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A new laboratory test chamber for the determination of diffusive sampler uptake rates

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Abstract

Diffusive samplers are today widely used for air quality control in indoor and outdoor environments and for personal exposure studies as well. The uptake rate is a fundamental parameter of a sampler for the calculation of the concentration of the substance to be monitored depends directly on it. Uptake rates can be affected by numerous factors. Their values and the range of validity have to be determined in an appropriate exposure chamber.

The laboratory test chamber presented here consists of a loop made of glass, stainless steel and PTFE containing the generated atmosphere in which diffusive samplers can be tested. It is possible to accommodate several samplers simultaneously and simulate various environmental conditions such as temperature, wind speed, wind direction, humidity, atmospheric composition, total pressure and exposure duration. All working parameters have to be monitored including the concentrations of the components of the generated atmosphere. It is shown that the expected concentration of a volatile compound like benzene can be reached very quickly whereas those of less volatile compounds like toluene or xylenes takes longer. The procedure for overcoming this difficulty is described in this paper.

By means of an application it is also shown that exposure duration can unequally affect diffusive sampler uptake rates depending on sampler geometry and the nature of the adsorbent. It appears that a radial high-uptake rate diffusive sampler packed with a thermally desorbable material may be unsuitable for long-term monitoring of a volatile compound like benzene. However an axial low-uptake rate diffusive sampler, also packed with a thermally desorbable material, seems more appropriate for this application due to the higher stability of its uptake rate.

Keywords: Atmospheric simulation; Diffusive samplers; Air quality; Benzene; Toluene; Xylene

1. Introduction

The assessment of ambient air quality by diffusive methods has been expanding continuously in Europe especially after the publication of the EC Air Quality Framework Directive (1996). Diffusive samplers have been extensively used in several indoor and outdoor environments including dwellings (Brown and Crump, 1998; Cocheo et al., 2000; Gonzalez-Flesca et al., 1999; Gonzalez-Flesca et al., 2000), petrol stations (Gonzalez-Flesca et al., 2002) and street canyons (Vardoulakis et al., 2002).

The way these samplers work has been described in the literature: (Brown et al., 1981) so there is no need for a detailed description here. Diffusive samplers can be

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seen today as cost effective, sensitive and reliable tools for the assessment of air quality and personal exposure in both indoor and outdoor environments. However, under certain environmental conditions, these samplers can deviate from their normal behaviour. For example, when trying to sample aromatic hydrocarbons with a Perkin–Elmer-type tube sampler packed with Carbotrap B, in the presence of tropospheric ozone, reactive compounds such as styrene will oxidise during the sampling, showing an apparent uptake rate (rate at which a substance is collected from an atmosphere) much lower than expected. On the other hand, for more stable compounds such as benzene or toluene it will remain unaffected (Bates et al., 2000).

Another well-documented example is the case of DNPH silica impregnated tubes. These samplers are specifically designed for carbonyl compounds. If they are exposed to tropospheric ozone, several artefacts will affect the quality of the sample (Arnts and Tejada, 1989; Jaouen, 1996; Sirju and Shepson, 1995).

A given sampler, packed with two different adsorbents, can exhibit different uptake rates. This can be seen from the expression derived from the first Fick's law of diffusion. The mass collected by an axial diffusive sampler during a time t can be written as

$$m_s = A * D(C_0 - C_1)t/L, \qquad (1)$$

where A is the adsorbent-pack cross sectional area, D the molecular diffusion coefficient of the investigated substance, L the air gap length, measured between the sampler front-end and the adsorbent bed, C_0 is the concentration to be measured and C_1 the concentration in the "vicinity" of the adsorbent. Under ideal behaviour, C_1 equals zero, fulfilling the zero sink condition. In such a case, the performance of the sampler will depend only on its geometry and on the diffusion coefficient D. In reality however, things are different, that is why the following equation is preferred:

$$m_s = A * D * C_0 * t * k/L. \qquad (2)$$

In Eq. (2) if k differs from unity it will reflect a non-ideal behaviour. In general, k will depend on several factors including the nature of the pair adsorbent/adsorbate. In practice, the parameter k, or the overall value of the uptake rate $Q = DAk/L$, will have to be determined experimentally.

In order to provide users of diffusive samplers with guidance and standardised procedures, CEN/TC 264 WG11 and WG13 groups have been working in two standards EN 13528 (2003) and EN 14662-4 (2005). These standards, should facilitate the use of diffusive samplers and provide solid basis for the implementation of QA/ QC procedures. Part III of the EN 13528 standard specifies that though the performance of a diffusive sampler can be determined theoretically, it is a good practice to have it determined experimentally in an exposure chamber where environmental conditions in which the sampler is intended to be used can be reproduced.

According to the standard, exposure chambers should be able to:

- Accommodate several samplers for simultaneous exposure.
- Produce a continuous reference atmosphere for a duration up to several weeks.
- Simulate variable wind speeds.
- Vary humidity and temperature.
- Provide equivalent loading conditions for all samplers being exposed.

Characteristics and performances of some already existing exposure chambers are available from the literature (Goelen et al., 1992; Perez Ballesta et al., 1999; Martin et al., 2003; Chung et al., 1999; Jaouen et al., 1995).

2. Part I: description of the chamber

The exposure chamber is schematically represented in Fig. 1.

Basically, it is a loop made of glass, stainless steel and PTFE containing the generated atmosphere where diffusive samplers are exposed. Glass elements are double walled and are implemented with conical flanged

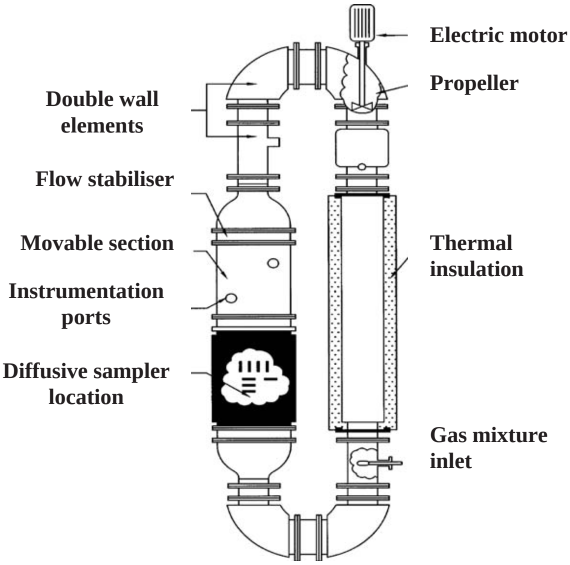

Fig. 1. Schematic representation of the exposure chamber. The whole apparatus is thermally insulated with removable insulating jackets (only partially shown).