GC-MS Performance of a Novel Capillary Atmospheric Pressure Chemical Ionization (cAPCI) Source

Yessica Brachthäuser; Sonja Klee; Dennis Klink, Marco Thinius; Klaus J. Brockmann; Thorsten Benter

Physical & Theoretical Chemistry
Wuppertal, Germany
Institute for Pure and Applied Mass Spectrometry

Introduction

State of the Art:

Atmospheric Pressure Chemical Ionization:

- Corona discharge sources generate proton bound water clusters $[H(H_2O)_n]^+$ (generally proton bound solvent clusters $[H(S)_n]^+$) as reactant ions [1]
- Reactant ion clusters either directly interact with the analytes by ligand switching or association reactions, respectively, or further downstream in the intermediate pressure regions within the ion transfer stages of the mass spectrometer via electrical driven collisional decomposition reactions [1]
- In common APCI sources generation of additional ion signals in the observed mass spectra due to oxidation or other ion transformation processes is often observed

Capillary Atmospheric Pressure Ionization (cAPI) Sources:

- Fluid dynamic conditions in common API sources are often complex and difficult to control [2]
- As a consequence the operation points of classical API sources tend to be unstable
- Ionization within such sources potentially leads to memory effects, poor reproducibility, and signal fluctuations due to extensive ion transformation processes resulting from the large reaction times within the source
- cAPI sources spatially separate the primary reactant ion generation region from the analyte gas flow; thus the direct contact of the analyte and e.g. the hot corona discharge region is avoided.
- Due to the turbulent flow in the inlet capillary vigorous analyte/reagent ion mixing leads to efficient chemical ionization
- cAPI sources are designed with the aim of widely controlled operational conditions (see #MP284) such as
  - gas flows, gas temperature, primary ionization region, ion-molecule reaction region

Challenge:

- Development of a highly stable ion source within the inlet capillary using protonated water clusters ($[H(H_2O)_n]^+$) as reactant ions, generating $[M+H]^+$ as analyte ion signal
- Determination of the analytical performance of a cAPCI source coupled to a gas chromatographic (GC) stage

Methods

Experimental Setup

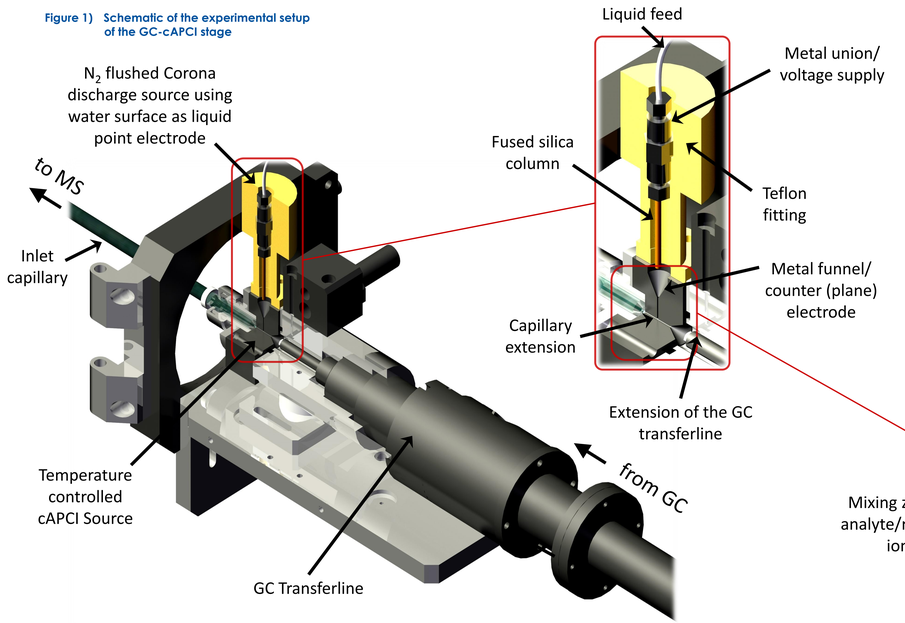
MS:	Bruker micrOTOF, Bruker Esquire 6000 QIT
Ion Source:	Custom capillary Atmospheric Pressure Ion (cAPCI) Source
GC:	7890 A, Agilent Technologies Inc.
Transferline:	Custom temperature-controlled GC-transferline

Experimental Setup

Capillary Atmospheric Pressure Chemical Ionization (cAPCI) Source:

- Reactant ion generation by corona discharge source using liquid point electrode (see #MP 274)
  - → Well established reactant ion equilibrium distribution ($[H(H_2O)_n]^+$, n = 4-9 [3])
  - → Reactive neutral species potentially generated in the hot plasma region recombine or react before they can interact with the analyte
- Temperature controlled metal extension of the MS inlet capillary
  - Adjustable cAPCI source temperature (RT – 150 °C)
  - Due to the small inner diameter of the source the gas velocities are kept high
- Mixing of two different gas flows inside the capillary extension
  1. Sheath gas embedded GC flow carrying the neutral analyte (GC transferline temperature approx. 350 °C)
  2. Regulated nitrogen flow (@AP) including fully thermalized and equilibrated reactant ions
- Inlet capillary is used as reaction chamber for chemical ionization
- $[M+H]^+$ is the dominant ion signal in the mass spectra. Ion transformation processes (e.g., oxidation) are strongly suppressed. (see #MP 274)

Figure 1) Schematic of the experimental setup of the GC-cAPCI stage



GC Coupling:

- Re-design of the commercially available transferline (TFL)[4] for the Bruker Multi Purpose Atmospheric Pressure Ion Source (MPIS) [4]
- Extension of the heated GC column enclosure with a metal funnel matching the inlet capillary dimensions at the exit. Neutral analyte embedded in the adjustable sheath gas flow is thus injected into the capillary gas flow at high gas velocity
  - → Analyte loss at the walls and peak broadening is minimized
- Depending on the individual flow settings the analyte dwell time in the gas transfer region is on the order of milliseconds

Results

				TOF 600 mL/min sheath gas; 150 °C source temperature			Ion Trap 50 mL/min sheath gas; 50 °C source temperature		
No.	Analyte	m/z	Concentration [ng/µL]	Peak Width (FWHM) [sec]	Peak Area	S/N	Peak Width (FWHM) [sec]	Peak Area	S/N
1	tert-Butyl methyl ether	88	12	n.d.	-	-	1,9	1485345	109
2	2-Propoxy ethanol	104	10	2.4	27717	49	8,8	1000472	18
3	1,2-Propandiol ether acetate	132	11	4.3	1226530	690	3,6	78345788	1253
4	Ethylene glycol butyl ether	118	12	3.7	120215	93	3,0	16904335	63
5	γ - Butyrolactone	86	15	n.d.	-	-	2,7	9851433	302
6	Isobutyl isobutyrate	144	11	4.6	27826	16	3,6	32303917	167
7	Diethylene glycol monomethyl ether	120	13	5.2	2719284	276	n.d.	-	-
8	Diethylene glycol dimethyl ether	134	13	5.1	2269265	855	3,5	47516748	181
9	Benzaldehyde	106	14	n.d.	-	-	2,0	1332940	72
10	Methyl heptanoate	144	12	2.5	82223	95	2,1	18790116	134
11	Benzyl acetate	150	14	n.d. (see „Remarks")	-	-	0,7	3045816	89
12	Tributyl amine	185	10	2.2	1066125	3450	3,7	3355194	21
13	Nicotine	162	12	1.9	2076674	2023	7,1	1702209	65
14	Caffeine	194	10	2.3	3164743	16332	1,5	44023698	169

Table 1) List of analytes present in the GC – test solution (cf Fig. 2)

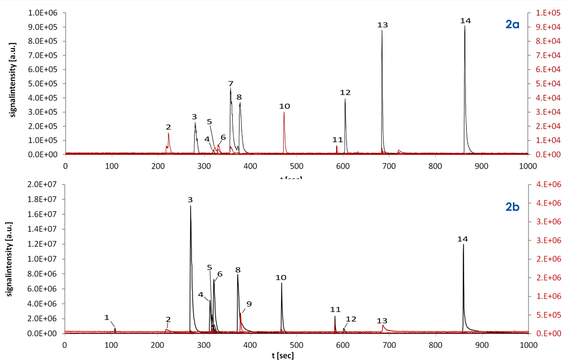


Figure 2)
Gas chromatogram of a GC - test solution containing 14 analytes (see table 1). (a) GC-cAPCI source coupled to TOF at 600 mL/min sheath gas flow and a source temperature of 150 °C. (b) GC-cAPCI source coupled to an ion trap at 50 mL/min sheath gas flow and a source temperature of 50 °C.

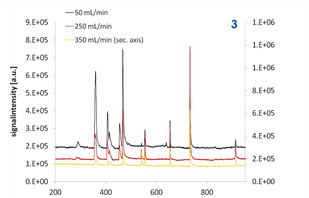


Figure 3)
Effect of sheath gas variation on the signal intensities. The TIC is shown for three different sheath gas flows. (source temperature 40 °C).

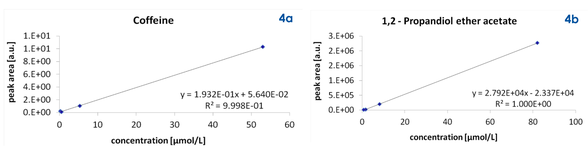


Figure 4)
Determination of the linear range of the GC-cAPCI-TOF setup for caffeine (a) and 1,2-propandiol ether acetate (b)

Limit of Detection (S/N = 3):

Caffeine	1.9 pg/µL
1,2-Propandiol ether acetate	47 pg/µL

Remarks:

- *Impact of sheath gas flow on signal distribution in the chromatogram*:
  Early eluting analyte signal intensities seem to increase with increasing sheath gas flow while those of late eluting analytes decrease (cf. fig. 2 and 3)
- *Peak Tailing*:
  The GC peak tailing appears to be independent from the source temperature (cf. fig.5); thus there is no effect of cold spots in the source. Validation of the chromatographic setup by FID measurements is work in progress.
- *Mass discrimination by the ion optical stages:*
  The low intensity of low mass compounds (e.g., tert-butyl methyl ether, γ-butyrolactone) is most probably caused by mass discrimination of the ion optics of the employed oaTOF-MS instrument.
- *Fragmentation:*
  Benzyl acetate fragments easily upon non-thermal collisions within the ion transfer stages and is thus not detected as $[M+H]^+$ but as tropylium ion (m/z 91) in the TOF measurements (depicted as "11" in fig. 2a). The ion trap measurements show the $[M+H]^+$ and the tropylium ion signal with comparable intensities. The ion transfer in the employed TOF instrument is known to be accompanied by rather high collision energies.
- *No detection of diethylene glycol monomethyl ether in the trap experiment:*
  Diethylene glycol monomethyl ether was detected with high intensity in early GC - ion trap runs. This contradictory finding is currently under investigation

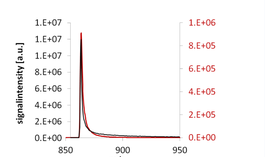


Figure 5)
The tailing (analyte: caffeine) does not noticeably change for different source temperatures (red trace 50 °C, black trace 150 °C).

Conclusions

- Novel corona discharge source was successfully implemented (cAPCI source)
- GC-MS performance of the cAPCI source was investigated
  - Signal dependency on sheath gas flow needs further investigations
  - Ion source temperature appears to be of minor importance for the performance of GC-cAPCI
    - → High gas velocities and envelope of gas within the source reduce ion interaction with the walls to a minimum
- Hardly any fragmentation or other common ion transformation processes encountered with classical APCI occurs; $[M+H]^+$ is the dominant ion signal
  - Reactive species (e.g. OH radicals) do not reach the analyte mixing region
  - Exclusively soft ionization by proton bound clusters

Future research:

- Comparison of GC-FID and GC-cAPCI-MS measurements
  - → Reduction of chromatographic tailing
- Application of different matrices for the reactant ion generation
- LC coupling of the cAPCI source
- Investigations with the cAPCI source in the negative ion mode

References

[1] Sonja Klee; Sascha Albrecht; Valerie Derpmann; Hendrik Kersten; Thorsten Benter *„Generation of Ion Bound Solvent Clusters as Reactant Ions in Dopant Assisted APPI and APLI"* accepted for publication as "paper in forefront" in *Anal. Bioanal. Chem.* **2013**.

[2] Thorsten Poehler; Robert Kunte; Herwart Hoenen; Peter Jeschke; Walter Wissdorf; Thorsten Benter *„Computational Fluid Dynamic Model of a Commercial Atmospheric Pressure Ion Source" Denver, 2011, American Society for Mass Spetrometry, Proceedings of 59th ASMS Conference.*

[3] Walter Wissdorf; Valerie Derpmann; Sonja Klee; Hendrik Kersten; Thorsten Benter ; Wolfgang Vautz, *„Numerical Simulation of Reacting Flows of Ions at Atmospheric Pressure - the Reactant Ion Peak in IMS" Vancouver, 2012, American Society for Mass Spetrometry, Proceedings of 60th ASMS Conference.*

[4] Ralf Schieweck; Matthias Lorenz; Ronald Giese; Klaus J. Brockmann; Thorsten Benter; Siegmar Gäb; Oliver J. Schmitz *"Development of a multi-purpose ionsource for LC-MS and GC-API MS" Anal. Bioanal. Chem.* ***2008, 392, 87-96.***

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