

Broad Lane Sheffield S3 7HQ, UK
Telephone: +44 114 289 2606
Facsimile: +44 114 289 2850
Email: andrew.thorpe@hsl.gov.uk



**EFFECTS OF DUST LOADING ON THE
PERFORMANCE OF THE VSCC CYCLONE
for BGI Incorporated**

A Thorpe, D Mark and L Kenny

IR/L/EXCON/01/09

Project Leader: D Mark
Biomedical Sciences Group

DISTRIBUTION

Mr R A Gussman, BGI Inc

Dr N G West

Archive

RESTRICTED - COMMERCIAL

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

Issue Authorised by Mr D Mark

Date of issue: June 2001

Job Number: JC42.00004

Registry File: EC/CO/08

Word File: BGIrept5.doc

Figures: VCSSetc.xls

SUMMARY

The Very Sharp Cut Cyclone (VSCC) is a tangential round-entry cyclone geometry that has been designed to offer size selectivity with sharpness on a par with the WINS impactor for $PM_{2.5}$ sampling.

This report details an experimental evaluation of the effect of dust loading on the particle size-selective performance of the VSCC cyclone. The dust loading tests were conducted in line with the criteria set out by EPA in part of 40 CFR part 53. This describes the loading periods at an exposure concentration of $150 \mu\text{g m}^{-3}$ after which the VSCC should show no significant signs of changes in cut-point or 'sharpness of cut' values. The critical loading interval is defined by EPA as the minimum exposure period up to which the VSCC should show no change in performance. It would be difficult to generate a concentration as low as this and the tests would be too lengthy. Therefore, higher concentrations of ISO 12103-1 fine test dust (ATD) were generated for shorter intervals to give equivalent 1 day exposures of $150 \mu\text{g m}^{-3}$.

BGI supplied HSL with a VSCC cyclone fitted with the EPA standard PM_{10} low-flow louvered inlet and a FRM cassette which fits at the outlet of the cyclone. The dust was generated inside a calm air chamber using a Wright dust feed (WDF) aerosol generator and the VSCC was exposed for 1,2,3,7,14, 30 and 90 days at an equivalent concentration of $150 \mu\text{g m}^{-3}$.

After each exposure interval, the performance of the VSCC was measured using an Aerodynamic Particle Sizer system in the same calm air chamber, using methods previously developed and applied routinely by HSL in the characterisation of aerosol fractionators.

CONTENTS

SUMMARY

| | |
|--|----------|
| 1. INTRODUCTION | 1 |
| 2. EXPERIMENTAL METHODS | 1 |
| 2.1 Loading of the VSCC with dust | 1 |
| 2.2 Determination of aerosol penetration curves | 3 |
| 2.3 Data Analysis | 4 |
| 3. RESULTS | 5 |
| 4. DISCUSSION | 6 |
| 5. CONCLUSIONS | 6 |
| 6. REFERENCES | 6 |

1. INTRODUCTION

The VSCC (Very Sharp Cut Cyclone) is a designation for a novel cyclone geometry that should offer sharpness on a par with impactor systems. In order to realise this concept BGI Incorporated constructed a prototype VSCC cyclone with PM_{2.5} aerosol sampling applications in mind. BGI is applying to EPA for class II equivalency designation for FRM samplers using the VSCC as part of 40 CFR part 53 criteria. This criteria describes a dust loading protocol which will be followed during these tests. The device will be challenged with a concentration of ISO fine test dust which is at an equivalent to an ambient concentration of 150 µg/m³ over a 24 hr period. It is the intention of this work to verify the ability of the VSCC to perform within the EPA criteria and as such the key exposure periods are two weeks, 30 days and 90 days.

2. EXPERIMENTAL METHODS

2.1 Loading of the VSCC with dust

The dust loading tests were carried out inside the same chamber used to carry out the VSCC penetration curves. This was so that the cyclone was moved as little as possible during the tests, since dust inside the VSCC collects on a dry deposition container rather than an oiled impactor plate and could possibly be disturbed. The test dust used to load the VSCC was ISO 12103-1 fine (commonly referred to as Arizona Road Dust or ATD, by EPA). The dust was generated inside the chamber using a Wright dust feed (WDF) which was serviced before use and was fitted with the Tungsten carbide tipped blade. The dust emitted from the WDF entered the chamber at the top where it was mixed and neutralised using an ioniser fan. It then passed through aluminium honeycomb into the working section. The WDF was set to the minimum speed at which it would operate consistently (0.05 rpm) and the dispersion air was set to 0.5 bar pressure. At this speed the WDF should run for around 60 hours before it requires re-filling. The air flow through the chamber was then adjusted using a butterfly valve situated at the base of the chamber to give a concentration of approximately 10 mg/m³ inside the working region which simulated a 24 hour test at 150 µg/m³ in approximately 20 minutes. The velocity through the chamber was less than 0.04 m

s⁻¹. The dust concentration inside the chamber was measured using two thin walled samplers set up according to the Lui and Agarwal (1980) criteria. These were fitted with 25 mm GF/A glass fibre filters and the dust laden air was pulled through at 4 l/min using Rotheroe and Mitchel sampling pumps. At the same time the temporal variation in concentration was monitored using the Microdust 880 nm direct reading dust monitor. This could then be calibrated using the gravimetric measurements. The Microdust 880 nm was very useful as a tool for checking that the dust generator was operating properly. However, its main use was as a predictor of exposure time at any given concentration to give the equivalent 150 µg/m³ 24 hour exposure. The Microdust 880 is calibrated with ATD.

An important consideration in producing valid test results during loading is producing the correct size distribution. If a very fine aerosol is being produced then the VSCC will collect very little material and the tests will overestimate the cyclones required cleaning interval. Similarly, if the aerosol is too coarse, then a large amount of the mass will be removed by the PM₁₀ inlet and the interval may again be overestimated. For this reason the size distribution inside the chamber was measured using a Sierra 8 stage impactor which operates at a typical flow rate of 2 l/min. The impactor uses Mylar disks as the collection substrates which were greased in order to minimise losses due to particles bouncing off the surface. Fig 1. Shows a photograph of the experimental set-up.

Throughout the loading tests, the VSCC was fitted with the EPA standard PM₁₀ low-flow louvered inlet, and was operated at 16.67 l/min using a high flow rate pump. The dust penetrating the cyclone was collected on a 47 mm GF/A filter mounted inside a FRM cassette at the outlet of the cyclone. The test protocol agreed with BGI was as follows.

- a) Verify the penetration performance curve of the clean test object using standard glass microspheres (see 2.2).
- b) Generate a concentration of approximately 10 mg m⁻³ ISO 12103-1 fine test dust into the chamber, measure the concentration using the thin wall samplers and calibrate the Microdust

880 nm dust monitor. Determine the mass median diameter and standard geometric standard deviation of the test dust using the cascade impactor.

- c) During each loading test, determine the dust concentration measured by the VSCC, and the dust concentration inside the chamber using the calibrated Microdust 880 nm to predict the required sampling period.
- d) Carry out the tests for the following intervals:

| Test No | Equivalent days (nominal) (at $150 \mu\text{g m}^{-3}$) | Verify |
|---------|---|-----------------------------------|
| 1 | 1 | Penetration |
| 2 | 2 | Penetration |
| 3 | 3 | Penetration |
| 4 | 7 (1 week total) | Penetration |
| 5 | 14 (2 weeks total) | Penetration |
| 6 | 30 (4 weeks total) | Penetration and size distribution |
| 7 | 90 (12 weeks total) | Penetration and size distribution |

The intention of the above schedule is to verify the ability of the VSCC to perform within EPA criteria. The key tests are No. 5, which will verify a two-week cleaning interval, No. 6 to verify a 30 day cleaning interval and No. 7 for a 90 day interval.

All of the pumps used for gravimetric sampling were used with rotameters that were checked at the flow rate of interest using a calibrated Ametek bubble flowmeter.

2.2 Determination of aerosol penetration curves

The experimental methods used to test the cyclones were similar to those described in detail by Maynard and Kenny (1995). The tests were carried out in an aerosol chamber with a working section 1 m^2 . The chamber was purged with clean air prior to a cyclone calibration test to remove

traces of the dust used during loading. The test aerosol consisted of solid, spherical glass microspheres (Whitehouse Scientific) with physical diameters up to 25 μm , and density 2.45 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 ($< 2 \text{ cm}\cdot\text{sec}^{-1}$) steady downflow of air. The generated aerosol typically had a number median diameter around 1.5 μm and a mass median diameter around 4 μm . The number concentration was typically 100-200 particles per cubic centimetre, and was generally stable over the time scales necessary for the test (10 minutes per cyclone).

The test sampling lines were situated close to the centre of the chamber's working section, connected to an Aerodynamic Particle Sizer (APS3310) 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 cyclone to be measured accurately using calibrated Ametek 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 Ametek.

The test procedure involved placing the cyclone 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.

Files from the APS were exported and processed using an Excel spreadsheet in order to calculate the penetration curves, 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.

2.3 Data Analysis

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} , D_{16} and D_{84} diameters by interpolation. The sharpness values were calculated as:

$$Sharpness = \left(\frac{D_{16}}{D_{84}} \right)^{\frac{1}{2}}$$

Where necessary the raw data were normalised by scaling the penetration values so that they tended to unity for $d_{ae}=0$. The APS 3310 flow control does not compensate for the additional pressure drop through the cyclone, and so the raw penetration values usually reached a maximum value of 0.95 to 1.0. The VSCC design has a relatively low pressure drop compared to a WINS impactor and so the adjustments required to re-normalise the data were generally small.

3. RESULTS

A summary of all experimental data, with interpolated D_{50} , D_{16} , D_{84} and sharpness values, is given in Table 1. Bias estimates are presented in Table 2. Penetration curves measured after the various loading intervals are shown in Fig 2.

Penetration curves for the VSCC cyclone after the various loading intervals were analysed and the relationship of D_{50} and sharpness of cut to exposure interval (at an equivalent concentration of $150 \mu\text{g m}^{-3}$) is shown in Figure 3.

In order to assess the impact of differing size selection curves, with loading on apparent PM2.5 concentrations, the three ambient aerosol 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 2. Bias values in the range -5% to +5% are permissible for FRM equivalent samplers. These calculations have been performed for each time interval for which a penetration curve of the VSCC was determined (1, 2, 3, 7, 15, 30 and 90 days). A detailed discussion of how these calculations are performed has been presented by Kenny *et al* (2000).

4. DISCUSSION

The results shown in Fig 2 and Table 1 indicate that the VSCC can operate at an equivalent dust concentration of $150 \mu\text{g m}^{-3}$ for a minimum of 90 days without any significant change in the cyclone cut-point. A small increase in the sharpness of cut value was observed over the same period.

The size distribution of the challenge aerosol was measured on 3 occasions using the Sierra 8-stage cascade impactor and once using the APS at a reduced concentration to minimise coincidence effects within the instrument. Table 1 shows that there is good agreement between the individual cascade impactor results and also between the cascade impactor results and the APS results.

The Wright dust feed was able to generate and maintain a very constant dust concentration within the test chamber and ran without problems for the full duration of the tests.

The penetration results for the clean VSCC are comparable to those obtained at HSL on a previous occasion. (Kenny, L. C. & Thorpe, A, 2000)

The calculation of bias on observed mass concentrations for all of the test intervals up to 90 days was 1% for the 'typical' and 'fine' modes. The 'coarse' mode started at 4% and descended to 3% at day three, rising to 4% at day 90.

5. CONCLUSIONS

The VSCC was able to operate at an equivalent concentration of $150 \mu\text{g m}^{-3}$ for a period of at least 90 days with little effect on the d_{50} cut point and only a small increase in the sharpness of cut. Bias calculations demonstrated that the VSCC never exceeded the EPA '5%' criteria at any time, throughout the study.

6. REFERENCES

Agarwal, J.K., and Lui, B.Y.H. (1980). A criterion for accurate aerosol sampling in calm air. *J. Am. Ind. Hyg. Assoc*, **41**, 191-197

Kenny, L.C. and Thorpe, A (2000). Evaluation of VSCC cyclones. HSL internal report no. IR/L/EXM/01/01

Kenny, L.C., Gussman, R. and Meyer, M. (2000). Development of a Sharp-Cut Cyclone for Ambient Aerosol Monitoring Applications. *J. Aerosol Sci. and Tech.*, 32(4), 338-358.

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.

Peters, T.M, and Vanderpool, R.W (2000). Design and Calibration of the EPA PM2.5 Well Impactor Ninety-Six (WINS). *J. Aerosol Sci. and Tech.*, 34(5), 389-397.

Table 1. Summary of loading results

| Nominal exposure time at $150 \mu\text{g m}^{-3}$ (days) | Total concentration inside calm air chamber (mg m^{-3}) | PM _{2.5} conc (mg m^{-3}) | Exposure time (mins) | Equivalent exposure time at a conc of $150 \mu\text{g m}^{-3}$ (days) | Cumulative exposure time at a conc of $150 \mu\text{g m}^{-3}$ (days) | d ₅₀ | d ₁₆ | d ₈₄ | Sharpness of cut | Aerosol particle size | |
|--|--|---|----------------------|---|---|-----------------|-----------------|-----------------|------------------|-------------------------------|--|
| | | | | | | | | | | Mass Median (μm) | Geometric standard deviation (μm) |
| 0 | | | | | 0 | 2.54 | 2.86 | 2.22 | 1.135 | * 5.1 | 1.67 |
| 1 | 8.33 | 2.46 | 23.1 | 0.89 | 0.89 | 2.59 | 2.9 | 2.22 | 1.143 | | |
| 1 | 11.78 | 2.76 | 20.8 | 1.13 | 2.02 | 2.55 | 2.88 | 2.19 | 1.147 | | |
| 1 | 11.1 | 2.52 | 19.25 | 0.99 | 3.01 | 2.55 | 2.9 | 2.2 | 1.148 | # 5.75 | 2.29 |
| 4 | 10.23 | 2.18 | 88.43 | 4.19 | 7.20 | 2.51 | 2.86 | 2.12 | 1.161 | | |
| 7 | 10.54 | 2.46 | 160.85 | 7.85 | 15.05 | 2.54 | 2.9 | 2.16 | 1.159 | | |
| 16 | 10.7 | 2.41 | 320.67 | 15.89 | 30.94 | 2.52 | 2.9 | 2.12 | 1.17 | 5.81 | 1.62 |
| 60 | 13.3 | 3.1 | 979.2 | 60.29 | 91.23 | 2.54 | 2.98 | 2.11 | 1.19 | 6.01 | 1.62 |

* Size distribution carried out inside calm air chamber before dust loading tests commenced

Size distribution measured with Aerodynamic particle sizer (APS model 3310) at a reduced concentration to minimise coincidence errors

Table 2. % Bias in VSCC PM2.5 concentrations for three ambient aerosol size distributions.

| Interval Days | 'Fine Aerosol' | 'Typical Aerosol' | 'Coarse Aerosol' |
|------------------|-------------------|----------------------|---------------------|
| 0 | 1 | 1 | 4 |
| 1 | 1 | 1 | 4 |
| 2 | 1 | 1 | 4 |
| 3 | 1 | 1 | 3 |
| 7 | 1 | 1 | 3 |
| 14 | 1 | 1 | 3 |
| 30 | 1 | 1 | 3 |
| 90 | 1 | 1 | 4 |

Fig 1. Experimental set-up for loading of VSCC with Arizona road dust

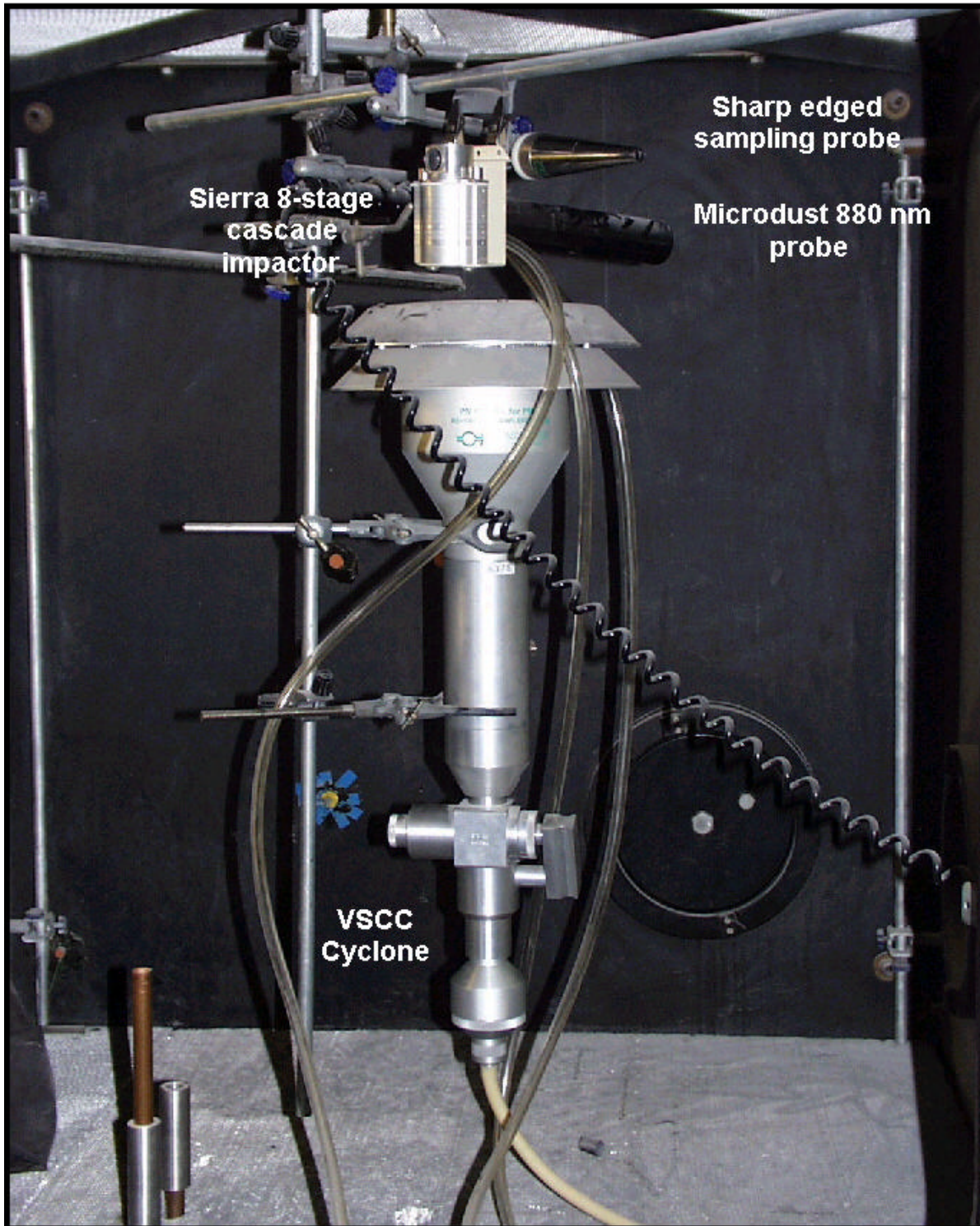


Fig 2. Loading of VSCC with Arizona road dust

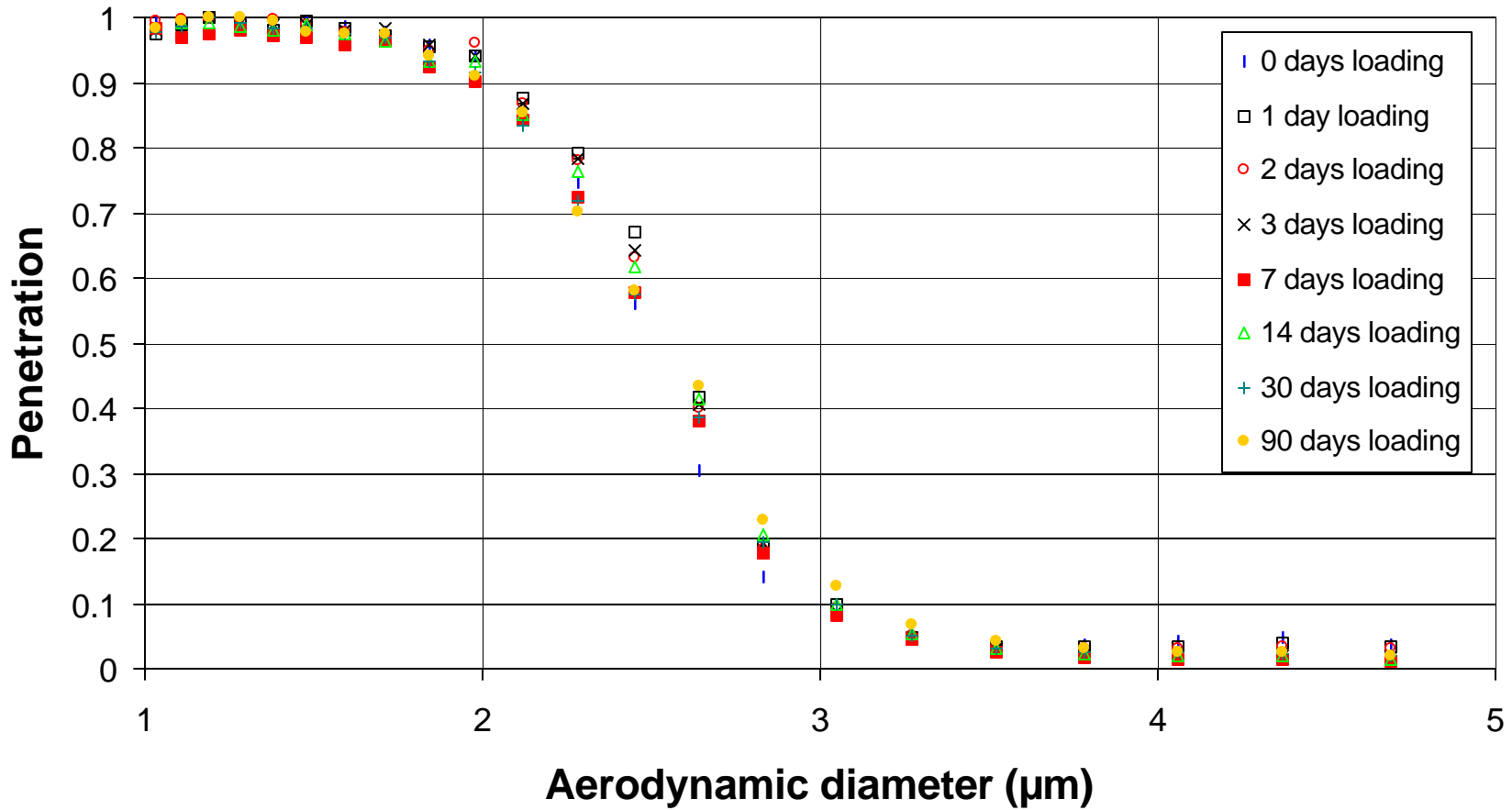


Fig 3. Effect of dust loading on VSCC d_{50} and sharpness of cut

