A rapid detection method for policy-sensitive amines real-time supervision

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ARTICLE INFO

ABSTRACT

Many organic amines that comprise a benzene ring are policy-sensitive because of their toxicity and links to social harm. However, to date, detection of such compounds mainly relies on offline methods. This study proposes an online pptv (parts per trillion by volume) level of detection method for amines, using the recently-built vacuum ultraviolet photoionization mass spectrometer (VUV-PIMS) combined with a new doping technique. Thus, the dichloromethane doping-assisted photoionization mass spectra of aniline, benzylamine, phenethylamine, amphetamine, and their structural isomers were recorded. The dominant characteristic mass peaks for all amines are those afforded by protonated amines and the amino radical-loss. The signal intensities of the amines were enhanced by 60–130 times compared to those recorded without doping assistance. Under 10 s detection time, the sensitivities of aniline and benzylamine in the gas phase were determined as 4.0 and 2.7 counts pptv^{-1}, with limits of detection (LODs) of 36 and 22 pptv, respectively. Notably, the detection efficiency of this method can be tenfold better in future applications since the ion transmission efficiency of the mass spectrometer was intentionally reduced to ~ 10% in this study. Therefore, dichloromethane doping-assisted photoionization mass spectrometry has proven to be a highly promising on-line approach to amine detection in environmental and judicial supervision and shows great potential for application in the biological field.

1. Introduction

Many organic amines have been attracting much attention because of their chemical toxicity and medical indications [1–3], while some are under close supervision because of their link to social harm [4–7]. Aniline and its derivatives are industrially released as chemical residues [1,8,9] and have also been reported as breakdown products of herbicides and pesticides [1]. Since aniline can induce various adverse physiological responses and is a strongly suspected carcinogen [1,10–12], it is listed as a high-priority compound [11]. Benzylamine (BZA) is a medium-strong base with a primary amine functional group attached to its benzyl group. In analytical fields, it is generally and abundantly used as a solution and a deriving agent [13–19]. BZA has been reported to provoke detectable changes in several indexes of glucose and lipid homeostasis [20]. Moreover, some studies have reported its effect as a potassium channel blocker [21]. Phenethylamine (PEA) is featured as a specified substance on the World Anti-Doping Agency (WADA) Prohibited List because it represents the core structure of stimulant-like drugs [7,22]. Currently, this ingredient is widely found in some dietary supplement products marketed for weight loss,

enhanced energy, and improved athletic performance [23]. Moreover, this compound has been detected in some food items such as cocoa products, cheese, and wine [24–26]. As an endogenous amine, PEA has been linked to the pathogenesis of several neuropsychiatric disorders such as schizophrenia, depression, attention-deficit, and Parkinson's disease [27]. Generally, PEA and amphetamine (AMP) are detected simultaneously in judicial samples [21]. Globally, the amphetamine-type stimulants (ATS) are the second-most widely used drugs after cannabis, exceeding both cocaine and heroin; they also contribute towards environmental pollution [28]. Nowadays, PEA and AMP drug abuse testing and health assessments only make use of urine, blood, and hair samples [29–34] and no effective instrumentation for drug smuggling screening is available.

The current detection methods for the aforementioned amines are mainly limited to the liquid phase and rely on offline methods. Immunoassay is commonly used for toxicological investigations [35]. The biosensor approach is a cheaper alternative that allows the use of a portable machine to provide in situ results [36]. Although these methods are highly sensitive to their targets and can be performed rapidly, immunoassay is still very limited because it responds poorly (low

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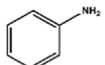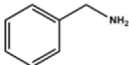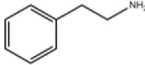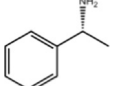E-mail address: jshu@rcees.ac.cn (J. Shu).
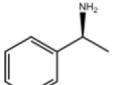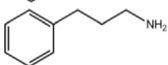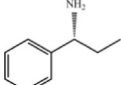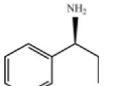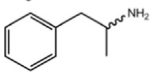
Table 1
List of properties of the relevant amines.

Chemical	Structure	Molecular Weight (Da)	Vapor Pressure at 25 °C (mmHg)	Ionization Potential (eV)
Aniline		**93.13**	**0.6[a]/0.791[b]**	**7.72[c]**
Benzylamine		**107.15**	**0.757[b]**	**8.49[c]**
Phenethylamine		**121.18**	**0.409[b]**	**8.50[c]**
(R)-(+)-1-Phenylethylamine			**0.5[d]/0.541[b]**	**Not available**
(S)-(-)-1-Phenylethylamine				
3-Phenylpropanamine		**135.21**	**0.125[b]**	**8.89[c]**
(R)-(+)-1-Phenylpropanamine			**0.201[b]**	**Not available**
(S)-(-)-1-Phenylpropanamine				
Amphetamine			**0.310[b]**	**8.99[c]**

[a] Experimental data from the National Institute for Occupational Safety and Health (NIOSH) method.
[b] Predicted data is generated using the Estimation Program Interface (EPI Suite; US Environmental Protection Agency).
[c] Data obtained from the National Institute of Standards and Technology (NIST) database.
[d] Experimental data from SynQuest Labs, Inc.

cross reactivity) to a wide range of different designer drug structures and few commercial molecular imprinted polymers (MIPs) against amphetamine are available to date [35,37]. Mass spectrometric analysis is widely used in analytical chemistry and is most popularly applied in illicit drug detection [36,38–40]. In this area, electron impact (EI), electrospray ionization (ESI), and chemical ionization (CI) have been reported as ionization sources [30,32,36,41–44]. However, these approaches may generate substantial complex unexpected fragments [38–40,45]. Popular mass spectrometry methods such as gas chromatography–mass spectroscopy (GC–MS), liquid chromatography with tandem mass spectrometry (LC–MS/MS), and capillary electrophoresis coupled with UV and electrospray mass spectrometry (CE-ESI-MS) are time consuming, expensive, and cumbersome [35,36,46] because chemical derivatization of the amino group procedures is necessary to enhance their sensitivity, selectivity, and separation efficiency [2,44]. Moreover, liquid–liquid extraction (LLE) and solid-phase extraction (SPE) are often required to optimize the detection signal [1,31,41,42,46]. Spectrophotometry and voltammetry are sometimes used, however, these methods are also need to be coupled with chromatography or electrophoresis [30,32,41].

This study proposes a direct monitoring method for pollutant and drug vapours using a time-of-flight mass spectrometer (TOF-MS) with a doping-assisted photoionization system. Although TOF-MS is well suited for composition control, rapid analysis, and portable use with unlimited mass ranges and high repetition rates [47], its suitability for illicit drug detection has not been investigated to date. Photoionization (PI) with vacuum ultraviolet (VUV) light is a promising standard and universal ionization method because of its 'soft' ionization character [45,48]. However, its ionization efficiency is limited by the

photoionization cross section of the analyte as well as the photon energy, even if it is above the ionization potential [49,50]. Previous studies have demonstrated that dichloromethane doping can enhance the photoionization efficiency of gaseous oxy-hydrocarbons by dozens of times, however, this technique is ineffective for non-oxygenated organics like benzene [51,52]. To the best of our knowledge, this study is the first of its kind to utilize PI technology coupled with the dichloromethane-doping technique to detect amines. Besides further insight into the protonation process, this study also indicates the potential use of this technique in biomaterial detection.

Related chemicals are listed in Table 1. AMP could not be procured for legal control purposes; thus, aniline, BZA, PEA, and some structural isomers were investigated to elucidate the detection performance of these kinds of substances. For convenience, PEA and its structural isomers are collectively referred to as PEAs and structural isomers of AMP are referred to as AMPs henceforth.

2. Material and methods

2.1. Instrumentation

Fig. 1 illustrates the analytical instrument used in this experiment. Briefly, it consists of a lamp-based vacuum ultraviolet photoionization mass spectrometer (VUV-PIMS) and a 120-L calibration chamber. The lab-built VUV-PIMS has been described in detail in a previous study [53]. In this study, the RF-powered lamp was filled with 5% krypton in 330 Pa helium, providing photons with energies of 10.0 (78%) and 10.6 (22%) eV. For a 13.56-MHz RF power supply running at 60 W, the output of the VUV light through a magnesium fluoride (MgF) window