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HEALTH & SAFETY LABORATORY

EVALUATION OF VSCC CYCLONES

for BGI Incorporated

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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 PM2.5 sampling. This report details an experimental evaluation of the particle size-selective performance of prototype VSCC cyclones, constructed by BGI with ambient aerosol sampling applications in mind. The preliminary work enabled the design to be optimised and the final VSCC design was then calibrated at 16.67 l/min.

BGI supplied HSL with a single test specimen of the VSCC body, and with two prototype test specimens of the vortex finder section. The cyclone combinations were tested using an Aerodynamic Particle Sizer system in calm air, using methods previously developed and applied routinely by HSL to the characterisation of aerosol fractionators. Tests were carried out at a flow rate of 16.67 l/min, using an aerosol of glass microspheres. The initial test results were used to calculate the optimum length for the vortex finder tube. One of the vortex finder sections was then modified to the predicted length, and the cyclone subjected to final calibration.

The calibration consisted of five independent repeated tests at 16.67 l/min, carried out on three separate days. Tests at four other flow rates were also carried out to elucidate the design model for the VSCC. The results were analysed to calculate both the D_{50} and sharpness of the final VSCC design. They are compared in this report to a similar set of five evaluations of the EPA WINS impactor, carried out on three separate days.

CONTENTS

1. INTRODUCTION

An extensive programme of research into the effects of cyclone geometry on cyclone cut-point (i.e. D50) and sharpness (Kenny and Gussman, 2000) has resulted in a better understanding of how to construct tangential flow cyclones with exceptionally sharp size-selection characteristics. 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 PM2.5 aerosol sampling applications in mind. This report details an experimental optimisation and calibration of the VSCC PM2.5 cyclone design, carried out for BGI Inc. by HSL.

2. DESCRIPTION OF CYCLONE TESTED

The Very Sharp Cut Cyclone is a tangential, round-entry cyclone based on the design of the SCC cyclone described by Kenny *et al*. (2000), and other ambient cyclones for PM2.5 selection. The cyclone geometry was selected for optimum sharpness of the selection curve, as suggested by the direct design approach of Kenny and Gussman (2000). Design modifications from existing cyclones were principally the enlarging of the cyclone cone (longer cone, wider base diameter) and decrease in the inlet and outlet tube diameters. The cyclone body diameter is smaller than the corresponding SCC cyclone, to compensate for the effects of these changes in geometry on D_{50}. A prototype VSCC cyclone with body diameter cm was constructed for testing. This body diameter was estimated to give a D_{50} value close to 2.5 µm at a flow rate of 16.67 l/min.

To adjust the design so that a cut point of 2.5 µm exactly was obtained, the generalised cyclone design model discussed by Kenny and Gussman (2000) also suggested that the cyclone could be optimised by changing to the length of the vortex finder, rather than by re-machining a cyclone with a new body diameter. Hence an important part of this study was to evaluate the change in D_{50} and sharpness as a function of vortex finder length, and to find the optimum value. Having fixed the optimum VSCC cyclone geometry, the final design was then calibrated at a flow rate of 16.67 l/min in the normal way. Additional tests at other flow rates were carried out in order to elucidate the VSCC family model.

3. EXPERIMENTAL METHODS

3.1 Determination of aerosol penetration curves

The experimental methods used to test the cyclones were similar to those described in detail by Maynard and Kenny (1994). The tests were carried out in an aerosol chamber with a 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 2.45 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 $cm.sec^{-1}$) 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 a Gilibrator 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 Gilibrator.

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.

3.2 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 maximim 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.

4. RESULTS

A summary of all experimental data, with interpolated D_{50}, D_{16}, D_{84} and sharpness values, is given in Table 1.

Penetration curves for the VSCC cyclones with different vortex finder lengths were analysed and the relationship of D_{50} to vortex finder length is shown in Figure 1. Interpolation of Figure 1 indicated that the optimum vortex finder length for the VSCC cyclone is cm, and so the longer of the two initial vortex finders was adjusted to shorten it to this length.

This final VSCC design was re-tested on five occasions at 16.67 l/min, on three different days. The raw data are shown in Figure 2, along with a curve fit to the mean of the five runs.
Further tests of the VSCC cyclone penetration were carried out a four flow rates between 12 and 20 l/min. The relationship between D_{50} and flow rate is shown in Figure 3.

5. DISCUSSION

The observed relationship between vortex finder length and D_{50} was consistent with the behaviour predicted by the direct design approach (Kenny and Gussman, 2000). The two vortex finders originally supplied for the prototype VSCC bracketed the desired D_{50}, and the correct vortex finder length was easily obtained by linear interpolation. The direct design model had also predicted that the relationship would be linear over the small range of lengths considered. For extreme lengths the relationship is predicted to become non-linear.

Figure 4 compares the best fit curve for the pooled VSCC data from Figure 2, to a similar curve fitted to five independent tests on the clean WINS impactor (data taken from Kenny et al, 2000). The VSCC is shown to be as sharp as the WINS. In the tests carried out at HSL the WINS was found to have an average D_{50} value of 2.48 µm and a sharpness value of 1.22. These data for the WINS are not quite as sharp as the ideal WINS curve published by Peters et al. (2001), although it should be noted that the ideal curve is derived from only a small subset of the available EPA data on the WINS. If all the EPA data were pooled the resulting curve would certainly be no better than the HSL WINS data. The results of the VSCC final design tests give a cut-point of D50 = 2.50 um at a flow rate of 16.67 lpm, and a sharpness value of 1.157.

The VSCC design model follows the relationship

$$\ln(D_{50}) = a + b\ln(D_C) - (b-1)\ln(Q) \qquad [1]$$

where

D_{50} is the penetration cut point in micrometers,

D_C is the cyclone body inside diameter in cm,

Q is the flow rate in litres per minute,

and a, b are empirical constants determined using non-linear least squares regression.

Best fit values for a and b at this time are: a = ; b = and the model is plotted alongside the experimental data in Figure 3 . The number of data points available to fit the VSCC design model is currently too small for the model to be regarded as definitive. As with previous cyclone designs, e.g. GK cyclones, SCC cyclones, data from several different VSCC cyclones will be needed in order to finalise the model.

6. CONCLUSIONS

- The direct cyclone design approach used to design the VSCC was demonstrated to be successful, with the cyclone characteristics exhibiting the trends expected.
- The VSCC cyclone was confirmed to select PM2.5 when operated at a flow rate of 16.67 l/min.
- The VSCC cyclone design is confirmed to give size selection at least as sharp as the WINS impactor.

7. REFERENCES

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TABLES

Table 1: Summary of experimental data

Flow L/min	Vortex length mm	D50 µm	D16 µm	D84 µm	Sharpness
16.67		2.322	2.714	2.026	1.157
16.67		2.26	2.66	1.96	1.164
16.67		2.6	2.974	2.182	1.211
16.67		2.47	2.827	2.114	1.156
16.67		2.48	2.828	2.111	1.157
16.67		2.49	2.855	2.10	1.166
16.67		2.54	2.87	2.18	1.147
16.67		2.50	2.85	2.128	1.157
15		2.758	3.179	2.352	1.163
18		2.36	2.69	2.03	1.151
12.4		3.57	4.13	3.08	1.158
15.7		2.66	2.96	2.35	1.122
18.7		2.30	2.59	2.00	1.138

FIGURE 2: VSCC penetration at 16.7 lpm

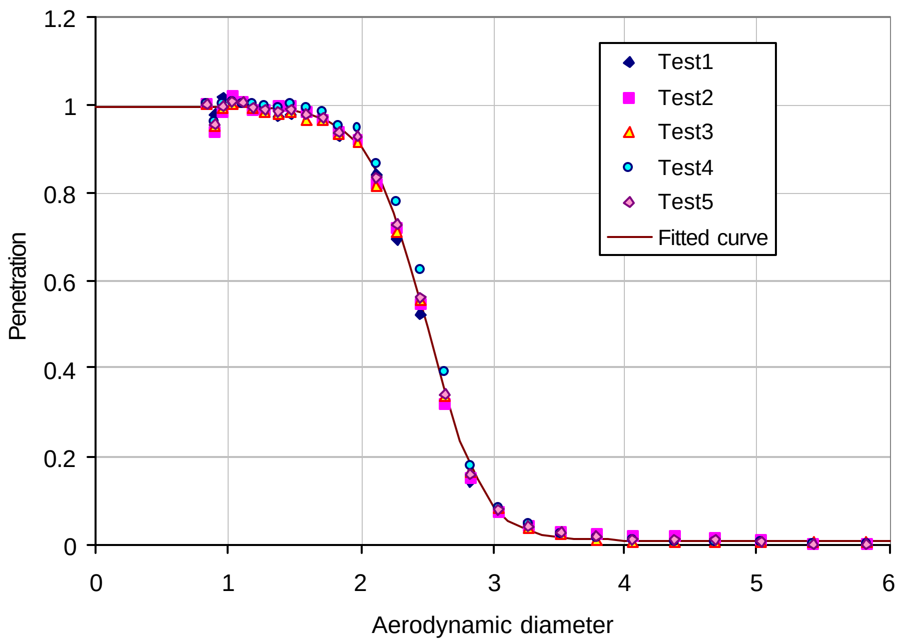

FIGURE 4: Comparison of WINS and VSCC
(curves fitted to data)