Characterizing an ESI-MS Interface Based on the Ion Utilization Efficiency

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Overview

- Study of the electric current transmitted through different electrospray ionization mass spectrometry (ESI-MS) interfaces.
- Evaluation of the ionization efficiency and the ion transmission efficiency for the different ESI source and MS interface configurations.
- Establishment of a general metric, based on the ion utilization efficiency, to evaluate the overall efficiency of any ESI-MS interface designs.

Introduction

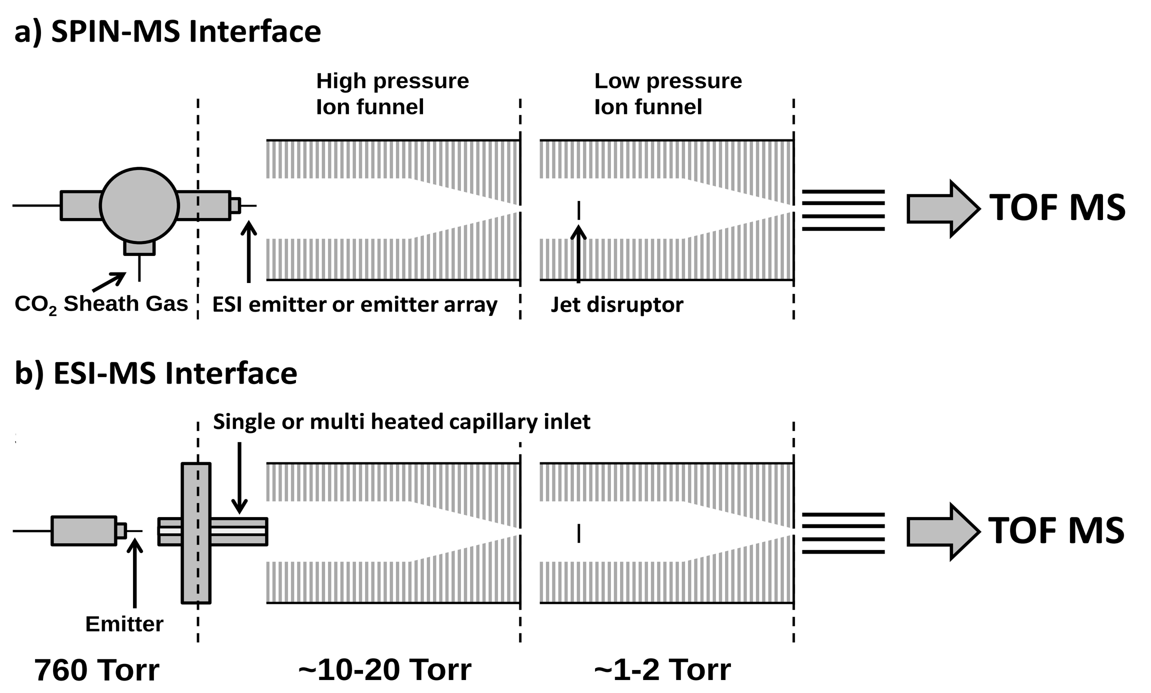
Achievable sensitivity of ESI-MS is largely determined by 1) ionization efficiency in the ESI source, and 2) ion transmission efficiency through the ESI-MS interface. These characteristics are difficult to evaluate and compare among different ESI source and ESI-MS interface designs.

We present a universal method based on the ion utilization efficiency[1] to evaluate performance of ESI-MS interfaces. ESI-MS interface ion utilization efficiency is defined as the percentage of analyte molecules in a sample solution being converted into gas phase ions and transmitted through the interface. It is determined by measuring the total gas phase ion current transmitted through the interface and the ion abundance in the corresponding mass spectrum.

Using this method we systematically compared efficiencies of different ESI-MS interface designs, including a single emitter/single inlet capillary, single emitter/multi-inlet capillary,[2] and a subambient pressure ionization with nanoelectrospray MS interface with a single emitter[3] and an emitter array.[4]

Methods

Instrument configurations



Ion utilization efficiency

The theoretical maximum ion current, I_J, for analyte J if all the molecules in the solution were converted into gas phase ions:

$$I_J = QF\sum_{z=1}^{i(J)} z\delta_{z,J}C_J$$

where Q is the liquid flow rate, F the Faraday constant, $\delta_{z,J}$ the fraction of J that carries z charges, C_J the molar concentration, and $i(J)$ the maximum charge state of J

The maximum total analyte ion current, I_A, for a mixture of N compounds under the complete ionization condition:

$$I_A = QF\sum_{J=1}^{N}\left(\sum_{z=1}^{i(J)} z\delta_{z,J}C_J\right)$$

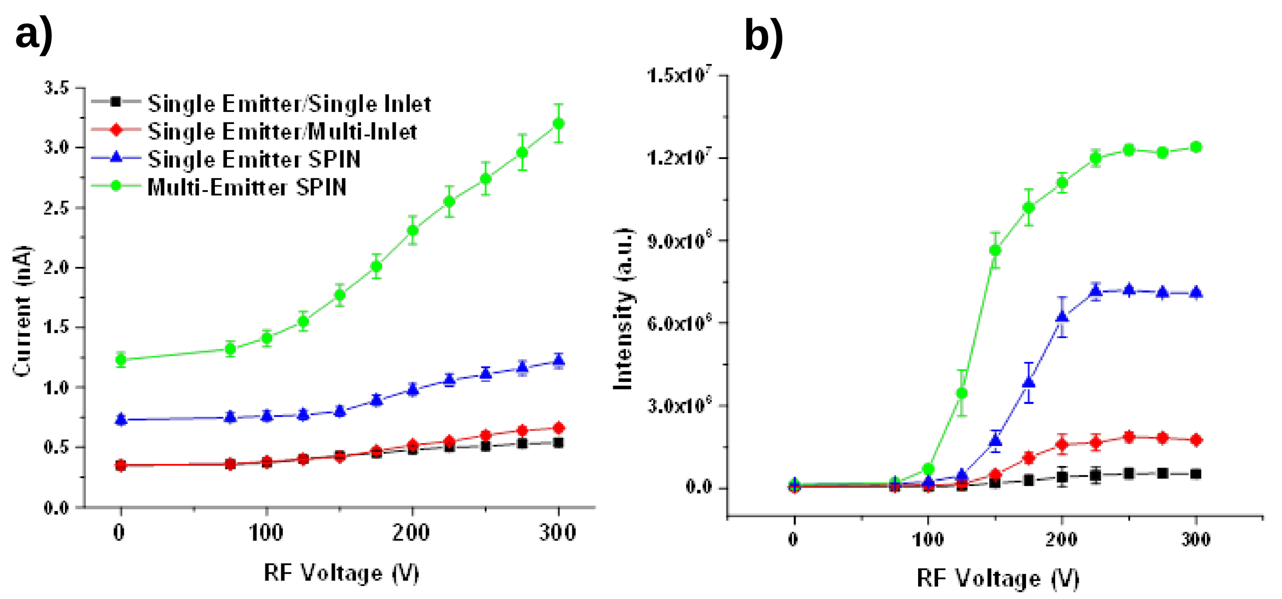
The ion utilization efficiency ε_J for analyte J and ε_A for all the analytes in the sample mixture:

$$\varepsilon_J = \frac{\sum_{z=1}^{i(J)} \Delta i\, X_{z,J,TIC}}{I_J} \quad \text{and} \quad \varepsilon_A = \frac{\Delta i X_A}{I_A},$$

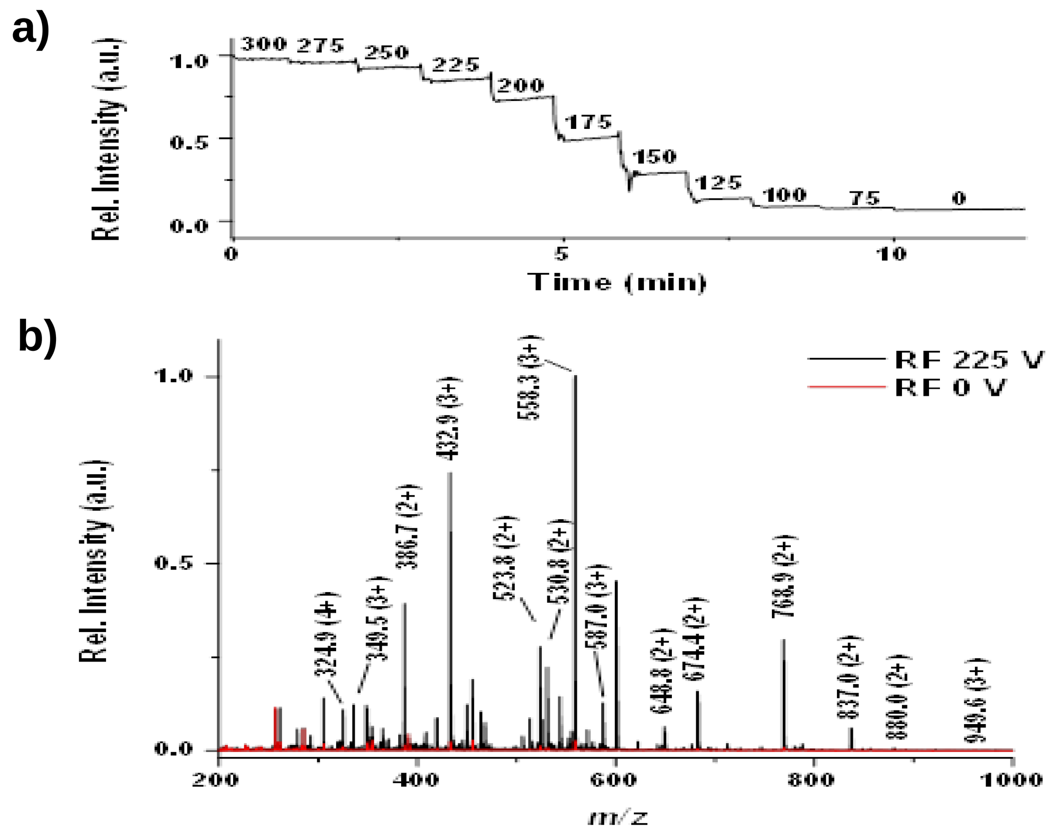
where Δi is the fraction of gas phase ion current in the total transmitted electric current through a MS interface, $X_{z,J,TIC}$ is the ratio of extracted ion current (EIC) for z charge state of analyte J to the total ion current (TIC) from a corresponding mass spectrum, X_A is the ratio of total analyte current (summing all the analyte EICs) to the TIC.

Results

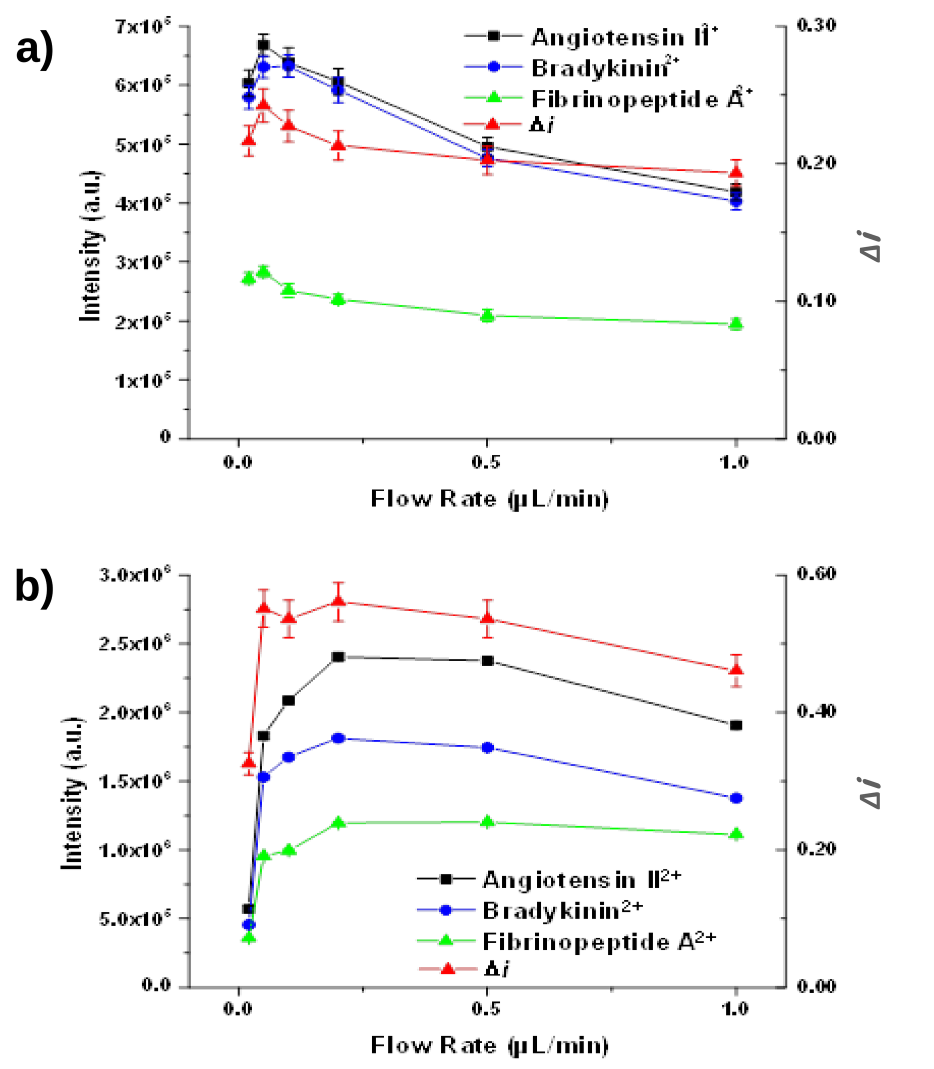
a) Electric current transmitted through the high pressure ion funnel and b) EIC for 3+ neurotensin (m/z = 558.3) at different high-pressure ion funnel RF voltages and with different interface configurations.



a) TIC at different high pressure ion funnel RF voltages and b) representative mass spectra at RF voltages of 225 Vp-p, and 0 Vp-p using 100 nM peptide mixture for single emitter/SPIN source configuration.



Δi and analyte peak intensity for a) a single emitter/single inlet ESI-MS interface and b) single emitter/SPIN interface at different flow rates.



Comparison of ion utilization efficiencies (%) for different MS interface configurations.

Peptide	Single Emitter/ Single Inlet ESI (100 nL/min)	Single Emitter/ Multi-Inlet ESI (100 nL/min)	Single Emitter/ SPIN (100 nL/min)	10 Emitter Array/ SPIN (200 nL/min)	Single Emitter/ SPIN (20 nL/min)
Fibrinopeptide A	4.8 ± 0.1	3.3 ± 0.6	9.6 ± 0.3	9.3 ± 0.7	17.2 ± 0.4
Substance P	3.9 ± 0.1	4.6 ± 1.1	6.0 ± 0.4	8.8 ± 1.6	34.6 ± 2.1
Angiotensinogen	4.9 ± 0.1	2.1 ± 0.6	5.6 ± 0.3	10.2 ± 2.0	11.0 ± 1.2
Neurotensin	3.4 ± 0.3	7.0 ± 1.2	12.9 ± 1.4	34.5 ± 3.6	50.3 ± 2.8
Bradykinin	3.9 ± 0.2	7.5 ± 1.1	2.8 ± 0.2	7.0 ± 1.6	30.0 ± 1.6
Angiotensin II	4.9 ± 0.2	5.1 ± 0.8	3.9 ± 0.7	9.6 ± 1.3	34.7 ± 1.8
Angiotensin I	5.1 ± 0.4	5.8 ± 1.2	7.0 ± 0.5	16.4 ± 2.1	48.7 ± 4.4
Kemptide	3.2 ± 0.1	5.0 ± 0.9	1.9 ± 0.4	6.0 ± 0.5	20.7 ± 1.1
Overall Ion utilization efficiency	4.0 ± 0.3	4.2 ± 0.8	6.5 ± 0.3	13.0 ± 2.3	26.7 ± 1.8

Conclusions

- The ion cloud transmitted through ESI-MS interface contains both fully desolvated gas phase ions and 'residue' not fully desolvated charged analyte/solvent clusters/particles.
- The portion of fully desolvated gas phase ions correlates well with the final intensity of the ion current detected by MS.
- Over an order of magnitude increase in transmitted analyte ion current was observed by using a 10 emitter/SPIN-MS interface compared to using a standard single-emitter/single-heated capillary inlet ESI-MS interface
- Of the interfaces evaluated in this study, an emitter array/SPIN-MS interface demonstrated the greatest ion current, highest MS-signal intensity, and subsequently the best ion utilization efficiency at a given total ESI flow rate.

Acknowledgments

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