Flowing Atmospheric-Pressure Afterglow Drift Tube Ion Mobility Spectrometry
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Abstract
Here, a Flowing Atmospheric-Pressure Afterglow Discharge (FAPA) is coupled for the first time as a desorption/ionization source to a home-built standalone Drift Tube Ion Mobility Spectrometer (DTIMS). The DTIMS features a Bradbury-Nielsen gate and an axial ion-repeller electrode to facilitate ion introduction into the drift region. Current-voltage behavior of the plasma created in FAPA demonstrates that the plasma belongs to the normal glow region. Ion mobility spectra for different analytes, including 2,6-Di-tert-butylpyridine as a standard, acetaminophen, and acetaldehyde, were investigated and their corresponding reduced mobilities calculated. The FAPA source improves the DTIMS as a portable analytical tool and permits the direct desorption and ionization of analytes (solids, liquids, gas).

Introduction
Drift Tube Ion Mobility Spectrometry (DTIMS) is an ion separation technique at atmospheric pressure where ions are separated based on their individual mobilities as they pass through the drift gas under a uniform electric field. DTIMS features excellent detection limits, fast responses, low costs, and portability which allows identification and quantification of trace substances like pharmaceuticals, explosives, and environmental toxins. [1] The ionization source is critical to the performance of DTIMS. Different kinds of ionization sources like radioactive sources, including nickel (Ni) and americium (Am), and non-radioactive sources, including corona discharge, low-temperature plasma probe (LTP), and electrospray ionization, have been used in DTIMS. Radioactive sources produce stable and reproducible signals, but ion generation rates are low and result in weak signal intensity and small dynamic range. Corona discharge gives higher ion signal than radioactive sources by about one order of magnitude, but it can typically only be used for gaseous samples and deterioration of signal stability happens due to the erosion of anode tip. Electrospray ionization source is mainly used for liquid samples and requires time-consuming and accurate sample preparation process. LTP has been coupled to DTIMS to directly desorb and ionize samples, however, samples were introduced in the high voltage region which restricts the safe sampling and accessibility. [2] FAPA uses an atmospheric pressure glow discharge that generates excited species and ions and its effluent is used to directly desorb and ionize the sample (solid, liquid, or gas) with minimal sample preparation, thus it significantly improves the potential of DTIMS as a portable analytical tool. [3] Here, we coupled FAPA as an ionization source to a standalone DTIMS for the first time. Samples are described and ionized outside the DTIMS high voltage region to ensure safe sampling and accessibility.

Methods: DTIMS
The home-made DTIMS is comprised of thirteen 10 mm thick stainless steel (SS) rings, separated by 2 mm PTFE rings, stacked together and connected through resistors (1MΩ) to create a uniform electric field. A home-built high voltage power supply was adjusted to 5.4 kV and connected to SS ring at the entrance of the 15.9 cm DTIMS cell to produce an electric field of 340 V/cm. An axial ion-repeller electrode, made up of tungsten with smoothed tip, was biased to a potential of 10.5 kV to enhance the ion injection into the DTIMS. The Bradbury-Nielsen gate (BNG) is composed of two series of parallel nickel-chromium wires (0.1 mm thickness) with a separation-distance of 0.5 mm to create an orthogonal electric field relative to the ion passage. A home-built pulse generator (250 μs pulse width at a frequency of 31 Hz) is connected to the BNG to inject the ions into the drift region for separation. An aperture SS grid is placed 1 mm from the Faraday plate. The ion current is amplified by a home-built electrometer with a gain of 105, that after further amplification is fed to the A/D converter and the resulting ion mobility peak is displayed on the monitor. Dry nitrogen gas (13X molecular sieve) was passed through the DTIMS cell with a flow of 750 ml/min.

Results

• Figure 4 demonstrates that plasma corresponds to the normal glow region in FAPA. [2]
• Reduced mobility coefficient (Kn) which represents the validity of mobility values was calculated for 2,6-Di-tert-butylpyridine as a standard according to equation (1) and is well consistent with the literature values. [4]

\[ \text{Kn} = \frac{0.116}{1.41 \times 10^{-5} \text{V} \cdot \text{s} / \text{cm}} \]

L: Drift region length = 10cm, E: Electric Field = 340 V/cm, \( t_1 \) : Drift Time = 19 ms, T: Temperature = 297 K, P: Pressure = 760 Torr

• Two intense ion mobility spectra were obtained for acetone with corresponding reduced mobilities of 1.88 cm2 V−1 s−1 for the monomer and 1.95 cm2 V−1 s−1 for the dimer. [2]
• Ion mobility spectra for acetalaminophen tablet gives two peaks with corresponding reduced mobilities of 1.34 cm2 V−1 s−1 for the dimer and 1.2 cm2 V−1 s−1 for the trimer. [5] Other observed peaks are pertinent to the sample matrix.
• Reactant ion peaks, mainly clustered hydronium ions, give a reduced mobility of 2.09 cm2 V−1 s−1.

Conclusions

• Successful coupling of FAPA source to DTIMS as a desorption/ionization source and identification of different analytes (solids, liquids, gas).
• Nitrogen plasma gas prevented secondary plasma formation and current-voltage curve demonstrates the normal glow region.
• Reduced mobility coefficient (Kn) calculated for 2,6-Di-tert-butylpyridine agrees with literature values and proves the validity of mobilities observed for analytes.

Future Work

• Systematic optimization of FAPA parameters: plasma gas flow rate, potential, current, angles, distances, etc.
• Obtain figures of merit for various analytes of interest under optimized FAPA conditions.
• Incorporate heating capabilities to the DTIMS to allow increased operating temperature to remove background peaks and reduce memory effect.

References

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