Particle collection efficiency of sorbent tubes

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ABSTRACT
Both the airborne particulates and the gas-phase VOC and SVOC are of importance for indoor air quality. The sampling of the various species, however, utilizes different techniques—it is a common procedure to sample particles on filter disks, whereas the gaseous compounds are trapped on solid sorbents. In many cases, the distribution coefficient of semivolatile organic compounds between the particulate and the gas phase are calculated by measuring gas phase and particulate phase concentrations of a certain substance. In some cases, such measurements were carried out in parallel.

In this study, the collection efficiency of standard solid sorbent tubes for thermal desorption filled with Tenax TA was determined. The tubes were challenged with a polydisperse NaCl particles with count median diameter 120 nm and particle concentration and size distribution upstream and downstream of different sorbent tubes was measured by SMPS. The overall collection efficiency for particles in the size range of 20–700 nm was found to be close to 90% for most tubes, thus indicating that particles as well as gaseous substances will be collected in these tubes and that sampling for the calculation of partitioning coefficients should only be carried out with specially designed combination samplers.

INDEX TERMS
SVOCs; Tenax; Sorbent tubes; Particles; Collection efficiency

INTRODUCTION

Adsorption tubes filled with Tenax are used widely for the collection and pre-concentration of volatile organic compounds. Nowadays the range of compounds analysed by thermal desorption (TDS) is more and more extended towards the less volatile substances (Clausen and Wolkoff, 1997). New thermal desorptions are designed to provide sufficient analytical performance up to C44 compounds, so it can safely be assumed that in the near future, a number of semivolatile substances will be analysed via TDS. The tubes used for the collection are normally expected to only collect compounds from the gas phase, but as first results of experiments carried at Queensland University of Technology suggest, the collection efficiency of such sorbent tubes might be surprisingly high, which means that semivolatile compounds adsorbed to fine particles might be collected and thermally released in the tube additionally to the portion of that compound present in the gas phase.

In this paper, first results of particle collection efficiencies for standard sorbent tubes are presented.

METHODOLOGY

The collection efficiency of sorbent tubes was determined using a methodology based on ASHRAE 52.2—1999 Standard for air filter testing (ASHRAE, 1999). The method is based

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on measuring particle number concentration and size distribution downstream and upstream of the sorbent tube using NaCl particles as the challenge aerosols (Jamriska *et al.*, 2002).

Instrumentation

The aerosol characteristics were measured by scanning mobility particle sizer (SMPS). The system consists of an electrostatic classifier (EC TSI 3071) and condensation particle counter (CPC TSI Model 3010), where particles are classified according to their electrical mobility in EC and optically counted in CPC. The system operated in under-pressure mode and measured particle number concentration and size distribution in the size range 20–700 nm. The size resolution was set at 16 channels per decade and one measurement took 2.5 min. The air temperature and relative humidity inside and outside of the chamber was measured by TSI IAQ monitor.

Challenge Aerosols

Tested sorbent tubes were challenged by polydisperse NaCl aerosols generated by a Colison atomiser (10% NaCl w/w solution in distilled water) into a large experimental chamber (3 m^3). Aerosols leaving the atomizer passed through a dehumidifier (silica column) and a neutralizer (Kr85 source) to eliminate the effect of moisture and electrostatic charges carried on aerosols. Upon delivery into the chamber, the test aerosols were mixed for approximately 60 min by a small fan located inside the chamber before the measurements started. Characteristics of aerosol during mixing period were monitored by SMPS sampling air from the experimental chamber with sampling point located near the chambers' centre. The schematic diagram of the test system is presented in Figure 1.

Calculation of Filtration Efficiency

The overall collection efficiency was determined from particle concentration measured downstream (C_{Down}) and upstream (C_{Up}) of tested sorbent tube as:

$$E = 1–P = 1–(C_{Down}/C_{Up}) \quad (1)$$

where E and P are collection efficiency and penetration of particles, respectively.

Measuring Methodology

The measurements were conducted in a sequence: (a) upstream; (b) downstream; (c) upstream of tested tube. The average of two consecutive upstream readings was used as an estimate of C_{Up} value in Eqn (1). Three sets of measuring sequences were conducted for each sorbent tube. The tubes were tested at a flow rate of 0.25 l min^{-1} provided by SMPS. The value is higher than the recommended 0.1–0.15 l min^{-1} flow rate for sorbent tubes sampling. However, it was the minimum airflow under which the SMPS can operate and the effect was considered as insignificant.

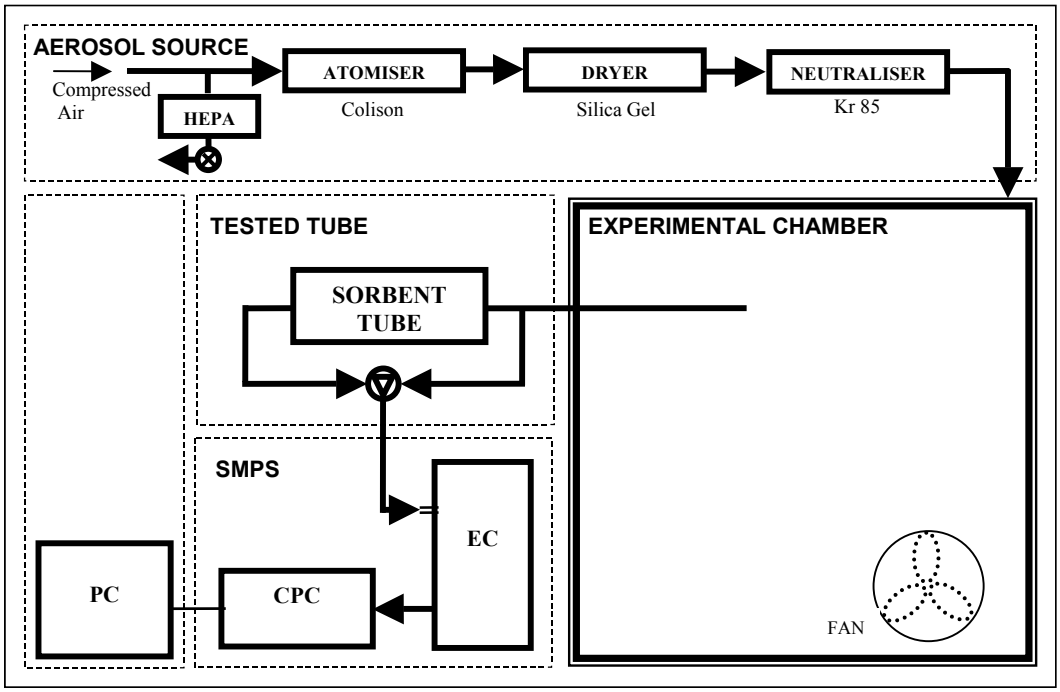

Figure 1 Schematic diagram of the test system used for assessment of collection efficiency of sorbent tubes.

Sorbent Tubes

Overall, eight sorbent tubes, characteristics of which are presented in Table 1, were tested. The tubes differ in the type of sorbent media, geometry and material used (SS or glass). The samples

Table 1 Characteristics of the sorbent tubes tested

No.	Sorbent tube code	Description	Sorbent[a]	Surface area (m^2/g)
1	Tenax A	Perkin Elmer stainless steel[b]	Tenax TA	35
2	Tenax B		Tenax TA	35
3	Tenax E		Tenax TA	35
4	Tenax C	Perkin Elmer stainless steel[b]	Tenax TA/CarboTrap	35
5	Tenax D[*b]	Gerstel-glass tube TDS2[c]	Tenax TA	35
6	Carbosieve	Perkin Elmer glass tube[b]	Carbosieve S- III	820
7	Chromosorb A	Perkin Elmer glass tube[b]	Chromosorb 106	700–800
8	Chromosorb B[c]			

[a]Each sorbent tube contains 0.3 g of sorbent. Tenax C tube consisted of two-bed sorbents: 0.3 g Tenax TA and 0.01 g Carbotrap.
[b]Perkin Elmer tubes SS and glass: length 88.9 mm, OD 6.35 mm, length of bed 60 mm, mesh 60/80.
[c]Gerstel glass tube. Length 178.9 mm, OD 6.35 mm, length of bed 60, mesh 60/80.

are representative of sorbent tubes typically used at WKI for routine sampling. They were prepared using the steps: (a) initial packing with a weighted amount of sorbent; (b) thermal conditioning (30 min) starting with 150°C until the maximum desorption temperature for each

sorbent (i.e. 330°C for Tenax, carbosieve and carbotrap, 220°C for Chromosorb); (c) adjustment of the rear sieve to compensate for the shrinking of the sorbent; (d) final conditioning step (60 min) with the maximum desorption temperature. The tubes are usually used with flow rates of 0.10–0.15 l min^{-1}.

RESULTS AND DISCUSSION

The efficiency of tested sorbent tubes was measured with NaCl aerosols in a series of individual test runs. For each test run, NaCl aerosols were generated into the experimental chamber. The generation process of challenge material was repeatable with size characteristics of NaCl aerosols similar at the beginning of the each test run. The upstream particle size distribution of the test aerosols was unimodal, lognormal with initial count median diameters approximately 0.12 μm and geometric standard deviation about 1.6. The concentration levels of test aerosols applied during filter testing varied between 1.0 and 5.0×10^4 particles cm^{-3} as compared to 3.0×10^3 particles cm^{-3} present in the laboratory air. Since the measurements were conducted over a relatively long period of time (1–2 h per sorbent tube), the test aerosol characteristics (size distribution and concentration) varied over this time interval (decay in concentration and particle growth due to coagulation). However, the effect of these was eliminated by the applied sampling sequence (described previously) and triplicate measurements for each tested tube. The temperature and relative humidity of the air in the chamber was continuously monitored and was within the range of 23–25°C and 60–65%, respectively.

The results of average collection efficiency values for tested tubes are presented in Table 2.

Table 2 Overall collection (filtration) efficiency of tested sorbent tubes for particles in the size range of 20–700 nm

No.	Sorbent tube code	Efficiency ± STD (%)
1	Tenax A	88.7 ± 0.5
2	Tenax B	88.1 ± 0.3
3	Tenax E	75.4 ± 0.8
4	Tenax C	62.7 ± 0.9
5	Tenax D	97.6 ± 0.1
6	Carbosieve	88.2 ± 0.7
7	Chromosorb A	96.0 ± 0.3
8	Chromosorb B	93.5 ± 0.7

The following observation can be made from the results presented:

- The efficiency of single bed Tenax tubes A, B and E varied between 75 and 89% with standard deviation less than 1%. The efficiency of Tenax C was 63%. The reason for deviation in case of tube C lies in the setup/construction of the tube: the Tenax C tube is a two-bed tube containing the sorbents Tenax and Carbotrap. After several thermal desorptions, the tenax packing tends to shrink and thus becomes less tightly packed. Unlike with single-bed tenax tubes, the packing cannot be repacked by adjusting the position of the stainless-steel sieve in the back of the tube without having to remove the carbotrap packing entirely. It is, therefore, very much possible that the used tube had a less tight packing compared to the other Tenax tubes and thus showed a reduced collection efficiency. A second possibility for the reduced collection rate is the carbotrap sorbent—if crushed or otherwise mechanically stressed, the fragile sorbent tends to become a source of fine particles itself. A more detailed assessment of similar experiments will be presented in a forthcoming paper.

● The collection efficiency of Tenax D, Carbosieve and Chromosorb A, B tubes was in the range of 88–98 %. Tenax D tube (Gerstel—glass tube) showed higher collection efficiency value compared to Tenax A, B, E tubes. This is likely to be associated with higher packing density of the sorbent (Tenax TA) and the tube's length parameter. The length of Tenax D tube (glass) was twice the length of the other tubes resulting in increased particle deposition losses on inner walls of the tube. Higher collection efficiency of Carbosieve and Chromosorb tubes (A, B) could be associated with larger surface areas of these sorbent materials compared to Tenax TA.

CONCLUSION AND IMPLICATIONS

The experimental results indicate that fine particles are collected with relatively high efficiency by standard sorbent tubes. Such sorbent tubes can, therefore, be used to trap organic compounds present in both the gaseous and the particulate phase. This fact raises a number of questions: Will volatile and semivolatile compounds adsorbed to the collected particulate matter be completely removed by the thermal desorption procedure? What happens to the collected particulate matter in the tube? Will it enhance or reduce the suitability of the tube? Will it reduce the stability of sensitive species on the tube? It is not very critical to have an answer to these questions as long as test chamber experiments or other set-ups under 'artificial' conditions are regarded, but it is certainly important if sampling takes place in the field, with unknown concentrations of particles present. More tests to assess the impact of these findings on routine sampling are, therefore, necessary.

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