Aerosol Penetration Characteristics of the Interagency Monitoring of Protected Visual Environments (IMPROVE) Sampler $PM_{2.5}$ Cyclone

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INTRODUCTION

The Interagency Monitoring of Protected Visual Environments (IMPROVE) program operates a network of integrated samplers for routine monitoring of particulate matter (PM) mass and composition. The IMPROVE sampler features three $PM_{2.5}$ channels and one PM_{10} channel. A particle size cutpoint (aerodynamic diameter corresponding 50% collection efficiency, $d_{p,50}$) is achieved at 2.5 µm using a custom cyclone which is immediately upstream of a manifold with four ports controlled by solenoid valves. A given solenoid is activated to collect particles on a filter attached to the respective port. The critical dimensions of the cyclone are based on the AIHL design (John and Reischl, 1980) which predicts $d_{p,50}$ for 2.5 µm particles at 21.7 LPM and a relatively weak dependence of the cutpoint on flow rate (dashed line in Figure 1). Testing of the IMPROVE cyclone at the University of California, Davis (CNL, 2004) found a $d_{p,50}$ for 2.5 µm particles at 22.8 LPM; this flow rate was selected as the setpoint for the $PM_{2.5}$ channels of the IMPROVE sampler. The CNL study reported a relatively strong dependence of the cutpoint on flow rate (solid line in Figure 1). This finding is significant since the IMPROVE sampler has passive flow control and there can be a substantial decrease in flow rate over a 24-hour run as the downstream filter becomes loaded with particles (the "A" channel is particularly prone to such drift because it uses a Teflon filter). The current study was undertaken to reconcile the presumed differences in the IMPROVE cyclone and AIHL cyclone collection efficiency characteristics.

METHODS

Two test rigs were constructed to characterize penetration through the cyclones. Preliminary studies were conducted at Washington University (WUSTL) using monodisperse polystyrene latex (PSL) spheres. The test rig featured a TSI Model 3076 atomizer followed by a Kr-85 neutralizer, addition of make-up air, and a large capacity radial diffusion dryer (silica gel). The entire air stream was pulled through the cyclone using a vacuum pump. Isoaxial – and nearly isokinetic – sampling probes were located upstream and downstream of the cyclone and connected to a MetOne HHPC-6 particle counter. Subsequently, tests were conducted at Aerosol Dynamics, Inc. (ADI).

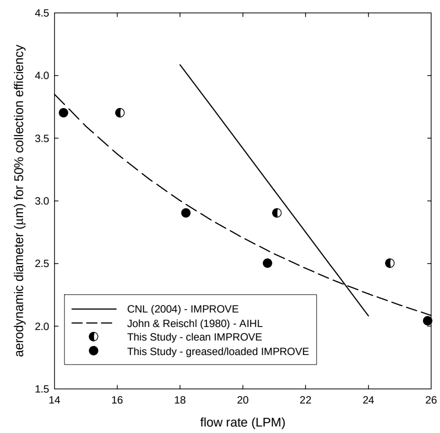

Figure 1. Cyclone cutpoint as a function of flow rate.

A De Vilbiss nebulizer and a TSI Model 3400A fluidized bed were used to suspend PSL (monodisperse and mixtures) and Arizona soil dust, respectively. The aerosol stream was mixed with dilution air in a ~0.2 m^3 box which provided sufficient residence time to stabilize the aerosol concentration. A vacuum pump was used to draw a sample stream from the box and through the cyclone. Isoaxial – and nearly isokinetic – sampling probes were located upstream and downstream of the cyclone and connected to a TSI Model 3321 Aerodynamic Particle Sizer Spectrometer.

Measurements were conducted to challenge both IMPROVE and AIHL cyclones with PSL and Arizona road dust. This abstract reports on the IMPROVE cyclone / PSL results; the Arizona soil dust tests and AIHL characterization are currently in progress.

RESULTS

Cutpoints as a function of flow rate were determined by generating monodisperse PSL and measuring penetration at several flow rates. For each PSL size, data bounding 50% penetration were interpolated to estimate the cutpoint flow rate which was subsequently confirmed by direct measurement at that flow rate. Tests using the ADI test rig were performed using monodisperse PSL, ~25% RH, and an IMPROVE cyclone that had been lightly greased (dilute solution of petroleum jelly in cyclohexane) and subsequently loaded with Arizona soil dust. These tests (closed circles, Figure 1) showed excellent agreement with the AIHL cyclone cutpoint curve (John and Reischl, 1980). The cutpoint is much less sensitive to flow rate than predicted by the CNL (2004) study. Tests using the WUSTL test rig were performed using monodisperse PSL, very low RH (likely <10%), and an IMPROVE cyclone that had been cleaned, not greased, and loaded only with PSL from that phase of tests. In this case, the cutpoint (half-filled circles, Figure 1) showed the same dependence on flow rate as the ADI test rig results but was shifted to higher flow rates for a given particle size. Additional tests were performed on the ADI test rig to explain these differences. Figure 2 shows the temporal evolution of 2.5 µm PSL penetration for a clean IMPROVE cyclone challenged by a PSL mixture. The initial penetration was consistent with the WUSTL studies described above (upper dashed line), and then gradually increased to approach the penetration observed in the ADI tests described above (lower dashed line). This result demonstrates that penetration near the cutpoint particle size can be very sensitive to test conditions. In contrast, for the conditions of Figure 2 the penetrations for 1.0 and 4.8 µm PSL were temporally invariant at ≥99% and ≤2%, respectively.

Penetration as a function of particle size was measured for seven PSL sizes at twelve flow rates. Figure 3 shows the penetration at 22.8 LPM (nominal) for a variety of test conditions. Vertical dashed lines connect data for a clean IMPROVE cyclone (monodisperse PSL, bone dry conditions) to data for a lightly-greased and soil dust-loaded IMPROVE cyclone (monodisperse PSL, ~25% RH). These conditions form an envelope which includes the data reported by John and Reischl (1980) and John *et al.* (1981) for the AIHL cyclone. Figure 3 also shows the penetration curve (solid line) for the $PM_{2.5}$ FRM WINS Impactor (Peters *et al.*, 2001). The IMPROVE cyclone and WINS Impactor exhibit similar penetration curves at their respective setpoint flow rates.

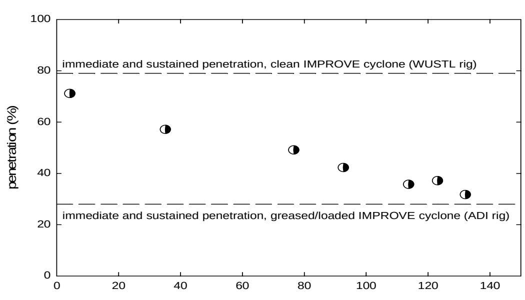

Figure 2. Temporal evolution of 2.5 µm PSL penetration at 22.8 LPM for a clean IMPROVE cyclone exposed to a mixture of 1.0, 2.5, and 4.8 µm PSL.

CONCLUSIONS

Our laboratory characterization of a lightly-greased and particle-loaded IMPROVE cyclone shows good agreement with historical AIHL performance data. Under certain conditions, lower collection efficiencies can be observed for clean cyclones presumably arising

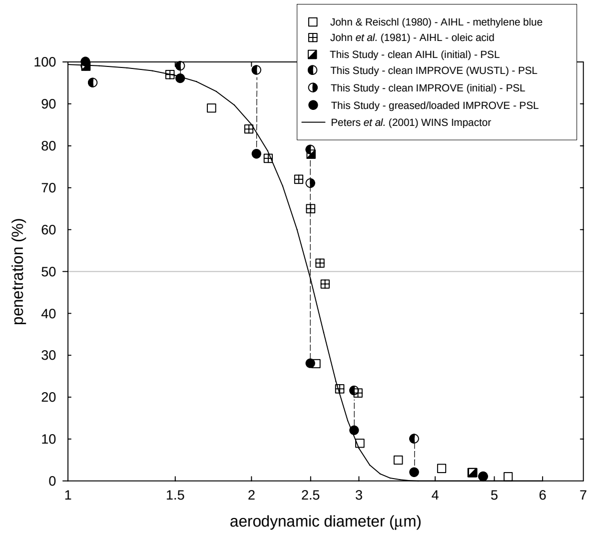

Figure 3. Aerosol penetration at 22.8 LPM (nominal) for the IMPROVE cyclone (circles) and AIHL cyclone (squares). All results from "This Study" from the ADI test rig unless noted as WUSTL. The solid line represents the $PM_{2.5}$ FRM WINS impactor at its setpoint flow rate of 16.7 LPM.

from particle bounce. However, it may not be necessary to grease the cyclone as the collection efficiency can ripen with even modest particle loadings. Additional tests are underway to further clarify these observations and understand their implications to routine monitoring and data analysis.

Keywords: *instrumentation, cyclone, IMPROVE*

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