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Size-selective Personal Air Sampling: a New Approach Using Porous Foams

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Simultaneous sampling of three dust fractions (inhalable, thoracic, respirable) has been achieved using porous polyurethane foams, which serve both as selecting and sampling media. The particle penetration was measured in laboratory tests. Foam geometries were predicted using a semi-empirical model. Prototype samplers were constructed based on the IOM and GSP inhalable personal samplers. Weighing and chemical analysis procedures were checked for the foams.

Keywords: foam; size-selective sampling

INTRODUCTION

Occupational diseases of the respiratory tract related to exposure to airborne substances are a major factor in the compensation by occupational insurances in all member states of the European Union. In order to get reliable data of worker's exposure, a measurement system ideally needs to be able to determine the three particle fractions in accordance with the standard EN 481 (CEN, 1993).

Within a European project (SMT4-CT96-2137) a new reference method for the simultaneous measurement of hazardous particulate matter in accordance with EN 481 is being developed. This development includes the design and testing of two three-stage personal air samplers based on the existing IOM and GSP samplers for the inhalable fraction incorporating additional porous plastic foams. Suitable analytical procedures are also being assessed.

Polyurethane foam has been found to serve well as a sampling and selection medium for particles (Aitken *et al.*, 1993; Vincent *et al.*, 1993; Chung *et al.*, 1997; Chen *et al.*, 1998; Kenny *et al.*, 1998, 1999; Page *et al.*, 2000).

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MATERIALS AND METHODS

The physical and chemical behaviour of porous foams was investigated using optical and scanning electron microscopy, pressure drop measurements, and elemental and organic chemical analyses (atomic absorption spectrometry, inductively coupled plasma mass spectrometry, extraction of organics and mass spectrometry).

A semi-empirical model was developed and used to predict foam plug geometries, suitable as good starting points for particle penetration tests using polydisperse dusts (glass microspheres) in wind tunnel (velocity: 0.15 m/s) and calm air chamber tests (Görner *et al.*, 2001). The foams were mounted in a holder or prototype sampler, and the penetration was compared with an empty reference holder or the surrounding total airborne dust, respectively. Particle distributions were measured with aerosol particle sizers (TSI, St Paul, MN). The resulting 50% penetration particle diameters (D_{50}) were compared with those required by EN 481.

The analysis of dust-loaded foams was checked by weighing experiments and suitable chemical analysis

procedures. Additional field tests with three-stage prototype samplers were carried out.

RESULTS AND DISCUSSION

Characterization of foams

The first steps were to assess the quality of polyurethane foams with open cell surfaces between the filaments and to determine their porosity. The structure of porous polyurethane foam is shown in Fig. 1 and is characterized by recurrent elements.

Manufacturers describe the porosity of foams in terms of pores per inch (ppi). The range generally deliverable is ~10–100 ppi. A foam cell is ideally characterized by a regular dodecahedron (Fig. 2), that is, 12 pentagons in a football-like configuration. The cell diameter in this ideal shape is used to characterize the porosity. It allows the more precise determination of the foam material rather than the empirical value p.p.i., and is the parameter on which the manufacturers own quality systems are based. The cell diameter can easily be measured by optical microscopy with a SD of ~5%.

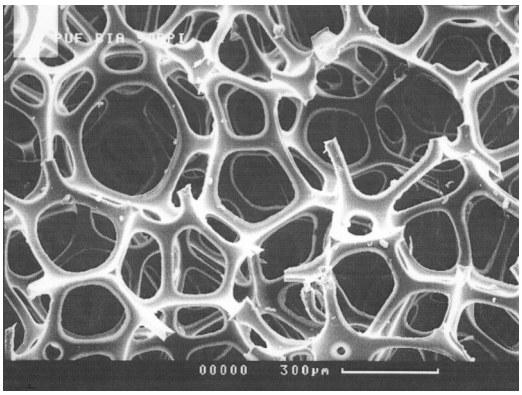

Fig. 1. Polyurethane foam of 90 p.p.i.

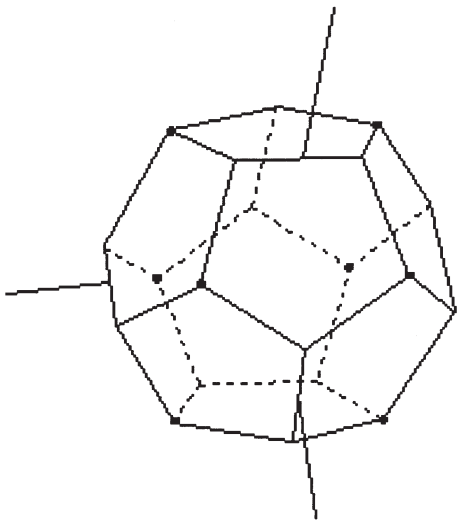

Fig. 2. Shape of an idealised foam cell, combining multiple pores: dodecahedron.

A theoretical model to predict foam plug geometries for desired aerodynamic functions supports the developments. With the help of this semi-empirical model, originally proposed by Vincent *et al.* (1993) and reformulated by Kenny *et al.* (2001), we can determine the penetration P of particles passing through such a foam material.

$$\ln(P) = \frac{t}{d_f}\{5.486St^{2.382} + 3.891Ng^{0.880}\}\times 10^4$$

The model uses impaction and sedimentation components, represented by the Stokes number, $\mathrm{St} = D_{ae}^2\,\gamma U/(18\eta d_f)$, and the gravitational parameter, $\mathrm{Ng} = D_{ae}^2\,\gamma g/(18\eta U)$. t is the thickness of the foam the particles have to pass through and d_f is the filament diameter, namely the solid parts or the edges of the cell. The parameters are given in SI units. The filament diameter has an empirical relationship to the cell diameter (Kenny *et al.*, 2001).

Using this model, we can determine the penetration starting with a selected foam geometry. Alternatively, if we fix the penetration as 0.5 for a certain particle diameter (e.g. 4.3 or 11.7 µm) according to the respirable and thoracic dust fraction (CEN, 1993), we can deduce the foam geometry. In this way, we have a good starting point to construct prototype samplers.

Several tests for particle penetration through foam plugs with nominal porosities of between 45 and 170 p.p.i. (equal to 1.5 and ~0.25 mm cell diameter) were carried out (Kenny *et al.*, 2001). The results indicated that selected foams with predicted geometry and porosity comply with the required penetration curves sufficiently well.

The data in Fig. 3 represent the particle penetration through two different foam modules in a prototype sampler based on the GSP inhalable sampler (similar to Fig. 4, upper row). Further results are given elsewhere (Görner *et al.*, 2001). Typical cell diameters of the foams used are 480 and 1600 µm.

Analysis of foams

Besides the development of a sampler, special attention is paid to the development of suitable analytical procedures to determine the mass and chemical composition of the sampled dust collected in each stage. For gravimetric analysis, foams are weighed before and after sampling, as they serve both as selecting and dust-retaining media. Tests showed that the dependency on humidity is similar to membrane filters, and the SD of weighing is <0.1 mg. Using better controlled conditions, such as in a glove

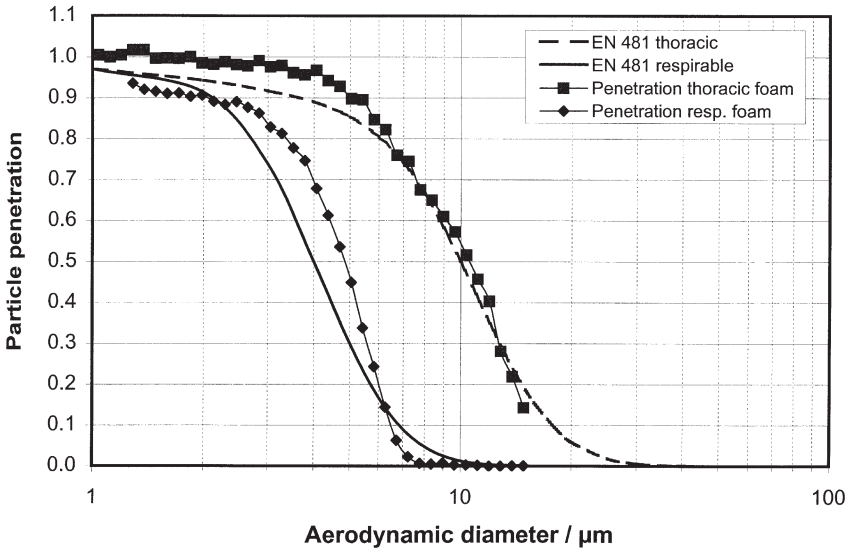

Fig. 3. Penetration of particles through foam plugs with selected geometry and porosity in a prototype sampler.

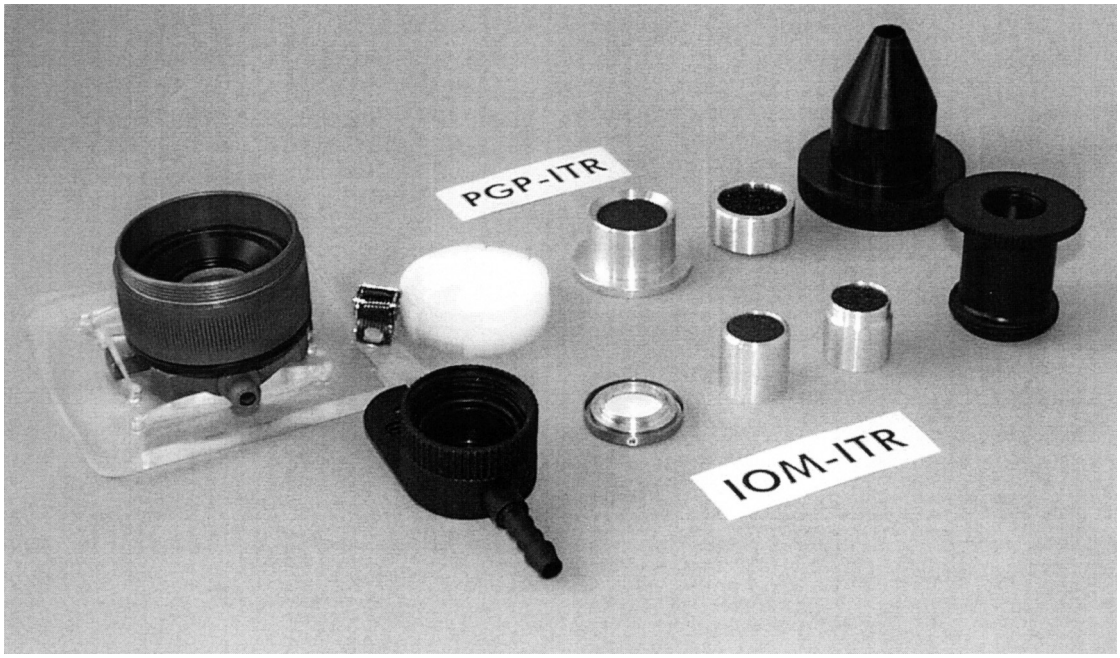

Fig. 4. Prototypes for three-stage dust sampling on the basis of the IOM and GSP inhalable samplers.

box, even one order of magnitude less can be reached. A limit of quantification is typically 0.6 mg. As a comparison, the typical limit of quantification of a membrane filter used in a GSP inhalable sampler by gravimetic analysis is 1 mg.

The chemical analysis of elements in the sampled dust can be performed using atomic absorption spectrometry or inductively coupled plasma with mass spectrometry with an acid digestion (HCl 25%, HNO_3 65%, 1:2) of the foam matrix, similar to standard procedures for membrane filters (BIA Folder, 2001). The foam material is sufficiently destroyed to reach the inner dust deposits. Because of high impurities in the polyurethane material, the analysis of calcium and tin is not recommended. In addition to the analysis of elements in dust loadings, the ability of sampling organic compounds is also investigated.

Prototype samplers

On the basis of the semi-empirical model, various plug geometries for the two size-selective foam plugs were chosen to fit into the modified IOM and GSP inhalable samplers. Penetration tests were conducted in the laboratory to show the applicability (Görner *et al.*, 2001) and match with the sampling conventions. Prototype samplers have been constructed and further field tests will be undertaken to provide information on the handling.

The three-stage samplers consist of two foam modules and one membrane filter in series (Fig. 4). By the appropriate choice of foam selection characteristics, a sampler of this type can collect the respirable fraction on the filter, the thoracic fraction on the filter plus the adjacent foam plug, and the inhalable fraction on the filter plus both plugs. The design details are to be discussed with potential manufacturers.

CONCLUSIONS

Porous polyurethane foam was found to be a suitable particle-selecting and sampling medium. The most important characteristic of a foam is its cell diameter, which can be measured sufficiently well. Appropriate geometries of foam plugs can be found with the help of penetration tests, so that the thoracic and respirable dust fractions can be separated in personal air samplers based on the IOM and GSP inhalable samplers. Weighing procedures can be applied to determine the mass loading of a foam. Standard elemental analyses are seen to be applicable after adaptation to the special needs of the polyurethane matrix.

At the end of the project, recommendations for subsequent use in different national air sampling systems shall be given in order to reach a higher degree of European harmonization in measuring occupational exposures.

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