this type, there is a resolution limit which can be also be seen.

Large Particle Sizing

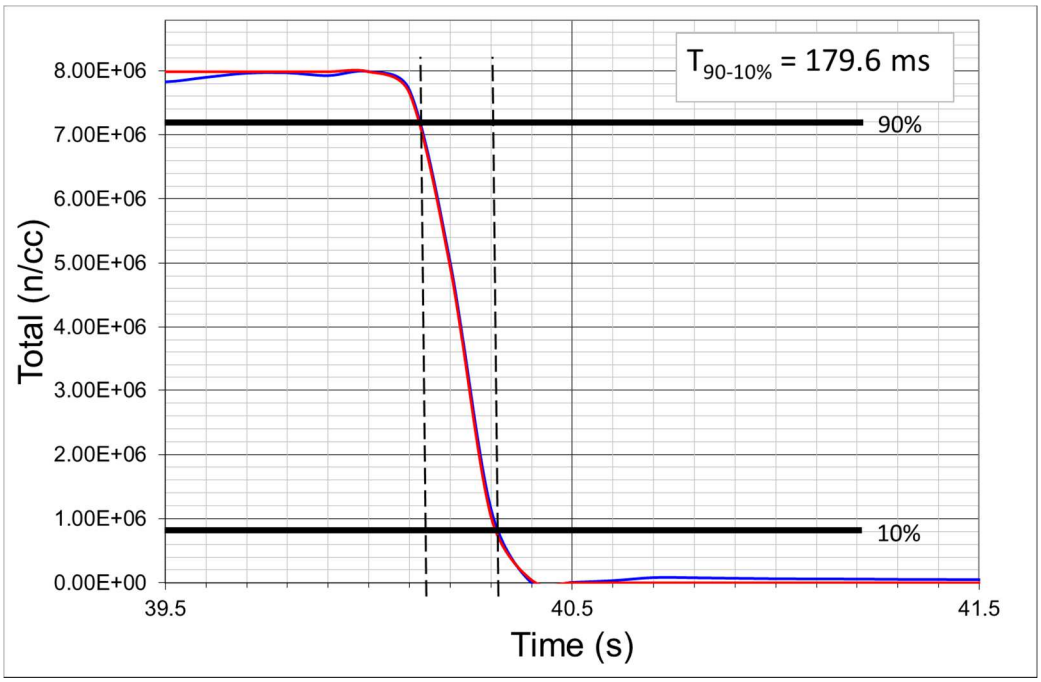
As described above, low pressure operation of the DMS500 allows the mobility inversion point of unipolar charging to be extended to larger sizes. The data below show DMS500 spectra of nebulised Thermo Scientific Polystyrene Latex (PSL) nanospheres, which are traceably certified for size. Two modes are produced, the broad, high concentration mode at smaller sizes in the blue region of the plot is caused by surfactant chemicals in the PSL, and impurities in the water used to suspend the PSL. The actual PSL peaks are in the green area of the plot, and show good agreement with the certified sizes of 300, 600 and 903 nm.



Time Response

A key advantage of the DMS500 compared with scanning instruments is the real time nature of the data available. However, a fast data rate, whilst necessary, is not sufficient to resolve transient events. The response of the instrument to a change in concentration must also be sufficient. Careful consideration of the fluid dynamics in the DMS500 means that along with a data rate of 10 Hz, its $T_{90\text{-}10\%}$ response to a step change in aerosol concentration is faster than 200 ms.

The ability of the DMS500 to respond to a rapidly changing aerosol may be demonstrated using a step change in aerosol concentration. In this case, dried NaCl aerosol is suddenly disconnected from the DMS500 to produce a rapid decrease in the input concentration.



Curve fitting of this data shows that the $T_{90-10\%}$ response time is 180 ms. Coupled with a data rate of 10Hz (appropriate for the physical response of the detectors) this demonstrates the DMS500's ability to resolve highly transient features.

A video of the User Interface during this test is available here:

www.cambustion.com/sites/default/files/instruments/DMS500/DMS500 Time Response.mp4

For more information on time response, see
http://www.cambustion.com/sites/default/files/instruments/DMS500/timeresponsevsdatarate.pdf

Conclusions

The DMS500 is capable of correctly resolving the size of DMA selected aerosols.

The DMS500 is also able to discriminate between two DMA aerosols sampled simultaneously (providing that these are separated by at least the resolution limit of the DMS500.

The DMS500's transient measurement capability and resolution is demonstrated through small step changes in the DMA which are correctly resolved.

The DMS500 is capable of accurately resolving and sizing multimodal real world aerosols, including PSL and nucleation generated aerosols.

The DMS500's time response is demonstrated by its response to a step change in signal.

Further Reading & References

DMS500: www.cambustion.com/products/dms500/aerosol

[1] Tammet, H., Mirme, A., Tamm, E.; "Electrical aerosol spectrometer of Tartu University". Atmospheric Research 62 (2002) 315-324. http://dx.doi.org/10.1016/S0169-8095(02)00017-0

[2] Reavell, K. “Fast response classification of fine aerosols with a differential mobility spectrometer”. Proc. AGM Aerosol Society, Lancaster, UK (2002).

[3] Reavell, K., Hands, T., Collings, N.; “Determination of real-time particulate size spectra and emission parameters with a differential mobility spectrometer”. Proc. ETH Conf. on Nanoparticles, Zurich, Switzerland (2002).

[4] Symonds, J., Reavell, K., Olfert, J., Campbell, B., Swift, S. “Diesel soot mass calculation in real-time with a differential mobility spectrometer”. J. Aerosol Science 38 (2007) 52-68.

[5] Symonds, J.P.R., “Calibration of fast response differential mobility spectrometers”. Metrology of Airborne Nanoparticles, Standardisation and Applications (MANSA), National Physical Laboratory, London http://www.npl.co.uk/8-9-jun-2010-mansa-calibration-of-fast-response-dr-jonathan-symonds

[6] Kittelson, D., Symonds, J., Collings, N., Reavell, K. St.J., “Evaporation of volatile aerosols” 8th ETH-Conference on Combustion Generated Nanoparticles, Zurich (2004)