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

INVESTIGATION OF THE EFFECTS OF LOADING ON PM2.5 SELECTORS

L C Kenny

IR/L/A/98/13

Project Leader: L C Kenny
Biomedical Sciences Group

HEALTH AND SAFETY LABORATORY
An agency of the Health and Safety Executive

DISTRIBUTION

Rupprecht and Patashnick Co. Inc.

BGI Inc.

Dr H K Wilson

Archive

RESTRICTED - COMMERCIAL

This report and the work it describes were undertaken by the Health and Safety Laboratory under contract to Rupprecht and Patashnick Inc. Its contents, including and opinions and/or conclusions expressed, do not necessarily reflect Health and Safety Executive policy.

Issue Authorised by Dr H K Wilson

Date of issue: October 1998

Job Number: C51.010.98

Registry File:

Word File: C5110-98.doc

Figures: C5110-98.ppt

SUMMARY

Four different PM2.5 selectors were tested to determine their aerodynamic size-selection characteristics, both before and after loading with dust, under laboratory and field conditions. The aerosol penetration curves were measured using an Aerodynamic Particle Sizer. Many repeat tests were performed on two specimens of the Well Impactor Ninety Six (WINS), two specimens of a novel sharp cut cyclone (SCC), one member of the GK cyclone family (GK4.39) and one University Research Glass (URG) cyclone.

Four loadings of the WINS and SCC were made in the laboratory using a narrow-fraction alumina dust. The penetration curves were measured after each loading. Five cumulative outdoor loadings were made by setting up four PM2.5 samplers, two with WINS and two with SCC's, in a suburban garden during the summer months. The penetration curves were measured at weekly intervals after sampling times ranging from 96 to 132 hours. Three further cumulative loadings were tested in a similar experiment in a city-centre underground car park.

When clean, all three PM2.5 size selectors have 50% penetration (D_{50}) values close to 2.5 µm, although the penetration curve shape differs for the three selector designs. Under loading the D_{50} value for both the WINS and SCC fell, with the decrease being largest for the WINS. With high loadings the SCC D_{50} fell to 2.35 µm and the WINS D_{50} fell to 2.15 µm. The WINS deviation is large enough to possibly lead to undersampling of PM2.5.

The SCC cyclone provides a sharp cut for ambient air sampling applications and is less affected than the WINS by loading. Additionally, the SCC is a dry system whereas the WINS uses an oiled substrate. While the WINS cut point is unlikely to shift to an unacceptable degree during 24 or 96 hour sampling periods, it would perform less well than the SCC over extended sampling periods.

CONTENTS

1. INTRODUCTION

Aerosol samplers for ambient PM2.5 typically utilise either impactors or cyclones to effect the aerodynamic particle size selection. In this work, Rupprecht and Patashnick Co. Inc. (R&P) asked the Health and Safety Laboratory (HSL) to determine the feasibility of developing a lower maintenance, higher loading sharp cut point selector for use with continuous PM monitors. This was to be accomplished by testing four different PM2.5 selectors, two pre-existing commercial designs and two novel cyclone prototypes developed by BGI Inc. The purpose of the work was to assess the characteristics of the novel cyclones, finalise the design, and to assess the effects of dust loading on the different types of selector. The work was carried out collaboratively by HSL, R&P and BGI.

The EPA requirements for an ideal PM2.5 selector are contained in the US Federal Register (USEPA, 1997. The Federal Register tabulates the desired aerodynamic size selection curve and requires that any PM2.5 sampling device should have a 50% penetration value (or cut-point) of 2.5+0.2 µm, and sampling bias for PM2.5 concentrations less than 5%. The sampling bias is calculated numerically for three specified ambient aerosol size distributions, designated ‘fine’, ‘typical’ and ‘coarse’, details of which are also given in the Federal Register. Hence the characteristics of any real sampling device can be tested against these criteria to determine whether it’s performance meets the required standard.

2. DESCRIPTION OF PM 2.5 SELECTORS TESTED

2.1 WINS impactor

The Well Impactor Ninety Six (WINS) impactor is described in the Federal Register and forms part of the designated PM2.5 Federal Reference Method (FRM). The design of the WINS Impactor is shown in cut away view in Figure 1. One of the principal features of the WINS Impactor is that it contains a well into which is placed a 37mm disc of fiberglass filter media and 1 ml of a low vapor pressure mineral oil, both of which are specified in the FRM. Concerns have been expressed as to the maximum interval between cleanings of the impactor well before a shift in the D_{50} cut will occur. The time factor is of concern because sequential PM2.5 samplers are intended to run without maintenance for 4 (USA) to 16 days (EUROPE); if the D_{50} shifts a false concentration will be indicated. The presence of the oil may also effect speciation sampling, in which the major chemical species present in the PM2.5 aerosol are separated and quantified. Whilst there is no proven deleterious effect that is proven to occur when passing an aerosol over a pool of low volatility oil prior to subjecting the particles to chemical analysis, the concern does exist.

The WINS impactor was tested during its development by EPA contractors (Peters and Vanderpool, 1996) who measured it's aerodynamic size selection characteristics both before and after loading. The cut point or D_{50} was shown to shift downwards under load to 2.25 µm, but the effect of the shift on PM2.5 sampling bias was just within the acceptable limits.

2.2 GK cyclone

The most logical alternative to an impactor as a size selective collection device is a cyclone. Indeed two cyclone designs were considered by EPA during the development of the WINS Impactor (Peters et al., 1996). Both of these designs were rejected by the investigators as being unsuitable for EPA purposes, due to either a cut point shift when loaded, or an insufficiently sharp cut.

These findings notwithstanding, it was felt that cyclones deserved further investigation. Early work for EPA on stack sampling produced a series of round entry cyclones of intriguing characteristics with regards to the steepness of their efficiency curves (Smith et al., 1979). Several of these round entry designs were evaluated by Kenny and Gussman (1997) and a model describing a family of cyclones - GK cyclones - was derived and successfully applied to the design of several cyclones for various air sampling applications. A prototype GK cyclone, designed to fit within a PM2.5 FRM sampler as a direct replacement for the WINS, was manufactured for testing within this project. The dimensions of this cyclone are given in Table 1.

2.3 SCC cyclone

The Sharp-Cut Cyclone developed within this project was based on the design of the SRI-III cyclone described by Smith et al. (1979). Two differently-sized cyclones based on the SRI-III geometry were tested previously by Kenny and Gussman (1997). For PM2.5 sampling applications, the dimensions of the SRI-III were scaled up as suggested by the previous results in order to achieve the required cut point (D_{50}=2.5 µm) at a flow rate of 16.7 $l.min^{-1}$. Following initial favourable test results, prototype SCC cyclones were fabricated that could be fitted within FRM samplers as an exact mechanical replacement for the WINS impactor. A cut-away drawing of the SCC is shown in Figure 2, and its dimensions are given in Table 1.

2.4 URG cyclone

The URG cyclone is based on the Stairmand design described and evaluated by Moore and Mc Farland (1993), and its dimensions are listed in Table 1. The cyclone is commercially available as an attachment for R&P's Tapered Element Oscillating Microbalance (TEOM) sampling system. One difference in the way the URG cyclone is used is that it is fitted as a replacement for the usual TEOM PM10 inlet, whereas the WINS impactor (and the SCC cyclones) are designed to be fitted downstream of the PM10 inlet. In principle this should have no effect provided that particles in the sub-2.5 µm range are aspirated with unit efficiency by both systems. However this assumption has not yet been validated by either wind tunnel or outdoor comparisons of the two systems.

3. EXPERIMENTAL METHODS

3.1 Determination of aerosol penetration curves

The experimental methods used to test the PM2.5 selectors were similar to those described in detail by Maynard and Kenny (1994). The tests were carried out in an aerosol chamber with working section 1 m^2. The test aerosol consisted of solid, spherical glass microspheres (Whitehouse Scientific) with physical diameters up to 25 µm, and density 2.95 g/cm^3. The aerosol was dispersed using a rotating brush generator into the separate mixing section at the top of the chamber. An aluminium honeycomb layer was used to remove eddies from the aerosol which was transferred into the working section by a slow (<2 $cm.sec^{-1}$) steady downflow of air. The generated aerosol typically had a number median diameter around 2 µm and a mass median diameter around 8 µm. The number concentration was typically 100-200 particles per cubic centimetre, and was very stable over the time scales necessary for the test (10 minutes per selector).

The test sampling lines were situated close to the centre of the chamber's working section, connected to an Aerodynamic Particle Sizer (APS) via two 15mm diameter vertical metal tubes. The APS was situated directly below the working section, outside the chamber. Access to the working section was gained through sealed glove ports in the side of the chamber, which allowed the flow through each test selector to be measured accurately using a Gillibrator bubble flowmeter placed inside the chamber. The flow through the system was maintained using a mass flow controller, calibrated and set before and after each test using the Gillibrator.

The test procedure involved placing a PM2.5 selector on one of the two sampling lines. Both sampling lines to the APS shared identical geometry and switching from one to the other was accomplished by means of ball valves. The size selection characteristics were measured by taking five 60-second samples of the polydisperse aerosol alternately from the two sampling lines. Hence the ratio of the aerosol size distributions measured through each line gives the size selective aerosol penetration through the selector alone, all other effects (including any aspiration and transfer losses) being identical in both lines.

Accumulator data files from the APS were stored and transferred to a separate PC for processing. A dedicated Pascal programme was used to reconfigure the particle counts in the 1024 APS accumulator channels into a histogram with selected aerodynamic diameter bin limits. The calibration function relating APS accumulator channel to particle aerodynamic diameter was derived using the calibration data file for the APS, taking into account the appropriate corrections for particle density. At the start of each working day the APS calibration was checked at three particle diameters, (3, 5 and 10 µm) using latex spheres traceable to Community Bureau of Reference (BCR) standards. The APS operating parameters were adjusted using the methodology described by Radar *et al.* (1990) to ensure that the actual calibration was in close agreement with the calibration data file.

For each aerodynamic diameter range, the average particle number counted with the selector present was divided by the average number counted without the selector present to determine the aerosol penetration for that diameter. The penetration values were analysed using the software package 'Tablecurve' (Jandel Scientific) in order to locate the D_{50} by interpolation. The raw data were normalised so that the penetration values tended to unity for d_{ae}=0. Normalisation is necessary with this test system as the pressure drop across the selector causes the flow rates through the two sampling lines to differ slightly when the valve system is switched. In all cases it was assumed that any departures from unity were anomalous, and a suitable scaling factor for the penetration axis was used to eliminate them. Very little correction was required when testing the cyclones, which have a much lower pressure drop than the WINS impactor.

3.2 Laboratory loading experiment

Controlled loadings of the WINS and SCC size selectors only were made in a separate aerosol chamber. The dust used for loading was an aluminium oxide grinding powder, Aloxite F1200, which is known to have a MMAD around 6 µm and GSD of around 1.4 (Mark and Witherspoon, 1985). Hence almost all the particle mass is contained within an aerodynamic particle size range of 3 to 9 µm. For each loading test a single WINS impactor, a single SCC cyclone and a reference sharp-edged probe with 37mm glass fibre filter were set up within the chamber. Teflo filters were used downstream of the selectors to capture any under-size particles. The SCC and WINS flow rates were set to 16.7 lpm using a calibrated bubble flow meter, whereas the reference probe was operated at 10 lpm. The aloxite dust was generated into the chamber using a rotating table generator and mixed to produce a homogenous aerosol at the sampling positions.

The quantities of dust collected within the PM2.5 selectors were estimated by weighing all filters, plus blanks of each type, before and after sampling. The weight changes on the SCC and WINS filters were indistinguishable from the blank weight changes, indicating that all the aspirated particles were retained within the selectors. The best estimate of mass loading within the PM2.5 selectors was therefore calculated by scaling the reference filter loading for the difference in flow rates.

After each loading the PM2.5 selectors were re-tested using the APS system to re-measure the particle size selection curve. The cycle of loading and testing was repeated for four different dust loadings, ranging from 0.4 to 4.5 mg.

3.3 Garden loading experiment

Five cumulative outdoor loadings were made by setting up four PM2.5 samplers, two R&P Partisol samplers and two BGI PQ200 samplers, in a suburban garden during the summer months. One of the Partisol samplers contained a WINS impactor, and one contained an SCC cyclone. Likewise, one WINS and one SCC were used in the PQ200 samplers. Both the Partisol and PQ 200, when used with the WINS, are US EPA designated, single channel refrence samplers. A schematic diagram of the sampling site is shown in Figure 3.

Clean pre-weighed 2 µm Teflo filters were used in the samplers for each run. The instruments were set up to sample continuously for periods ranging from 96 to 132 hours. At the end of each sampling period the filters were conditioned and re-weighed to assess the PM2.5 concentration. The PM2.5 selectors were carefully transported to the laboratory for re-measurement of their aerosol penetration curves, and then replaced in the samplers without cleaning. Hence over a five week period the change in D_{50} was monitored with cumulative loading of the selectors. At the end of the experiment, the selectors were cleaned and the aerosol penetration curves re-measured.

3.4 Car park loading experiment

Three further cumulative loadings were made by setting up the four PM2.5 samplers in a city-centre underground car park, open to the atmosphere during the day via large doors, but sheltered from winds. Clean pre-weighed 2 µm Teflo filters were used in the samplers for each run. At the end of each sampling period were conditioned and re-weighed to assess the PM2.5 concentration. The PM2.5 selectors were carefully transported to the laboratory for re-measurement of their aerosol penetration curves, and then replaced in the samplers without cleaning. The first week of this experiment showed very low PM2.5 concentrations, and it was continued in the second and third weeks with only two samplers, operated without their PM10 inlets. One sampler used the WINS and one was fitted with the SCC. This would subject the PM2.5 selectors to higher concentrations of large particles, normally removed by the PM10 inlet. At the end of the experiment, the selectors were cleaned and the aerosol penetration curves re-measured.

As a final test, the two samplers were run for one further week with one PM10 inlet in place and one removed, to check whether this had any effect on the apparent PM2.5 concentration.

4. RESULTS

4.1 Penetration curves for clean selectors

Table 2 summarises the number of penetration curve measurements obtained for each clean selector type during this project. The mean and standard deviation of the D_{50} values for each clean selector is shown. The averaged penetration curve for each selector is shown in Figure 4, along with the 'ideal' WINS curve as published in the FRM.

The large number of replicate measurements allows the precision of the test method to be assessed. Table 2 shows that the method allows determination of the D_{50} to within $\pm$ 0.7 µm. Obviously the precision of results obtained on the same test day is better, but this figure is a realistic estimate of the true repeatability of the method. Any systematic differences between individual selector specimens are too small to be detected.

4.2 Shifts in aerosol penetration after laboratory loadings

The results of the laboratory loading experiment are shown in Figure 5, which plots the selector D_{50} as a function of loading within the selector (as determined from the separate reference filter sample). Only one selector penetration curve was measured at each loading, which means that the D_{50} values can be measured to $\pm$ 0.0.07 µm. D_{50} values below 2.4 µm may be considered to represent a significant decrease from the 'clean' value.

The loading was seen to cause a hummock-like deposit to build on the WINS substrate. With the SCC cyclone, a diffuse deposit was spread over the whole interior of the cyclone, with only small amounts of material reaching the grit pot.

4.3 Shifts in aerosol penetration after outdoor loadings

The results from the garden experiment are summarised in Table 3, and plotted as D_{50} versus cumulative PM2.5 sampled mass in Figure 5. Again, only one selector penetration curve was measured at each loading, which means that the D_{50} values can be measured to $\pm$ 0.07 µm.

The actual loading of dust inside the PM2.5 selectors is not known for this experiment. However, it can be assumed that since the sampling location is remote from pollution sources, the aerosol is likely to be very fine, and hence most of the PM10 will also be PM2.5. Observation of the WINS substrates after five weeks of sampling suggested that the loading was not greater than the mid-range of the laboratory experiment. The WINS deposit was also more diffuse during the garden loading experiment, and the SCC deposit concentrated more towards the lower part of the cyclone. These observations support the assumption of a very fine aerosol.

The results from the car park experiment are summarised in Table 4, and plotted as D_{50} versus cumulative PM2.5 sampled mass in Figure 6. The PM2.5 concentrations showed a very large increase in the second and third weeks, which was continued in the fourth week of the supplementary experiment. This was probably due to the normal users of the underground car park (mainly motorcyclists) changing their parking habits in week 1 in response to the appearance of the four PM2.5 samplers. Over the course of the experiment the users returned to parking their vehicles close to the sampling site.

4.4 Calculations of expected bias in PM2.5 concentrations

In order to assess the impact of downward shifts in the particle size selection curves on apparent PM2.5 concentrations, the three ambient aerosol size distributions cited in the Federal Register can be utilised. The bias in PM2.5 concentrations that results from numerically 'sampling' these aerosols with selectors whose characteristics differ from the 'ideal' PM2.5 curve specified as the Federal Reference Method is shown in Table 5. Bias values in the range -5% to +5% are permissible for FRM-equivalent samplers.

5. DISCUSSION

The measurements on the clean PM2.5 selectors show that all four instruments have D_{50} values close to the ideal value (2.5 µm). However, the shapes of the selection curves are very different. The URG cyclone curve falls off very gradually at large particle diameters. The GK cyclone curve also has a significant large-diameter 'tail', although it is lower than that of the URG cyclone. The SCC curve is slightly less sharp than the WINS impactor at large particle aerodynamic diameters, but sharper at small diameters than the WINS. The WINS curve shown here, which is the averaged result from eight independent tests, is slightly less sharp than the 'ideal' WINS curve obtained by Peters and Vanderpool (1996).

If the 'sharpness' of the selectors is defined as $(D16/D84)^{0.5}$ as suggested by Peters and Vanderpool (1996), the mean values obtained are: WINS = 1.23; SCC = 1.19; GK = 1.28; URG = 1.45. For comparison, Peters and Vanderpool obtained a value of 1.18 for the current version of the WINS, and values ranging from 1.14 to 1.3 for other WINS variants they investigated. Hence overall, the SCC cyclone is as sharp as the WINS impactor.

When loaded in the laboratory with Aloxite dust, the WINS D_{50} shifted steadily downwards, whereas the SCC did not show a significant shift. The results obtained can be compared to those in a similar experiment by Peters and Vanderpool (1996), in which the WINS was cumulatively loaded with Arizona Road Dust. Their data indicate a shift to D_{50}=2.25 µm after apparently sampling a total of 24 mg of dust. Their report does not state the proportion of sampled dust retained within the WINS, but the quoted size distribution (MMAD 5 µm, GSD 2) would imply that around 60% of the sampled dust was between 2.5 and 10 µm. Hence the loading required to shift the cut-point to 2.25 µm would be in the range 14 mg, or <u>eight</u> times the amount of Aloxite apparently required to have the same effect in this experiment. The discrepancy between these two results cannot be explained.

The garden experiment did not show such a large shift in the WINS D_{50} as the laboratory experiment, although the shift (to D_{50} ~2.3 µm) after five weeks of sampling was significant. The SCC D_{50} also shifted, although to a lesser extent. The upturn in D_{50} towards the end of the experiment may have been caused by the deposits shifting during transport (by road) of the selectors to and from the laboratory. Given that that sampled aerosol was fine it is likely that the mass of particulate retained within the selectors was not more than around one quarter of the PM2.5 mass, i.e. less than ~1.5 mg.

In the car park experiment the main source of airborne particulate was again vehicle exhaust but the concentrations were much higher. With a fine aerosol, removing the inlets from the samplers would not have had much effect, and it is likely that the large concentration increases in weeks 2 and 3 simply reflect increased use of the car park. Assuming that the particulate retained within the selectors is between one quarter and one half of the PM2.5 mass, the maximum loading can be estimated as being less than 2 - 4 mg. The fall in D_{50} is approximately the same as for the laboratory loading experiment, reaching a minimum value of D_{50} = 2.15 µm. The SCC D_{50} also decreases, but by a lesser amount, to D_{50}=2.35 µm.

For loadings of this magnitude, Table 5 indicates significant under sampling of the coarse aerosol by the dirty WINS impactor (i.e. when D_{50} = 2.15 µm). The clean URG cyclone is calculated to overestimate the PM2.5 concentration of the 'coarse' aerosol by around 10%, and all other calculated concentration values are within the acceptable error band.

It is important therefore to estimate how long sampling can take place with the WINS impactor before the loading causes an unacceptable shift in the D_{50}. The results from this project suggest that WINS loadings greater than 3 mg are probably sufficient to cause significant undersampling. Table 6 shows the number of hours required to build up a loading of this magnitude for different (extreme) concentrations of the three suggested aerosol size distributions. This table implies that in rare instances of high concentrations of coarse aerosol, there may be problems with the WINS impactor over four-day (96 hour) sampling periods. For longer sampling periods, e.g. the 16-day (384 hour) periods suggested for air quality monitoring in Europe, the WINS impactor is likely to become overloaded even at moderate concentrations.

6. CONCLUSIONS

- The SCC cyclone has been shown to provide a sharp cut for ambient air sampling applications, although the shape of it's selection curve differs somewhat from that of the WINS impactor.
- When loaded with dust the cut-point of the WINS impactor shifts downwards. The loading required to produce a significant deterioration in the WINS performance was shown to be in the region of 3mg.
- The SCC cut point also shifts under loading, however not enough to cause a significant deterioration in performance for any of the loadings tested in this project. Additionally, the SCC is a dry system whereas the WINS uses an oiled substrate.
- The URG cyclone has a very shallow particle size selection curve and is likely to overestimate PM2.5 concentrations when the aerosol being sampled is coarse.

- The WINS cut point is unlikely to shift to an unacceptable degree during 24 hour sampling periods, or even for 96 hour sampling periods under typical circumstances. However the WINS would perform less well than the SCC over extended sampling periods.

7. REFERENCES

Kenny, L.C and Gussman, R.A (1997). Characterisation and modelling of a family of cyclone aerosol preseparators. *J. Aerosol. Sci.*, **28**(4), 677-688.

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

Moore, M.E and McFarland, A.R (1993). Performance modelling of single-inlet aerosol sampling cyclones. *Environ. Sci. Technol.* Vol. **27**(9), 1842-1848.

Peters, T.M. et al., (1996). Development and Evaluation of Sampling Components for Measuring Particulate Matter under 2.5 Micrometers, R.T.I. Report No. 6360-011, Jan, 1996.

Peters, T.M., Vanderpool, R.W. (1996) .Modification and Evaluation of the WINS Impactor, R.T.I. report No. 6360-011, Sept. 1996.

Radar, D.J., Brockmann, J.E, Ceman, D.L and Lucero, D.A (1990). A method to employ the Aerodynamic Particle Sizer factory calibration under different operating conditions. *Aerosol Sci. Technol.*, **13**, 514-521.

Smith, W.B, Wilson, R.R and Bruce, D.B (1979). A five-stage cyclone system for in-situ sampling. *Environ. Sci. Technol.* Vol. **13**(11): 1387-1392.

USEPA (1997). Federal Register, Environmental Protection Agency 40 CFR Parts 50, 53 and 58. July 18, 1997.

ACKNOWLEDGEMENTS

Thanks to Mike Meyer from R&P and Bob Gussman from BGI for their personal contribution to this work, their help in loaning apparatus for the field experiments and the pleasure of their company. Thanks also to ETI Group Ltd and SKC Ltd for material support.

Table 1. Dimensions (in cm) of Cyclones Tested Based Upon Body Diameter

	D	Din	De	B	H	h	Z	S	Hcup	Dcup
URG Relative dimensions	2.08									
GK 4.39 Relative dimensions	4.39	0.878 0.2D	1.01 0.23D	0.878 0.2D	5.707 1.3D	1.756 0.4D	3.951 0.9D	1.01 0.23D	3.819 0.87D	0.878 0.2D
SCC Relative dimensions	3.495									

Table 2: Summary of penetration curve measurements for clean PM2.5 selectors

Selector	Number of tests	Number of test days	Mean D_{50} μm	D_{50} standard deviation
WINS	8	5	2.44	0.034
SCC	5	3	2.46	0.035
GK	4	4	2.37	0.029
URG	3	3	2.46	0.015

Table 3: Summary of results from the garden experiment

week	sampling time hours	result	PQ WINS	PQ SCC	Partisol WINS	Partisol SCC	Mean PM2.5 (st.dev)
1	96	PM2.5	8.94	9.07	9.82	8.74	9.14
		D_{50}	2.52	2.45	2.45	2.49	(0.47)
2	108	PM2.5	5.73	6	6.05	6.47	6.06
		D_{50}	2.45	2.4	2.4	2.5	(0.31)
3	108	PM2.5	7.98	9.53	dropped	7.63	8.38
		D_{50}	2.45	2.4	2.4	2.49	(1.01)
4	132	PM2.5	6.77	7.86	6.77	7.07	7.11
		D_{50}	2.39	2.34	2.34	2.45	(0.51)
5	132	PM2.5	8.97	9.51	8.47	9.24	9.05
		D_{50}	2.38	2.42	2.28	2.43	(0.44)
After	cleaning	D_{50}	2.47	2.45	2.45	2.5	

PM2.5 concentrations are in µg/m3; D_{50} values are in µm.

Table 4: Summary of results from the car park experiment

week	sampling time hours	result	PQ WINS	PQ SCC	Partisol WINS	Partisol SCC	Mean PM2.5 (st.dev)
1	168	PM2.5	5.4	6.73	6.57	6.74	6.36
		D_{50}	2.43	2.48	2.49	2.5	(0.64)
2	168	PM2.5		18.14	18.93		18.54
		D_{50}		2.34	2.26		
3	118	PM2.5		15.49	15.69		15.59
		D_{50}		2.36	2.15		
4	166	PM2.5		37.9	36.4		37.15
After	cleaning	D_{50}		2.48	2.45		

PM2.5 concentrations are in µg/m3; D_{50} values are in µm.

Table 5: Bias in PM 2.5 concentrations for three ambient aerosol size distributions

Selector	'Fine' aerosol	'Typical' aerosol	'Coarse' aerosol
Clean WINS	-1%	0%	0%
Clean SCC	0	+1%	+2%
Clean GK	+1%	+2%	+5%
Clean URG	0	+3%	+10%
Dirty WINS[1]	-3%	-2%	-4%
Dirty WINS[2]	-4%	-3%	-6%

1: WINS D_{50} = 2.25 µm; 2: WINS D_{50} = 2.15 µm

Table 6: Number of hours of sampling required in order to build up a loading of 3 mg within a WINS impactor

Idealised distribution	PM2.5/PM10 ratio	Hours sampling at 10µg/m^3 PM2.5	Hours sampling at 50µg/m^3 PM2.5
'Coarse'	0.27	411	82
'Typical'	0.55	667	133
'Fine'	0.94	5000	1000

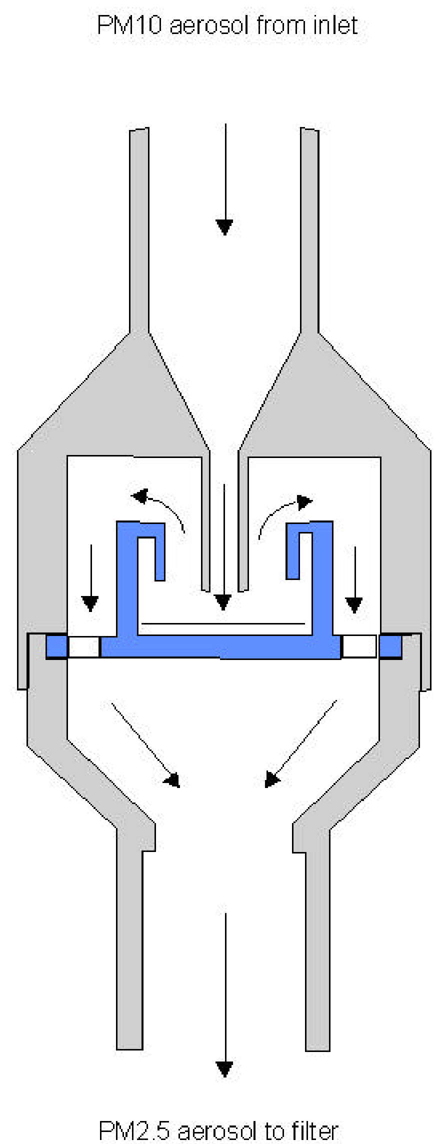

Figure 1: Schematic view of the WINS impactor

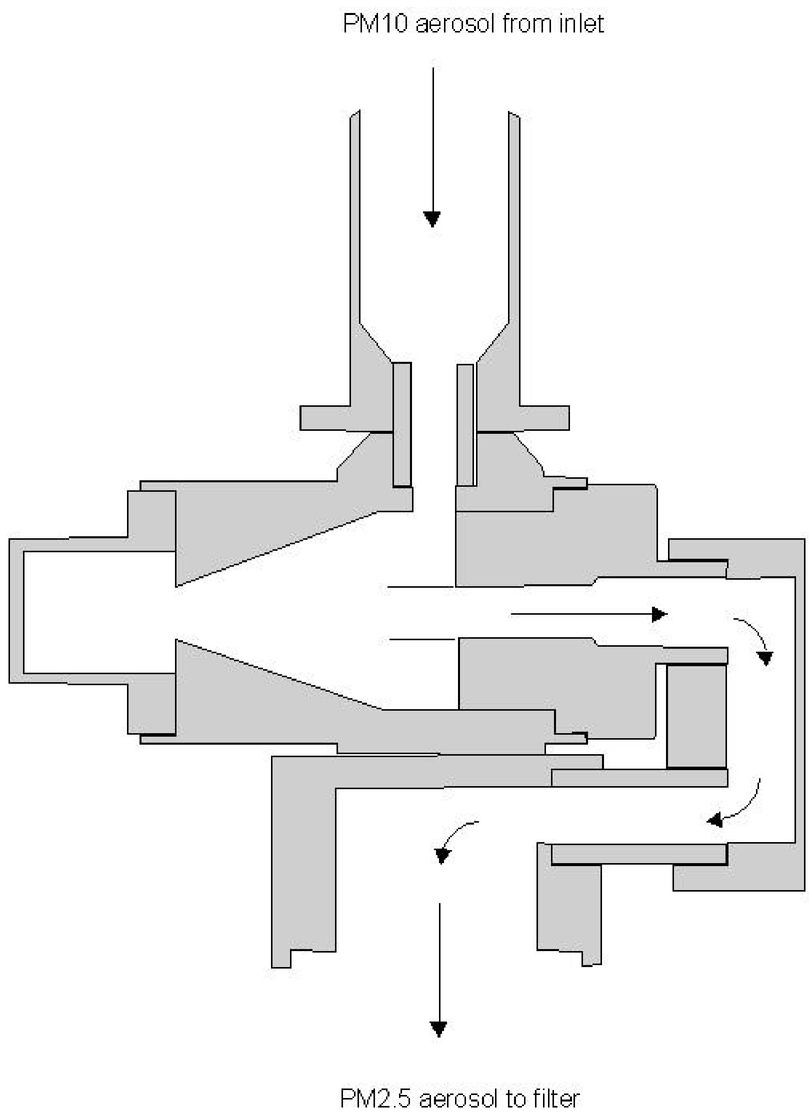

Figure 2: Schematic view of the SCC cyclone

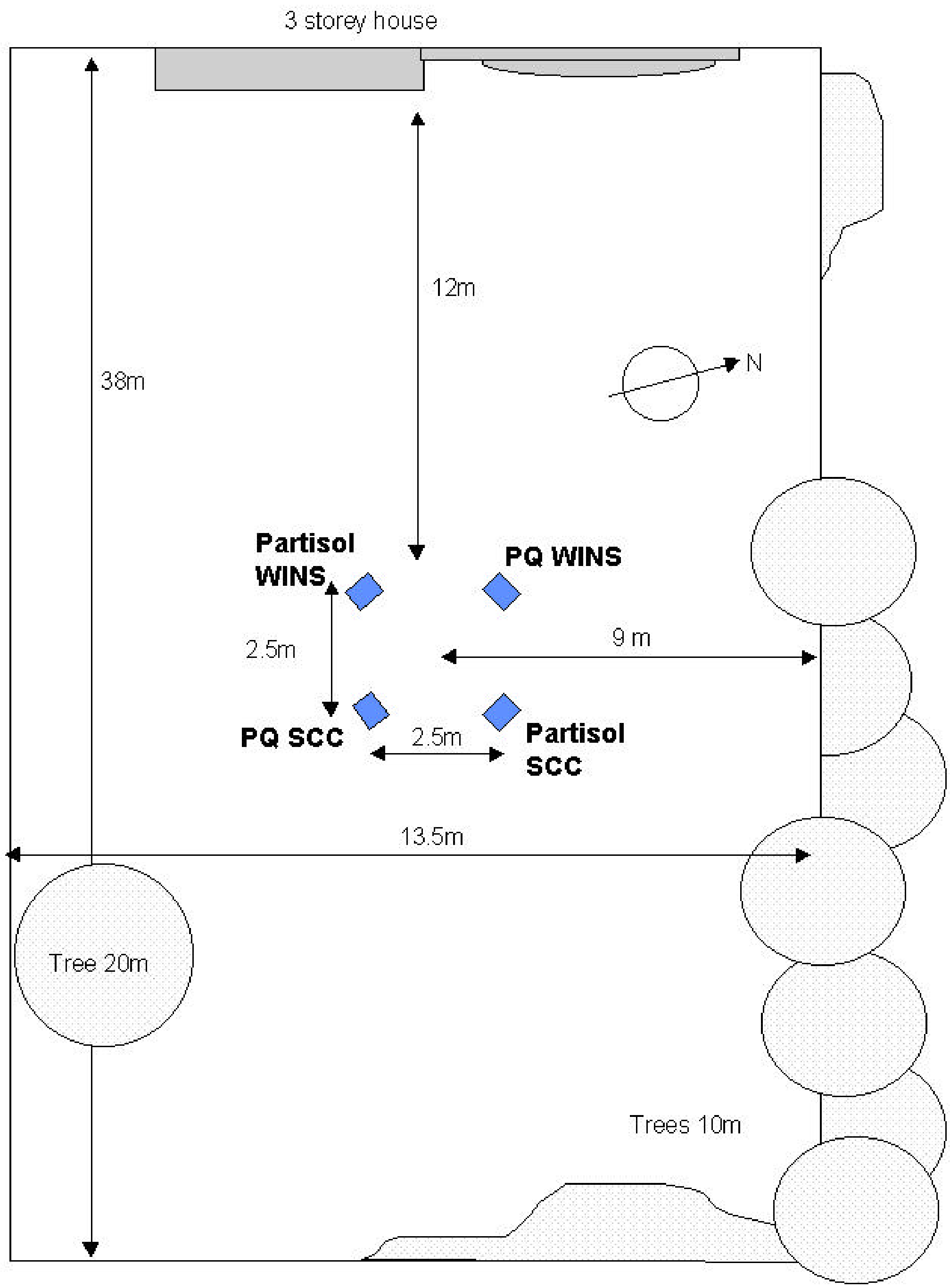

Figure 3: Schematic layout of garden experiment

FIGURE 4: Penetration curves of PM2.5 selectors

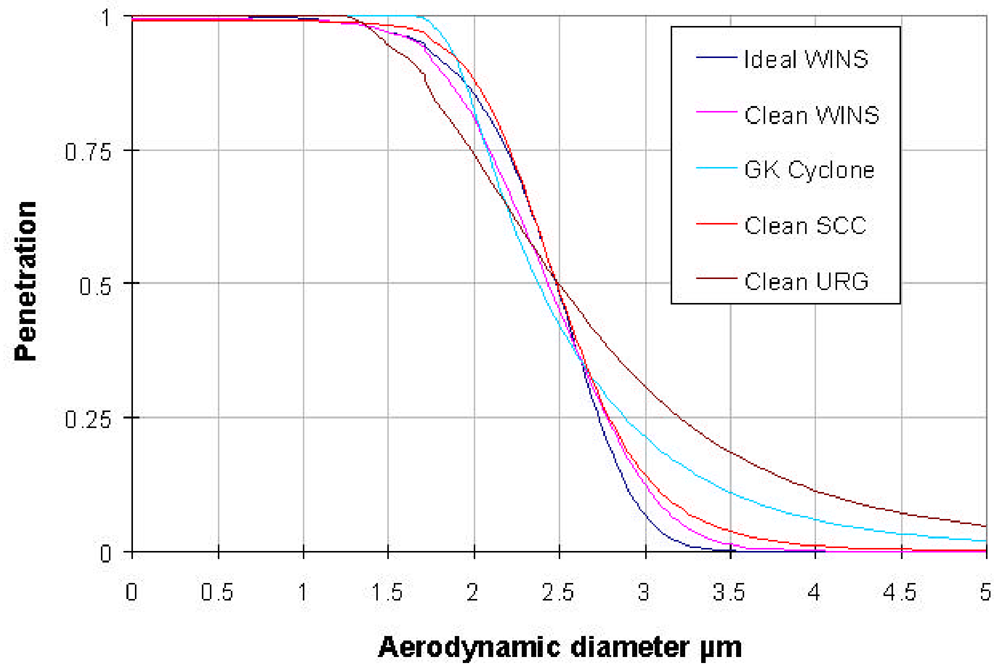

FIGURE 5: Results of laboratory loading experiment

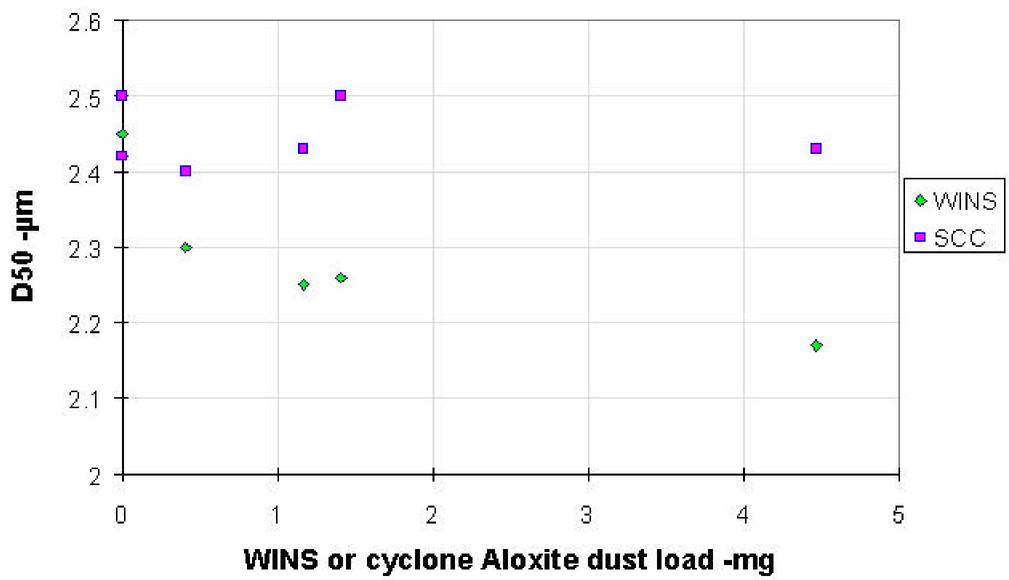

FIGURE 6: Results from garden loading experiment

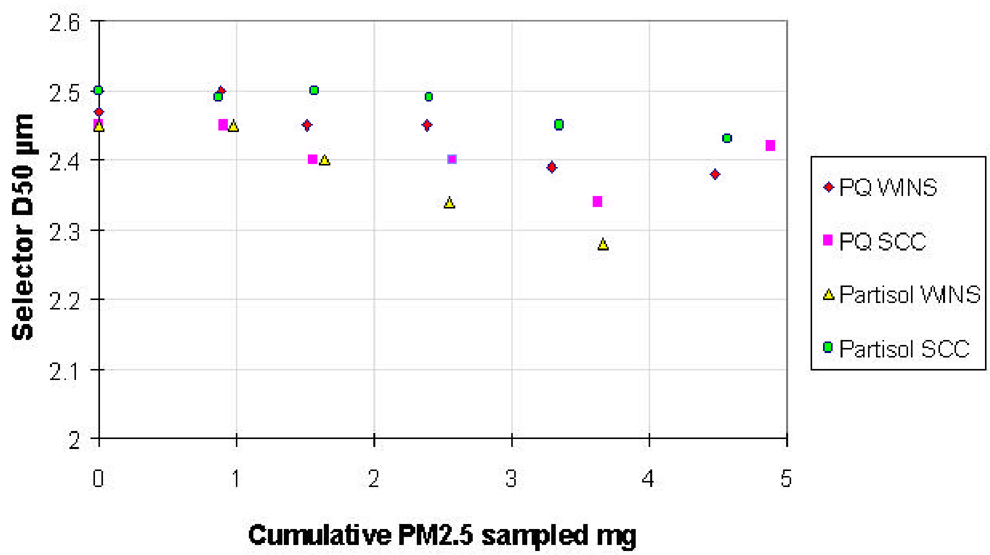

FIGURE 7: Results from car park loading experiment