OPTICAL DETECTION OF BTEX: REVIEW OF DIFFERENT TECHNIQUES

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ABSTRACT

Introduction
On average a person spends 80%-90% in indoor environments where exposure to various indoor air pollutants is inevitable [1]. Among these air pollutants, Benzene, Toluene, Ethylbenzene and Xylene (BTEX) can pose a serious threat to human health. Among BTEX, benzene is toxic and classified as carcinogenic [2,3]. In 2013, the EU proposed a maximum exposure limit value of 5 µg/m³ (1.6 ppb) for benzene in public indoor spaces [4,5] and this will be decreased down to 0.64 ppb in 2018 [6]. For in situ continuous monitoring of BTEX, a detection technique which is high sensitive and selective, portable and have a capability of miniaturization is needed. This paper considers alternative optical approaches to the detection of air borne BTEX.

BTEX Detection Techniques: Optical Detection
Currently different technologies are available for BTEX detection. A detailed comparison is shown in Table 1 and figure 1. Optical gas sensors have features of high sensitivity and selectivity, non-destructive, respond quickly and are less prone to drift. They are inherently reliable and have zero cross-response from other gases. Numerous optical gas-sensing techniques have been developed and can be categorized into direct spectrometry and reagent/film mediated optical sensors. Different optical configurations are used for sensing application from free-space sensors to fiber based configurations to optical waveguides [7].

In direct sensors, the analyte is detected directly based on the measurement of intrinsic properties like absorption spectra e.g., spectrophotometry. In reagent/film mediated sensor, a change in the optical response of an intermediate agent is used to monitor the analyte. S.K.Sulick et al. reported this type of sensor using a disposable colorimetric sensor array made from a diverse set of chemical responsive colorants. It is portable and has good sensitivity (limit of detection 0.2 ppm for benzene)[8]. Interferometry based gas sensors can be considered as film-mediated optical sensors. This paper considers both spectrometric and interferometric based detection techniques for BTEX.

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**Table 1.** Comparison of different sensing techniques for BTEX detection

<table>
<thead>
<tr>
<th>Method/Technique</th>
<th>LOD</th>
<th>Advantages</th>
<th>Limitations</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PID</td>
<td>1.2 ppt – 1.4 ppt</td>
<td>High sensitivity. Quick response. Portable</td>
<td>Lower selectivity, all the gases with IP equal or lower the photon may be detected. Complex electronics. Cost.</td>
<td>[11]</td>
</tr>
<tr>
<td>μ-GC</td>
<td>15 ppb</td>
<td>High sensitivity. High selectivity.</td>
<td>High cost and size Complex analytical setup and fabrication.</td>
<td>[12]</td>
</tr>
<tr>
<td>Piezoelectric</td>
<td>1.2 to 2.1 ppm</td>
<td>Excellent sensitivity. Portable.</td>
<td>Large measurement noise. Weak selectivity. Zero drift and cross reactivity.</td>
<td>[13]</td>
</tr>
<tr>
<td></td>
<td>100ppb</td>
<td>Good dynamic range.</td>
<td>Interference from humidity and temperature.</td>
<td>[14]</td>
</tr>
<tr>
<td></td>
<td>4 ppb-1000 ppm</td>
<td></td>
<td></td>
<td>[15]</td>
</tr>
</tbody>
</table>

**Spectrophotometry**

Spectrophotometry based gas sensors offer a reliable and gas specific approach for BTEX detection. It relies on the intrinsic properties of gases i.e., unique absorption spectra (fingerprints) at specific wavelength. The absorption level follows the Beer Lambert law. The sensitivity is highly dependent on the optical path length which is defined by the design of absorption cell. The absorption cell can be single pass, multiple pass or a resonant cavity. For single pass cells, optical path lengths up to 1 m can be achieved but drawbacks are limited sensitivity and optical losses. In multiple pass cells, mirrors are used which allow longer optical path lengths. It is relative sensitive but have limited spectral bandwidth and high sensitivity towards external vibrations [16]. Horiuchi et al. reported BTEX sensor based on integrated single pass absorption cell [17]. Absorption cell of length 2 cm coated with platinum was used and detection limit of 25 ppb for benzene was achieved. The LOD was improved to 1 ppb by using a hollow fiber of length 12 cm with wall coated aluminum [18]. There is a good potential of improving the sensitivity to sub ppb by designing absorption cell that is capable of miniaturization and have the least optical losses possible.

A Hollow Core Waveguides (HCW) offer an alternative to absorption cell and have been applied for spectrometry and sensing applications [19]. The use of HCW provides a distinct advantage of combining a compact gas cell with an efficient radiation guide for the measurement of small gas concentration. A compact light weight spectrophotometer can be developed by using chip scale HCW. However the major limitation is the lack of low optical loss waveguide design. Recently a novel HCW design is developed by Weijian et al. made from two planar, parallel, silicon-on-insulator wafers with subwavelength gratings for IR applications [20]. This design has a distinct advantage of efficiently guiding light (optical losses 0.37 dB/cm) without sidewalls for a 9 μm waveguide, which allow the inflow and outflow of gases from the side. Silicon has low band energy and absorbs UV-visible radiations (1.1eV) which limits its application for BTEX detection. A material with high band energy i.e., Aluminum Nitride, Gallium Nitride and Silicon carbides can be a viable option to replace silicon [21]. The multilayer fabrication of high band energy material can be technical challenge for our design.

**Interferometry**

Interferometry based detector for BTEX is a film-mediated optical sensor. Interferometric based measurement techniques are very sensitive and have been utilized for pressure, temperature and concentration measurements [22,23]. Martinex et al. used Pohl interferometry setup using PDMS thin layer as a sensing film for VOCs detection [24]. A setup has very limited sensitivity of 1500 ppm. Razak et al. used polyacrylate resin layer as a sensing layer in the waveguide and obtained a detection limit of 8 ppm [25]. Xiangping et al. applied interferometric configurations i.e., Faby-Perot (FP) and Sagnac interferometer (SI) with PDMS as sensing film for detection of VOCs [26]. A sensitivity of 9.02 x 10^4 nm/ppm and 1.17 x 10^3 nm/ppm was achieved using SI and FP interferometer respectively.
Karthik et al. also used FP interferometer with PDMS as sensing film integrated with µGC and detected toluene down to 25 ppb [27].

**Planned Work**

Michelson interferometer is developed for the measurement of BTEX concentration. PDMS is used as a sensing film which has the property of swelling and/or change of refractive index, when interact with BTEX. The schematic is shown in figure 2. The sensing film is attached onto the mirror which is exposed to BTEX. The interference of reflected beam I1 and I2 produce fringes pattern on the screen. The changes in the fringes are monitored to measure the concentration of the BTEX.

**Figure 1. Different BTEX detection Techniques: (A) MOS (B) Electrochemical (C) PID (D) Piezoelectric sensors.**

**Figure 1. Schematic of Michelson Interferometer for BTEX detection.**

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**References**