A high flow rate DMA with high transmission and resolution designed for new API instruments

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Overview

New generation planar DMAs readily coupled to different MSs are tested for transmission and resolution. The main improvement with respect to previous SEADM DMAs is a higher flow rate sampled and delivered to the MS, achieved without significantly reducing resolution. DMA transmission is measured and the possible causes for inefficiency are discussed.

Transmission measurements

- Relevant parameter for DMA-MS applications: signal transmitted to MS vs. maximum possible value, for a given ion concentration at the DMA inlet
- 100% transmission is understood as the ability to fill the DMA outlet flow to the MS with ions of a selected mobility at the same concentration as at the DMA inlet. Transmission is diminished by:
  - Dilution due to diffusion or space charge effects through the DMA
  - Outlet flow not being completely filled with on streamlines
  - Electrophoretic losses at the outlet geometry

METHODS

Tandem DMA-MS system for transmission measurement developed by P. McMurry (U. Minnesota), where the first DMA delivers a known ion concentration directly to the second DMA.

Figure 1 - Planar DMA operation

Exit orifice of particles at mobility $K = (117 \pm 2) V/nm/s$

- Separation of ions is based on electrical mobility (IMS)
- A mobility specific is obtained by scanning over the voltage difference $V_{bias}$ between two parallel plates
- Planar designs allow delivery of mobility-selected ions with high transmission from the electrophoretic source to the DMA inlet, and from the DMA outlet to the MS
- Aerodynamic size is key to operate in high-speed high-resolution conditions

Figure 2 - Transmission tests for DMA model P4, which sample $q_{ion} = 0.8 \text{pm}$

- Tested with THA by at DMA speeds (Mach -0.15, DMA Resolution ~ 40)

Transmission = $I_{out}/I_{in}$, $I_{out}$ = Maximum signal through the DMA, $I_{in}$ = Maximum signal through the DMA in the absence of ions

Linearity with inlet flow shows that virtually ALL the ions entering the DMA are passed to the MS

Further characterization underway on improved electrostatic injection of ions and effect of counterflow drying gas

Figure 3 - Sampling ability improvement on DMA prototype P4B

Prototype for ~1000 ppm ions (THA different DMA speeds (different THA voltages for THA))

Figure 4 - Comparison between THA at different DMA speeds (different THA voltages for THA)

High sampled flow rates separation

METHODS

Except for the DMA-LSM2010EV data (figure 4), the experiments have included mass analysis, relying on ion current measurement of the full beam jet formed by the DMA outlet-MS inlet orifice.

Tetra-alkyl ammonium ions are electrospray at the near sampling orifice of the DMA and drawn by the field into the DMA inlet, against a stream of counterstreaming air. Mobility spectra are obtained by timing the sheath gas speed inside the DMA, and scanning over the voltage difference $V_{bias}$ between the two DMA plates. This yields q~$V_{bias}$ spectra exhibiting sharp peaks. The DMA performance is tested with the tetraalkylammonium bromide monomer, THA, of $K_p = 1.0 \text{cm^2/s}$.

In the experiments testing the effect of the sampled MS flow, THA is regulated by a valve downstream of the outlet orifice. The flow rate is derived from pressure measurements on both sides of the orifice and a previous calibration.

Figure 5 - DMA P4B (optimized for LSM2010EV 1.5 pm sampling). Effect of sampled flow on DMA performance in different DMA and mobile phases (THA)

Figure 6 - THA - Peak shape DMA with sampled flow

Conclusions

- High transmission measured (~100%) of ions ingested at DMA inlet for a DMA delivering 0.8 pm sample flow into the MS. Signal limited to 50% of maximum possible due to limited ion injection at the inlet slit of the DMA
- High resolution (> 50) for mobility separation is maintained when delivering up to 2 pm ions into the MS. Higher sampling rates through the DMA are possible still at high resolution with different DMA outlet-MS inlet designs
- Transmission needs to be further quantified for the positive effect of external electric fields to increase ion injection, and of drying counterflow gas

Figure 7 - THA - Peak shape DMA with sampled flow

Figure 8 - THA - Peak shape DMA with sampled flow

The theoretical model seems well suited to predict the DMA behavior at different sample flows (Figure 5) and at different DMA speeds (Figure 6). Improved sampling rates up to 5 pm are achievable at high resolution, with DMAs specifically designed for the purpose.

Signal plateaus between 1.2 pm sampling indicates nearly 100% collection of the ions entering the DMA by the outlet flow, therefore:

- Dilution due to diffusion and space charge is negligible (at least at this size range) and while the sampled flow effect is apparent
- Measurement of electrostatic losses at the outlet is still pending. But the small dependence of transmission on the fluid velocities in the outlet orifice (signal drop 15% when they drop 40%) suggests this to be a small effect.

Figure 9 - THA - Peak shape DMA with sampled flow

Figure 10 - THA - Peak shape DMA with sampled flow