Achieving ~50% ion source efficiency in ESI-MS

Ioan Marginean, Jason S. Page, Aleksey V. Tolmachev, Keqi Tang, and Richard D. Smith
Pacific Northwest National Laboratory, Richland, WA

Pacific Northwest NATIONAL LABORATORY

Overview

- A new design for the sub-ambient pressure ionization with nanoelectrospray (SPIN) source[1] was evaluated.
- Ion utilization efficiencies exceeding 50% from solution were achieved.
- Simple thermodynamic considerations suggest that extra energy input is required to further improve droplet desolvation.
- An electrostatic model was employed to calculate charged droplet and ion trajectories after generation by electrospray.
- The study led to improved understanding of charged aerosol evolution and electrospray ionization in sub-ambient pressure environment.

Introduction

- Ion losses can occur at every conductance limiting aperture during their transfer from outside of the mass spectrometer to the high vacuum region required for mass-analysis.
- Ion formation at different times and various locations within the charged aerosol challenges traditional approaches for ion collection and transfer into vacuum.
- The ion utilization efficiency from solution can be estimated as the ratio between the analyte current transferred into the gas phase and the maximum analyte current theoretically achievable: $I_{max} = n_A c_A Q F$, where c_A, n_A, Q, and F are analyte concentration, number of charges per analyte molecule, flow rate, and Faraday constant, respectively.
- Far less than 1% of the ions present in the solution eventually reach the MS detector after generation by a conventional ESI source;[2] the largest ion utilization efficiency reported so far (~10%) involved extremely low liquid flow rates (<1 nL/min).[3]
- The SPIN source eliminates the major ion losses at the atmospheric pressure ESI-MS interface.
- The SPIN source uses a high-pressure ion funnel to capture the charged aerosol produced by an electrospray operated at sub-ambient pressure and then focuses it through a conductance limiting aperture into a low-pressure ion funnel (**Figure 1**).

Methods

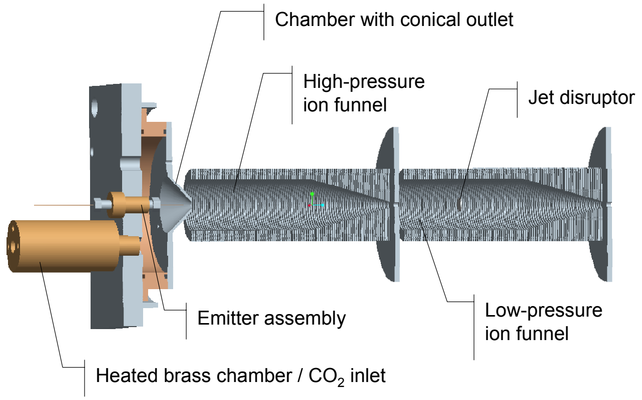

Figure 1. The sample is electrosprayed in a chamber with conical outlet maintained at ~20 Torr. CO_2 is heated in a brass chamber and used as sheath gas. A dual ion funnel assembly transfers the ions into the high vacuum region of the mass spectrometer.

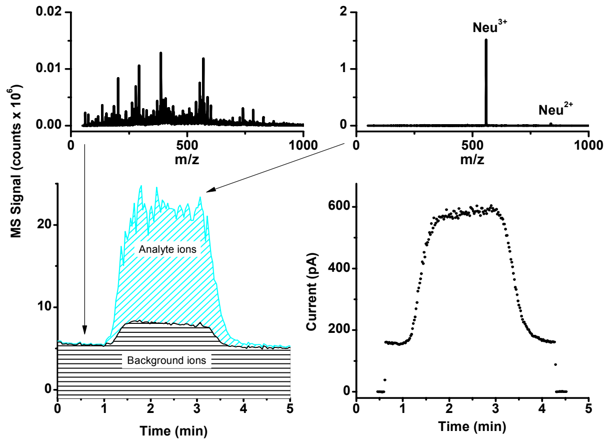

Figure 2. Typical solvent (top-left) and analyte (top-right) mass spectra. Total ion current showing a rise in baseline during the analyte plug elution (bottom-left) presumably due to poorly desolvated species (clusters). Current collected on the octopole following the low-pressure ion funnel (bottom-right).

Results

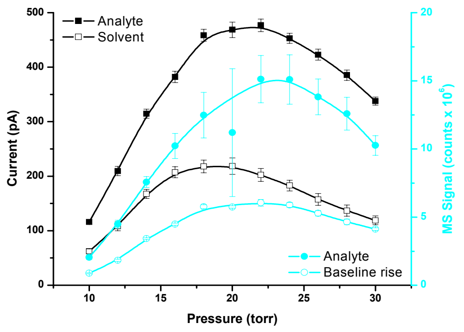

Figure 3. Effect of pressure on current and MS signal. Not all the extra current during the analyte plug elution is due to analyte ions: ~17-23% of the TIC increase is due to rise of baseline (see Figure 2). An operating pressure of ~20 Torr ensures optimum ionization with this source geometry.

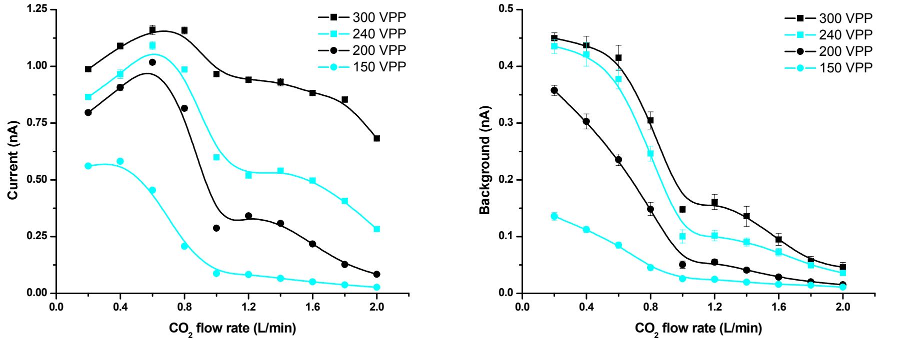

Figure 4. Effect of gas flow rate on current (nA). Lower gas flows provide longer residence times and improved ionization efficiencies (left). These improvements come with increased background (right), which can negatively impact performance of the present design due to space-charge. Ion production from droplets with bimodal size distributions can explain the influence of the RF voltage on the current. The large droplets entering the ion funnel at high gas flow rates are lost by small confining RF voltages before producing gas-phase analyte ions.

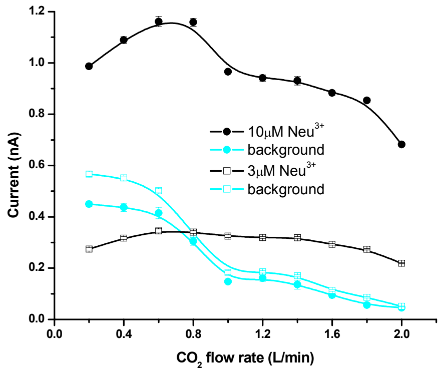

Figure 5. Effect of gas flow rate on current. Black traces may suggest concentration-dependent analyte distribution in small and large droplets. Efficiently ionizing analytes prefer small droplets at low concentrations.

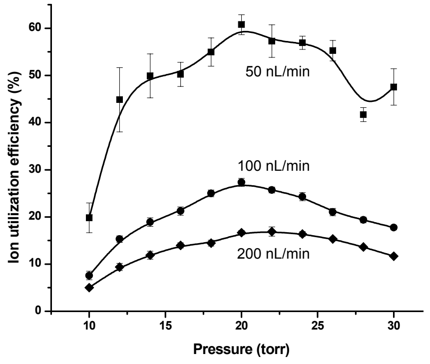

Figure 6. Ion utilization efficiency as a function of pressure and liquid flow rate. Reducing the flow rate (implicitly the initial droplet size) has the most dramatic effect on ion utilization efficiency.

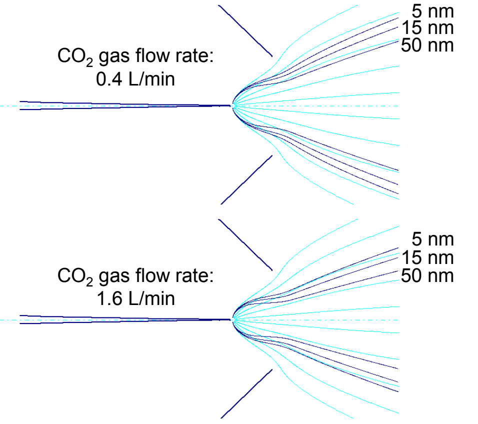

Figure 7. The interface model showing the field lines and the trajectories for droplets of 5, 15, and 50 nm. The model was calibrated against experimental data probing the transmission through the conical outlet

Conclusions

- The source operates optimally at pressures ~20 Torr, which provide the best compromise between efficient droplet desolvation and charged aerosol confinement in the ion funnel.
- Addition of the CO_2 sheath flow improved the stability of the SPIN source by eliminating electric breakdown incidents.
- The highest ion utilization efficiency was achieved at very small liquid flow rates. Even higher ion utilization efficiency may be achievable with an emitter array without the losses specific to atmospheric pressure electrosprays.
- The sheath gas flow rate provides a means for tuning the droplet residence time. Longer residence times improve the ionization efficiency for both the analyte and the background/solvent species.
- The most efficiently ionized analytes form gas-phase ions earlier than background/ solvent species.
- The interface model provides important insights into the SPIN source operation, and direction for its further development.

Acknowledgements

Portions of this research were funded by NIH National Center for Research Resources (RR18522) and the U.S. Department of Energy Office of Biological and Environmental Research (DOE/BER). The work was performed in the Environmental Molecular Science Laboratory, a DOE/BER national scientific user facility at Pacific Northwest National Laboratory (PNNL) in Richland, Washington. PNNL is operated for the DOE by Battelle under contract DE-AC05-76RLO-1830.

References

1. JS Page, et al., *Anal. Chem.* **2008**, 80:1800-1805.
2. RD Smith, et al., *Anal. Chem.* **1990**, 62:882-899.
3. A El-Faramawy, et al., *J. Am. Soc. Mass Spectrom.* **2005**, 16: 1702-1707.

CONTACT: Ioan Marginean, Ph.D.
Biological Sciences Division, K8-98
Pacific Northwest National Laboratory
P.O. Box 999, Richland, WA 99352
E-mail: ioan.marginean@pnl.gov