REPORT FOR RUPPRECHT AND PATASHNICK Co.. Inc.

CHARACTERISATION OF POROUS FOAM SIZE SELECTORS USING POLYDISPERSE AEROSOLS

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SUMMARY

An empirical model for particle penetration through porous foam was used to calculate preliminary sizes and porosities of foam plugs capable of giving size separation according to PM10, PM2.5 and respirable conventions, at a flow rate of 2 lpm. These foam plugs were tested experimentally using techniques previously developed to measure the size selection characteristics of cyclones and impactors. The tests were carried out in a calm air chamber with an aerosol of polydisperse glass microspheres. 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 foam plug dimensions were optimised by repeating tests with plugs of different thickness until suitable dimensions had been identified. For the optimum plug sizes, tests were carried out with the foam plugs in three different orientations in the calm air chamber, and at three flow rates. The results showed that although the empirical model had underestimated the D50 obtained for the initial foam plugs tested, the experimental optimisation process allowed suitable plug dimensions and porosities to be identified.

SELECTION OF INITIAL PLUG DIMENSIONS

Vincent et al. (1993) derived the following empirical model for foam penetration:

$$\ln(P) = -\frac{t}{\left(0.009633 po^{-1.216}\right)}\left\{54.86 St^{2.382} + 38.91 Ng^{0.880}\right\}$$

Where P is penetration, t is the foam plug thickness, po is the porosity in pores per inch, St is the inertial parameter and Ng the gravitational parameter:

$$St = \frac{d_{ae}^2 \gamma U}{18 \eta d_f} \qquad\qquad Ng = \frac{d_{ae}^2 \gamma g}{18 \eta U}$$

Here d_{ae} is the aerodynamic diameter, γ the density of water, η the viscosity of air, U the velocity of air through the foam, g the acceleration due to gravity and d_f the equivalent 'fibre' diameter of the porous foam. The data used to derive the model were for 30 ppi and 60 ppi foams, measured at air velocities from 1 to 26 cm s^{-1}, but the model is also a reasonable fit to data from other authors, covering a range of foam porosities up to 100 ppi. The model applies only to penetrations measured with foam plugs orientated horizontally.

This model was used to select the initial plug sizes and porosities tested. The constraints imposed were that the flow rate should be 2 lpm in all cases, and if possible all three plugs should have the same diameter. The plugs should be sufficiently thick to permit easy handling. For selection according to PM10 and PM2.5 criteria the cut point or D50 should be as close as possible to 10 or 2.5 µm, whereas for respirable selection the curve selected should minimise sampling bias over a range of possible aerosol size distributions. The preliminary plugs identified were as follows: for PM10, 30 ppi foam, 15 mm in diameter and 18 mm thick; for PM2.5, 90 ppi foam, 10 mm in diameter and 25 mm thick; for respirable, 90 ppi foam, 15 mm in diameter and 10 mm thick. It was not possible to find suitable solutions that allowed all three fractions to be selected with plugs of the same diameter.

EXPERIMENTAL METHODS

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 1 m^3. The test aerosol consisted of solid, spherical glass microspheres (Whitehouse Scientific) with diameters between 1 and 24 µm. The density of the particles was 2.45 g/cm^3. The size distribution of the aerosol ensured that errors in the estimated penetration, due to counting uncertainties, were less than 1% at particle aerodynamic diameters up to 9 µm; measurements at larger diameters (up to 20 µm) were subject to greater uncertainty but useful results could still be obtained in this range. The concentration in the test chamber was generally kept below 150 $particles/cm^3$, in order to reduce coincidence effects in the APS. Phantom particles generated by the APS were subsequently removed by the data processing software. The aerosol was introduced and well mixed at the top of the calm air chamber and a very slow, steady flow towards the working section induced by balancing the inlet and extraction systems. Eddies were removed by a layer of aluminium honeycomb between the mixing and measuring zones. Electrostatic effects were minimised by introducing ions to the aerosol, both from a Kr^{85} source and a corona discharge ion generator.

The penetration through each foam plug was measured by taking five 40- or 60-second samples of the polydisperse aerosol, alternately with and without the foam plug in the sampling line to the APS. The APS data were stored and the penetrations subsequently calculated using the APS’s Large Particle Processor (LPP) data. Counts from the LPP for aerodynamic diameters between 1 and 20 µm were placed into suitable size intervals, and the penetration in each interval obtained by comparing the average counts for the background aerosol in the chamber, with average counts sampled through the foam plug.

Three sampling tubes were used between the APS and the calm air chamber to enable the effects of orientation to be measured. The foam plugs fitted closely into a cassette at one end of the tube which faced either upwards, horizontally or downwards in the calm air chamber. In the upwards-facing direction, particle sedimentation was acting in the same direction as the air flow, and in the downwards facing direction, against the air flow.

The plug dimensions were optimised by testing plugs of increasing thickness, in horizontal orientation only and at a flow rate of 2 lpm, until a suitable result was obtained. Three thickness values were tested for each sampling convention. For the optimised plug sizes, tests were then carried out with the foam plugs in upwards and downwards-facing orientations. For plugs in horizontal orientation only, tests were repeated at two different flow rates, 1.8 and 2.2 lpm. Repeat tests on different plug specimens were also carried out and showed very good reproducibility.

RESULTS AND CONCLUSIONS

The initial plugs chosen using the empirical model had larger D50 values than expected from the model, necessitating a considerable increase in plug thickness in order to match the sampling conventions. The final dimensions shown in Table 1 have D50's close to the required values. In the case of the PM10 foam the D50 values are less precise, owing to statistical errors in the data. Typical penetration data for these foam plug sizes are shown in the attached figures.

Orientation effects were negligible for the PM2.5 foam, and produced shifts in the D50 of the order of 0.25 µm for the respirable foam, and 0.3 µm for the PM10 foam. Flow rate effects were small for the PM2.5 foam and respirable foams (~0.15 µm), but much larger for the PM10 foam (~0.75 µm). In general the results at 2.2 lpm were closer to the desired D50's than at 2 lpm, but the optimum flow rate would probably be 2.1 lpm (in order to get the best PM10 result).

Table 1: Foam dimensions identified from this experiment

(D50's apply to horizontal orientation only)

	PM2.5 foam	*Respirable foam*	*PM10 foam*
Porosity (ppi)	90	90	30
Diameter (mm)	10	15	15
Thickness(mm)	30	20	30
D50 at 2 lpm	2.75 µm	4.7 µm	10.6 µm
D50 at 2.2 lpm	2.6 µm	4.55 µm	8.9 µm
Orientation effect	negligible	± 0.25 µm	± 0.30 µm

REFERENCES

Maynard, A.D and Kenny, L.C (1995)
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Vincent, J.H, Aitken, R.J and Mark, D (1993)
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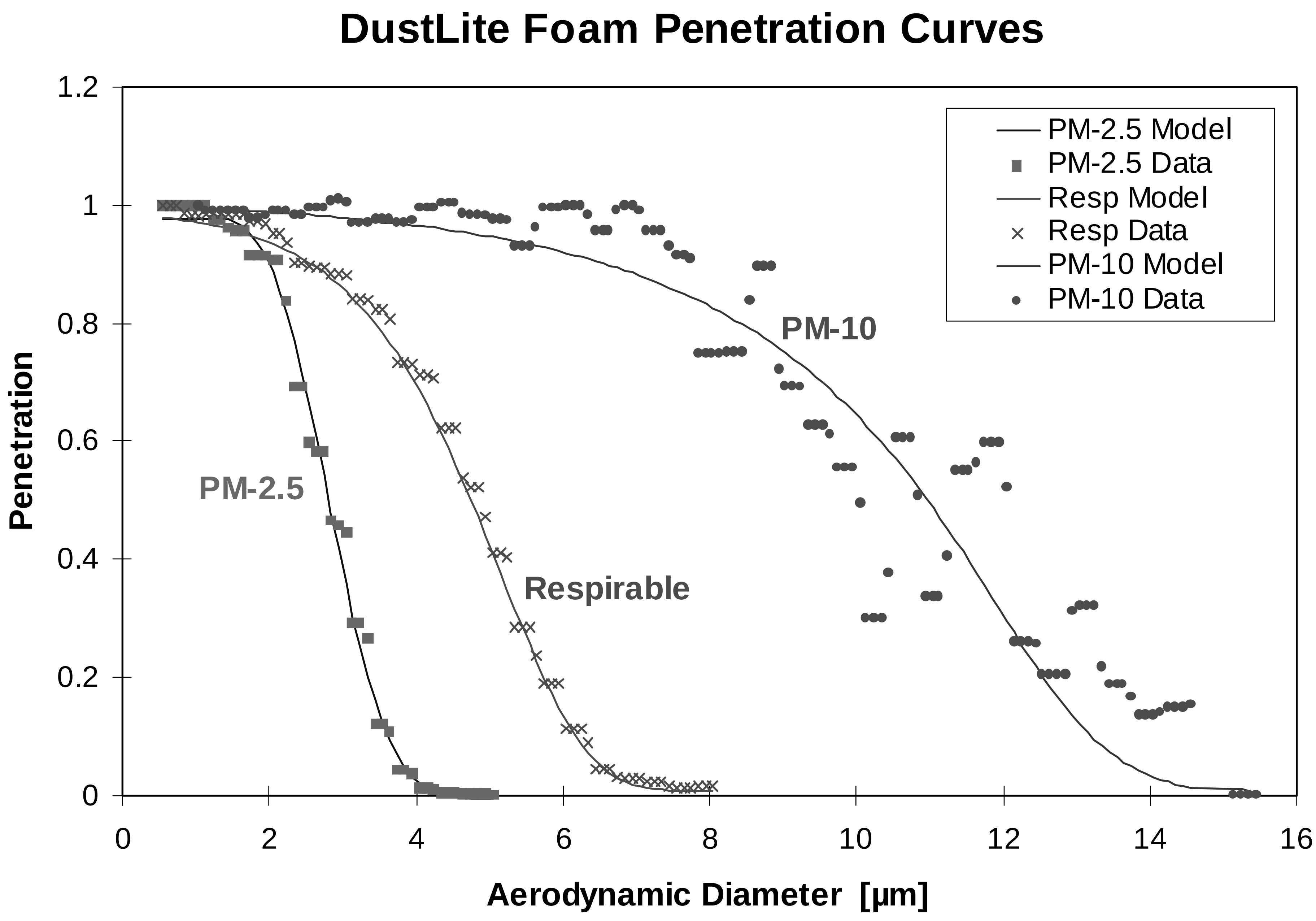
DustLite Foam Penetration Curves
Penetration
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
14
16
Aerodynamic Diameter [µm]
PM-2.5 Model
PM-2.5 Data
Resp Model
Resp Data
PM-10 Model
PM-10 Data
PM-2.5
Respirable
PM-10