

Broad Lane Sheffield S3 7HQ, UK
Telephone: +44 114 289 2606
Facsimile: +44 114 289 2850
Email: Lkenny@dust.demon.co.uk

**CHARACTERISATION OF POROUS FOAM SIZE SELECTORS
FOR THE CONICAL INHALABLE SAMPLER
L.C. Kenny and J.D. Stancliffe**

SUMMARY

An empirical model for particle through porous foam was used to calculate preliminary sizes and porosity of foam plugs capable of giving size separation according to PM10, PM2.5, Thoracic and Respirable conventions, at a flow rate of 3.5lpm. Cassettes for incorporating these foams within the cone of a Conical Inhalable Sampler (CIS) were designed and machined from aluminium. The foam-containing cassettes were tested experimentally using techniques previously developed to measure the size selection characteristics of cyclones and impactors. The size-dependent aerosol penetration through the foams was measured by taking samples alternately with and without each foam plug in line with the inlet of an Aerodynamic Particle Sizer (APS). The cassette designs and foam plug dimensions were optimised by repeating tests with different plugs until suitable dimensions had been identified.

With suitable preparation and analytical procedures, the modified CIS foam samplers developed can be used for personal monitoring of exposure to PM10, PM2.5, Thoracic and Respirable aerosol fractions. Some practical aspects of utilising the foam samplers are described in this report, although it must be stressed that as yet we have little practical experience of field sampling with foam samplers and hence some refinement of procedures is likely to be necessary in the future.

CONTENTS

1.0 INTRODUCTION

2.0 TEST METHOD

3.0 SELECTION OF INITIAL PLUG DIMENSIONS

4.0 RESULTS

5.0 UTILISATION OF THE FOAM SAMPLERS

5.1 Pre-treatment of PUFs

5.2 Inserting PUF plugs

5.3 Removing PUF plugs

5.4 Gravimetric analysis

5.5 Bioaerosol analysis

5.6 XRF and ICP-MS analysis

5.7 Loading effects and particle retention

6.0 REFERENCES

TABLES

FIGURES

1.0 INTRODUCTION

The conical inhalable sampler (CIS) is now accepted for the use as a personal inhalable sampler in the UK, and is described in MDHS14/2. HSL have carried out preliminary work to develop a cassette system for the sampler, containing two foam inserts in addition to the filter, which enables the sampler to be used for thoracic and respirable sampling in addition to inhalable sampling. The advantage of this approach to size-selective sampling is that the cost is very low, and all three fractions can be measured simultaneously. Similar work has been carried out to adapt foam size selectors to the IOM sampler. This work was presented at the 1997 Aerosol and British Occupational Hygiene Society conferences by HSL and has also submitted for publication in the AIHA journal.

The previous work indicated that it would also be possible to identify foams for selecting both the PM10 and PM2.5 fractions with the CIS, which would provide a low cost solution to personal sampling of environmental aerosols. The aim of the work reported here was to validate the foam plug specifications required for PM10 and PM2.5 sampling using the CIS, and also to provide optimal solutions for thoracic and respirable sampling. Although HSL have already published a description of a combination foam system for thoracic and respirable sampling using the CIS, the solution arrived at was not ideal because the thoracic foam was too flimsy and therefore presented handling difficulties.

2.0 TEST METHOD

The experimental methods used to test and optimise the foam plugs are broadly similar to those described in detail by Maynard and Kenny (1994). Tests were carried out in a calm air chamber with working section 1m^3 . The test aerosol consisted of solid, spherical glass microspheres (Whitehouse Scientific) with diameters between 1 and $24\mu\text{m}$, and density $2.45\text{g}/\text{cm}^3$. The size selection characteristics of each foam plug (or plug combination) was measured by taking five or seven 60-second samples of the polydisperse aerosol, alternately with and without the foam plug in the sampling line to the APS. All samples were taken through a modified CIS sampler with cassette, however in the 'reference' line the foam plugs were not included in the cassette, and in the 'foam' line, the plugs were included. Hence the comparison between the aerosol size distributions measured using each line gives the size selective properties of the foam plug alone, all other effects being the same in both lines. Stancliffe and Kenny (1997) have shown that the use of PUF holding cassettes within the CIS cone does not adversely effect the inhalable characteristics of the sampler. This system is able to measure the D_{50} of an aerosol sampler with an accuracy of approximately $\pm 0.2\mu\text{m}$.

3.0 SELECTION OF INITIAL PLUG DIMENSIONS

Initial foam plug specifications likely to yield the desired aerosol selection characteristics were identified using the empirical model for porous foam penetration derived by Vincent et al (1993). The constraints imposed were that the flow rate should be 3.5 lpm in all cases, and the plug dimensions should be small enough to fit within the CIS. For selection according to PM10 and PM2.5 criteria the cut point or D_{50} should be as close as possible to 10.0 and $2.5\mu\text{m}$, whereas for

respirable and thoracic selection the curve selected should minimise sampling bias over a range of possible aerosol size distributions. Previous experience with designing foam-based samplers suggested that the empirical model was likely to over-estimate the D_{50} by up to 30%, and this was taken into account in the calculations.

4.0 RESULTS

The D_{50} values measured for the various plugs tested, from the initial PUF plug selections to the final recommended solutions, are summarised in Table 1. The 30 ppi foam plugs chosen initially for PM10 and thoracic selection did not provide satisfactory data with which to determine the D_{50} values. It is thought that the open structure of and low thickness of these plugs led to poor particle retention and hence inconclusive data at particle sizes greater than 10 μm . This problem was addressed by changing to 45 ppi foam plugs which also required an increase in the plug diameter and thickness and therefore an alteration in the shape of the cassette. The 45 ppi foams provided satisfactory data with which to determine the D_{50} values for PM10 and Thoracic aerosol selection. Repeat tests were carried out on the optimal plugs in order to verify the reproducibility of the results and these are highlighted in Table 1. Figures 1 to 3 give diagrams of the final cassette configurations for PM2.5, PM10, and combined Thoracic/Respirable sampling. Examples of typical aerosol penetration curves for the recommended solutions are shown in Figures 4 to 6.

5.0 UTILISATION OF THE FOAM SAMPLERS

PUF inserts function as aerosol size selectors. Where a PM2.5 PUF selector is used the PM2.5 fraction is collected on the filter and aerosols greater than 2.5 μm in diameter are collected by the PUF. Where a PM10/Thoracic PUF selector is used the PM10/Thoracic fraction is collected on the filter and aerosols greater than 10 μm in diameter are collected by the PUF. Where twin foam Respirable PUF selectors are used the Respirable fraction is collected on the filter, the Thoracic fraction is collected by the filter and the second foam (90 ppi) and the Inhalable fraction is collected by the filter and both foams together. Hence in all cases where the foam cassette is used, the inhalable fraction is determined by weighing (or otherwise analysing) both the filter and the foams. Where only the PM10, PM2.5 or respirable fraction is to be determined then only the filter should be analysed. For the Thoracic/Respirable combination sampler, both the filter and the second foam should be analysed to obtain the thoracic fraction.

5.1 Pre-treatment of PUFs

The quality of particle size selection and the weight stability of PUF plugs can both be improved by first removing any impurities left over from the manufacturing process. Untreated foams may contain residues that increase the variability of the PUF particle size selection and also increase water vapour absorption from the atmosphere. The treatment process used at HSL involves placing the foams in approximately 10 times their volume of distilled water and then processing them in an ultra sonic bath for 20 minutes. The foams are then thoroughly rinsed in approximately 10 times their volume of distilled water a further 3 times before being dried at 70°C. The treated foams should be stored in a clean and preferably air conditioned environment.

5.2 Inserting PUF plugs

The PUF plugs should be carefully inserted into their respective cassettes so that any creasing or folding is avoided. The PM10/Thoracic selector foam is 10mm deep whilst the portion of the cassette designed to accept it is 8mm deep. In this case the 'overflow' of the foam from the top of the cassette is acceptable since the inside surface of the sampler cone will enclose it. It is very important that the lower surfaces of the PM2.5 and Respirable (foam2) selector foams are not allowed to come into physical contact with the filter - at least 1 mm spacing is recommended. The twin foams Respirable selectors, especially, should be checked for this once loaded. Ideally the PM 2.5 selector foam should be placed in the middle of the tubular cassette. PUFs should be inserted using clean, sterilised, tweezers and plastic gloves if they are to be chemically analysed following sampling.

5.3 Removing PUF plugs

If, following sampling, the PUFs require removal from their cassettes prior to analysis then clean, sterilised, tweezers and plastic gloves should be used to remove them. Where two PUFs are used in the same cassette, as in respirable sampling, then the foams should be extracted in opposite directions to reduce cross contamination of the fractions.

5.4 Gravimetric analysis

If the PUFs are to be used for gravimetric analysis, HSL recommends that before sampling they should be pre-treated as described in 5.1 and then conditioned in a well controlled environment before pre-weighing. A minimum of three blanks should always be used, and these blanks should be loaded into sampling heads and taken to the sampling site alongside the samplers to be used. Following sampling the exposed PUFs should be re-conditioned in a well controlled environment before re-weighing. The PUFs can be removed from their cassettes before weighing, but in order to reduce handling it is preferable for them to be weighed in their cassettes.

At present it is not known exactly how long the PUFs take to reach equilibrium with the environmental conditions in the balance room. As a minimum we would recommend a conditioning time of 12 hours, although it should be noted that for the CIP10 sampler (which uses larger foams), 72 hours is recommended.

5.5 Bioaerosol analysis

Prior to use for bioaerosol sampling PUF foams must be sterilised. This can be performed by using overnight soaking in ethanol or by use of a standard UV sterilisation method. Soaking in ethanol can result in the PUF becoming rigid and therefore increasing the risk of the foam plug falling out of the sampling cassette. UV sterilisation does not damage the PUF structure. PUFs are unsuitable for sterilisation by autoclaving. Sterilised PUFs may then be placed in sterilised cassettes which are installed in the sampler heads on site (use plastic gloves) and then placed in sterile plastic bags for transportation to the sampling site. Exposed cassettes may then be removed from the sampler heads and placed in sterile plastic bags for transportation. Alternatively, the foams and filter may be removed from the cassette using tweezers and placed in Peptone Inositol Tween (PIT - a biological buffer) solution for transportation.

5.6 XRF and ICP-MS analysis

PUFs may then be analysed directly using X-ray fluorescence spectroscopy, or by inductively coupled plasma mass spectroscopy following washing, ashing or dissolution of the foam matrix. In both cases a suitable number of blanks should be used, and the foams should be pre-treated as described in 5.1.

5.7 Loading effects and particle retention

Little is presently known of how PUF particulate loading affects the particle size selection characteristics of the insert. However it has been established that during the sampling of welding fume the D_{50} of the PUF will gradually decrease as the particulate loading increases. The extent to which these loading effects are dependent on particle type has not yet been investigated. Likewise the ability of foams to retain particulate during rough handling after sampling has not yet been quantified. It is therefore strongly recommended that PUF foams are not reused, even if re-washed, and that they are transported carefully from the sampling site.

6.0 REFERENCES

Maynard, A.D. and Kenny, L.C. (1995). Performance assessment of three personal cyclone models, using an Aerodynamic Particle Sizer. *J. Aerosol Sci.*, 26(4), 671-684.

Stancliffe, J.D. and Kenny, L.C. (1997). Sampling characteristics of modified personal inhalable sampler inlets. *J. Aerosol Sci.*, 28(S1), 601-602.

Vincent, J.H., Aitken, R.J. and Mark, D. (1993). Porous plastic foam filtration media: penetration characteristics and applications in particle size-selective sampling. *J. Aerosol Sci.*, 24(7), 929.

TABLES

Table 1: D₅₀ values measured for the PUF plugs tested.

Desired Aerosol Selection	PUF Porosity (ppi)	PUF Diameter (mm)	Cassette Diameter (mm)	PUF Depth (mm)	D50 (um)
PM2.5	90	10.5	10.0	15.0	2.5
	90	10.5	10.0	15.0	2.3
	Mean				2.4
PM10/ Thoracic	30	15.5	15.0	8.0	~11.5
	30	15.5	15.0	9.0	~11.0
	30	15.5	15.0	10.0	~10.0
	45	15.5	15.0	5.0	~10.0
	45	21.0	20.0	10.0	~11.5
	45	26.0	20.0	10.0	9.0
	45	24.5	20.0	11.0	8.8
	45	24.5	20.0	10.0	9.8
	45	24.5	20.0	10.0	10.2
	Mean				10.0
Respirable (Two foams in series)	45	24.5	20.0	10.0	With
	90	17.5	15.5	6.0	4.5
	45	24.5	20.0	10.0	With
	90	17.5	15.0	6.0	4.3
	45	24.5	20.0	10.0	With
				4.3	
	Mean				4.3

FIGURES

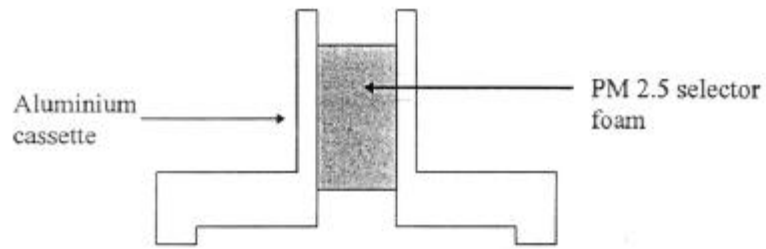


Figure 1 : Cassette holding a PUF for PM 2.5 aerosol sampling.

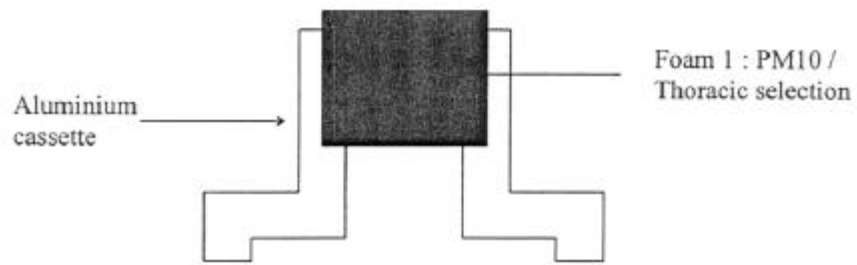


Figure 2 : Cassette holding a PUF for PM10 / CEN thoracic aerosol sampling, (note the slight 'overflow' of foam1).

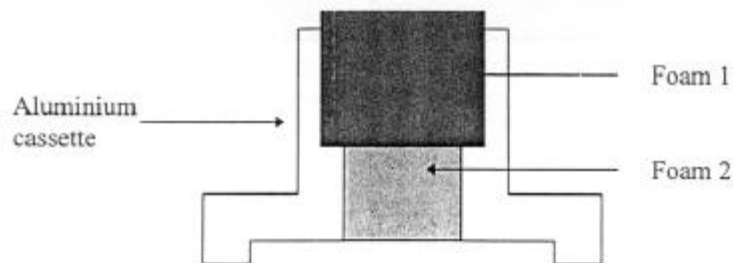


Figure 3: Cassette holding twin PUFs for CEN Respirable aerosol sampling, (note the slight 'overflow' of foam1).

Figure 4 : PM 2.5 Aerosol size selection
90ppi, 10.5mm diameter (10.0mm cassette), 15.0mm deep,
 $d_{50} = 2.4 \mu\text{m}$

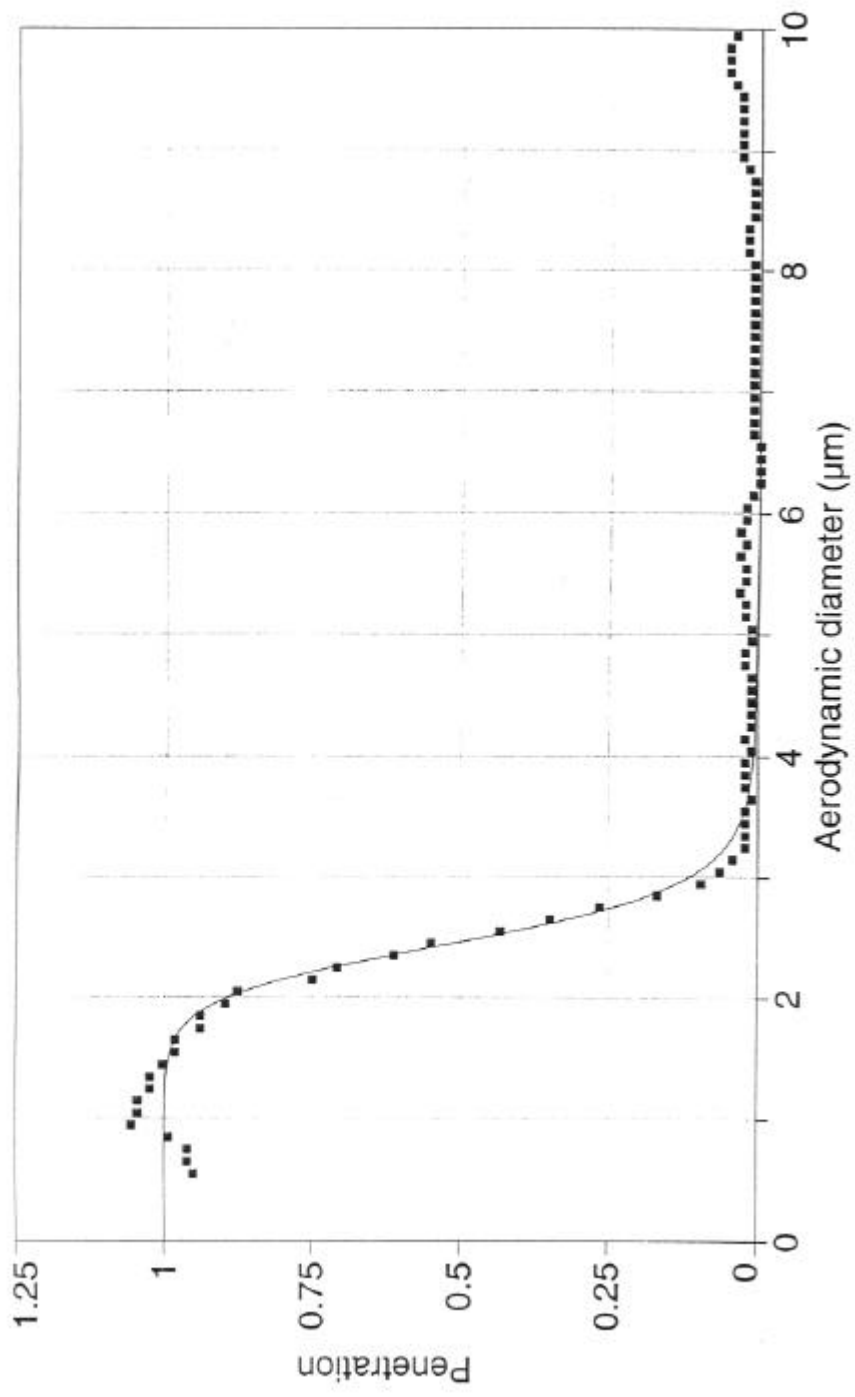


Figure 5 : PM 10/Thoracic Aerosol size selection
45 ppi, 24.5mm diameter (20.0mm cassette), 10.0mm deep,

$D_{50} = 10.2 \mu\text{m}$

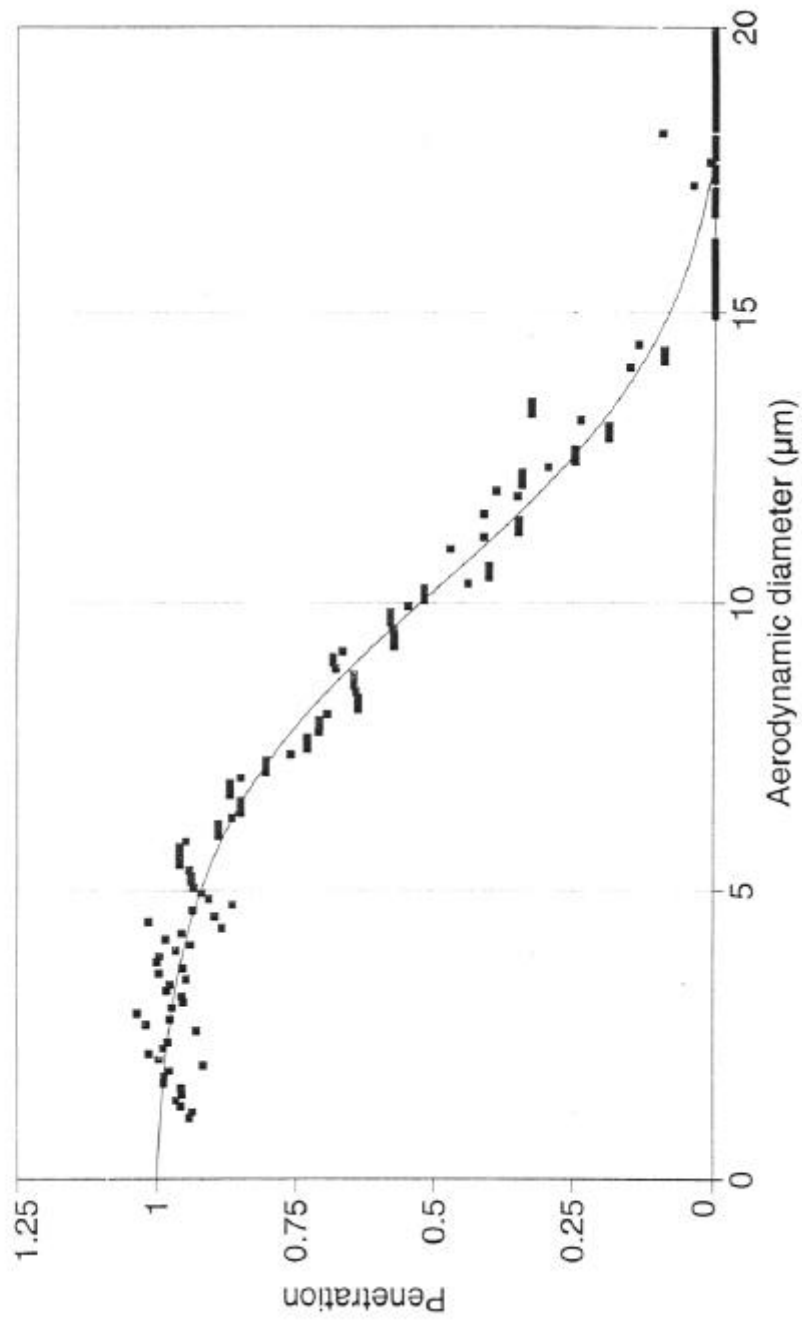


Figure 6 : Respirable Aerosol size selection
45 ppi, 24.5mm diameter (20.0mm cassette), 10.0mm deep and
90 ppi, 17.5mm diameter (15.0mm cassette), 6.0mm deep,

