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Project Summary

Validation of Samplers for Inhaled Particulate Matter

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Methods for testing inhalable particle samplers have been developed and applied to the dichotomous sampler and the size-selective hi-vol sampler. The sampling effectiveness of the inlet to the dichotomous sampler was measured and found to be excessively dependent on wind speed. A modification to improve the performance was designed as a retrofit to the existing inlet. Measured wall losses in the dichotomous sampler were small. The fine fraction is found to be correlated to error in nozzle concentricity, which is not within specifications for the typical commercial sampler.

Penetration of the size-selective hi-vol by solid particles larger than the 15-μm cutoff was measured by three methods. Near the cutoff, monodisperse spray-dried particles that were sized aerodynamically by a new laser sedimentation velocimeter were used. In the 35 to 60 μm range, glass beads and A/C test dust particles were produced by a new sonic fluidized microbed generator. Finally, ambient particles that were collected on a Nuclepore after filter were analyzed by scanning electron microscopy. All three tests show that excess penetration of the size-selective hi-vol by solid particles was acceptably small. Additional testing was conducted in ambient air using an array of side-by-side samplers including two dichotomous samplers, two monocut samplers, and a cyclone sampler.

This Project Summary was developed by the Environmental Monitoring Systems Laboratory, Research Triangle Park, North Carolina, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The Environmental Protection Agency (EPA) is considering revisions to the National Ambient Air Quality Standards (NAAQS) for particulate matter. Once promulgated, the revised standards would regulate only those particles that can be deposited in the human respiratory system. The rationale for a standard for inhalable particles, those particles smaller than 15 μm aerodynamic diameter,* which are deposited in the respiratory system below the trachea, has been presented by Miller, et al.

A network of inhalable particle samplers has been deployed across the United States by the Environmental Monitoring Systems Laboratory at Research Triangle Park, North Carolina (EMSL/RTP) to field test the sampling methodology and to acquire a data base in support of the new standard. Early results revealed that the samplers have some technical problems. These experiences emphasize the need for rigorous testing of the new samplers because they will generate data that will be the basis for control decisions.

During the present project, the dichotomous and size-selective hi-vol samplers used in the EPA network were tested in the laboratory. Additional testing was carried out on side-by-side samplers in ambient air. The new testing methods that were developed include measurement of nozzle alignment in the dichotomous sampler, precision wall loss measurements, and tests for particle bounce. These

*After the present work was completed, the EPA staff recommended a cutpoint of 10 μm for the revised particulate matter standard. Modified versions of the 15 μm samplers are now available. Some, but not all, of the test results presented here are outdated, but the test methodology is still current.

methods should be useful for the formulation of acceptance criteria for new candidate samplers and for quality assurance testing of commercial samplers.

Results

Laboratory testing of the dichotomous samplers included measurement of the critical dimensions of the inlets and the virtual impaction stage, determination of the effect of wind speed on the effectiveness of inlet sampling, and precision measurement of the wall losses in the samplers. Testing of inlets to commercial dichotomous samplers reveals that the critical dimensions adhere closely to manufacturing tolerances. However, wind tunnel and static chamber tests reveal that the inlet sampling effectiveness is excessively dependent on wind speed. Flow visualization studies show strong channeling of the flow inside the inlet. A theoretical model including inertial and gravitational forces accounts for the test data and provides a basis for an inlet modification consisting of an enlarged entrance slit and an inertial impactor. Tests of two variations of this modification show that this is a promising approach that permits a low-cost retrofit to existing inlets. The design also facilitates a change in particle size cutpoint.

The cutoff (coarse fraction vs. particle diameter) for the virtual impaction stage of the dichotomous sampler was measured with DOP-uranine aerosol. The results agreed with independent measurements by Loo and by McFarland. A casting method was developed to measure the critical dimensions of the dichotomous sampler stage. The nozzle concentricity was out of tolerance in three out of five samplers. Design faults were revealed and a simple method was suggested for improvement of the concentricity.

Laboratory tests with monodisperse aerosol show that the 50% particle size cutpoint of the impactor stage of the dichotomous samplers averages 2.4 μm and the wall loss at the cutpoint averages 2.3%, both acceptable figures. Wall losses peaked at the cutpoint and increased again above 10 μm. Most of the losses were on the collection nozzle (Figures 1 and 2). While the wall losses were small for 3-μm particles, the fine fraction correlated with error in nozzle concentricity (Figure 3); therefore, close adherence to the tolerance on the nozzle concentricity is recommended. The magnitude of the wall loss agreed with the measurements by Loo but did not agree with the results of McFarland. The losses at 2.5 μm are about twice as large as those reported by Loo for the prototype. This increase is probably caused by larger tolerances in the commercial samplers for nozzle concentricity and collection nozzle profile. However, the wall losses are acceptable in the commercial units. The high precision of the measurements obtained with standard laboratory equipment indicates that the present methodology provides a basis for a standard approach to sampler wall loss measurements.

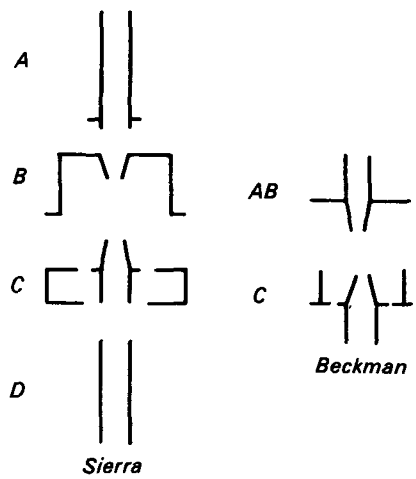

Figure 1. ***Schematic drawing of dichotomous sampler impactor parts that were washed separately to recover wall losses.***

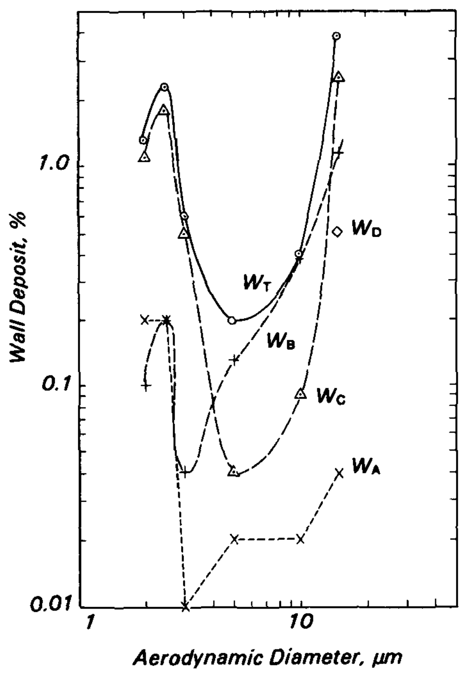

Figure 2. ***Wall losses measured for individual parts of the dichotomous samplers (parts are labelled as in Figure 1).***
W_T = Total wall loss ($W_A + W_B + W_C + W_D$).

Laboratory testing of the size-selective hi-vol sampler inlet included measurement of sampling effectiveness for liquid particles and determination of excess penetration by large solid particles. Measurements made with DOP-uranine to test the sampling effectiveness of the size-selective hi-vol inlet under static conditions agreed with previous measurements made by Wedding and by McFarland and Ortiz in a wind tunnel at 2 km/h. These data and the previously described results for the dichotomous sampler show that independent laboratories can use liquid aerosols to obtain consistent results for cutoff and effectiveness measurements.

Three methods have been developed for measurement of the penetration of a size-selective sampler by large solid particles. (1) Near the cutoff, monodisperse spray-dried particles were used from a vibrating orifice aerosol generator and sized aerodynamically with a laser sedimentation velocimeter. (2) Particles much larger than the cutoff were produced by a new sonic fluidized microbed generator using presized samples of glass beads and A/C test (Arizona Road) dust. (3) Penetration by large ambient particles was measured by microscopy after they were collected on a Nuclepore after filter.

The three methods were applied to the size-selective hi-vol sampler. Method 1 indicated a 25% excess penetration by solid vs. liquid particles at the 15-μm cutpoint (Figure 4). However, this penetration would not ordinarily lead to a serious error in sampled mass because the cutpoint for solid particles (17 μm) is only slightly larger than 15 μm and the test particles are bouncier than most ambient particles. Method 2 showed 3 to 4% penetration (by mass) of particles that had aerodynamic diameters in the range of 35 to 60 μm (Figure 5). Seven percent penetration was observed for 62 μm A/C test dust particles, but this may be caused by breakup of the particles, an inherent problem with A/C test dust. Glass beads were excellent test particles. Examination of the impaction plate showed that the particles did not adhere to the plate in the impaction zone but were collected near the bases of the collection tubes. Therefore, the particles bounced, but were not reentrained in the exit flow. Method 3

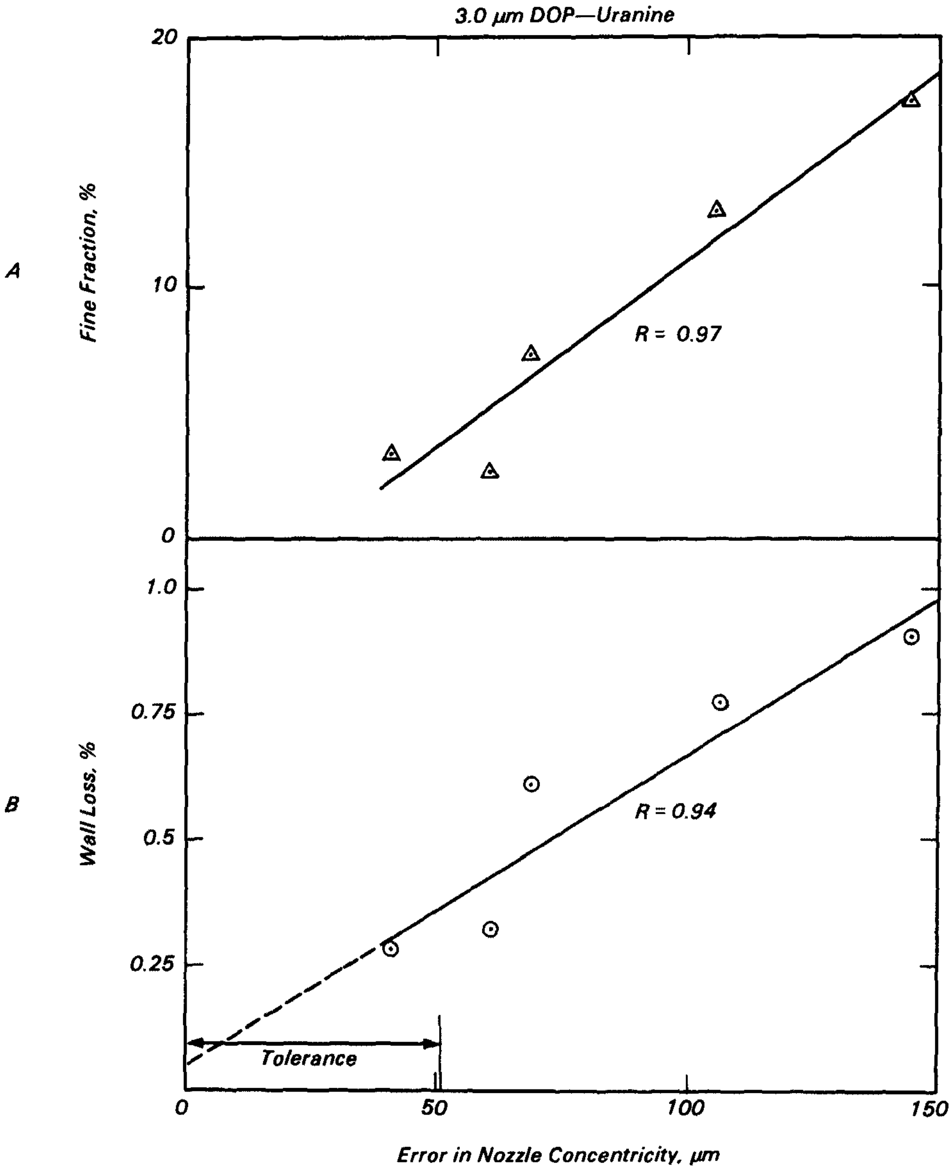

Figure 3. *A: Fine fraction of the dichotomous sampler vs. error in nozzle concentricity.*
B: Wall loss vs. error in nozzle concentricity.

gave a penetration efficiency of 5% for ambient particles that had aerodynamic diameters greater than 30 μm; these results agree with those of method 2.

Ambient air testing on side-by-side samplers shows that the standard deviation of the coarse fraction of the dichotomous sampler is more than twice that of the fine fraction and nearly twice that of the monocut samplers. The fine fractions correlated closely with the mass concentration from the Air and Industrial Hygiene Laboratory (AIHL) cyclone, and the sum of the coarse and fine fractions correlated closely with the mass concentration from two monocut inhalable particle samplers. One dichotomous sampler had a consistent bias of about -10% relative to the other samplers; the cause of this bias was undetermined.

Conclusions and Recommendations

The experience from the validation program for inhalable particle samplers emphasizes the importance of rigorous testing. Precise tests with laboratory aerosol can lead to correction of problems before costly tests are conducted in ambient air. Sampler inlets need to be wind tunnel tested to verify that wind speed sensitivity is within acceptable limits. Low wind speeds (not more than 2 km/h) should be included to ensure that particle sedimentation within the inlet is not significant. Samplers should be tested with monodisperse liquid particles for efficiency and wall loss measurements and with solid particles to determine possible excess penetration resulting from bounce and reentrainment.

This study resulted in the development of several testing techniques which are recommended for future work. The method for wall loss measurements is capable of accuracies approaching 0.1% and requires only standard apparatus. Three methods for measurement of solid particle penetration have been developed.

Additional work is needed for adaptation of the laboratory solid particle tests used in wind tunnel testing. Static sampling is sufficient for testing of an impaction stage in a sampler. Use of A/C test dust is not recommended because of its friable nature.

The following recommendations are based on the current test results:

(1) The inlet to the dichotomous sampler should be replaced with one that is insensitive to wind speed.
(2) Accurate nozzle alignment in the commercial dichotomous samplers should be ensured by the simple design change identified in the research report.
(3) The size-selective hi-vol, which performed well under all testing, should continue to receive consideration as a candidate sampler.

References

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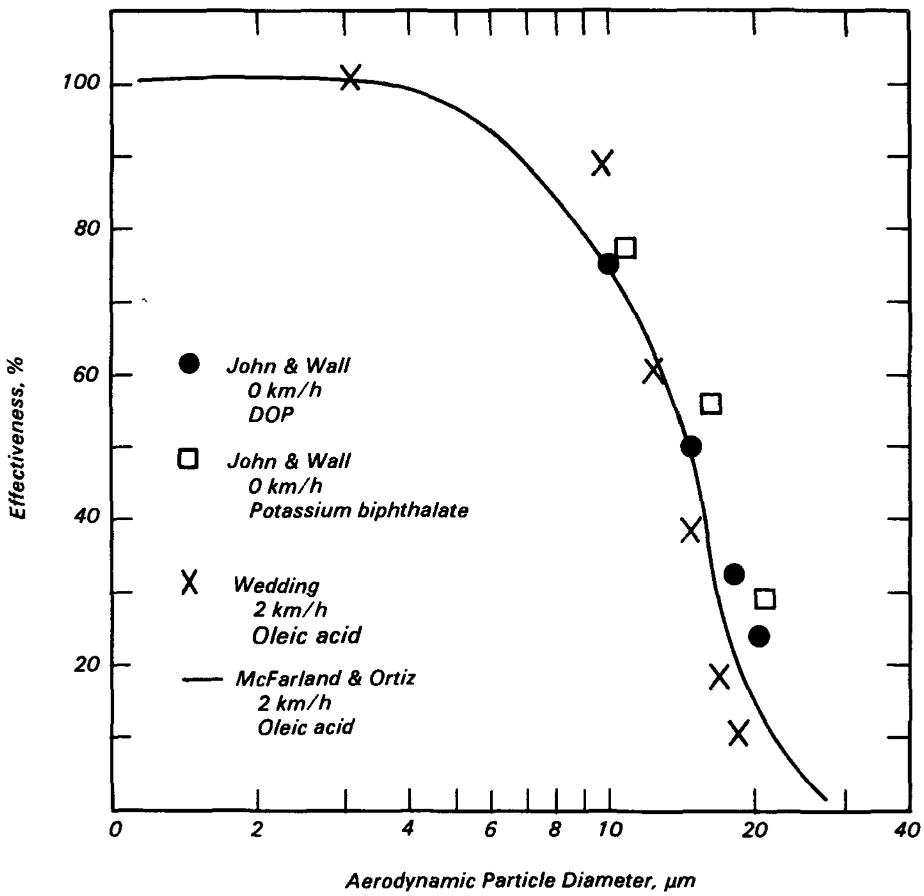

Figure 4. *Sampling effectiveness of the size-selective hi-vol measured at zero wind speed for liquid (DOP) and solid (potassium biphthalate) particles. Data from wind tunnel tests at 2 km/h wind speed are shown for comparison.*

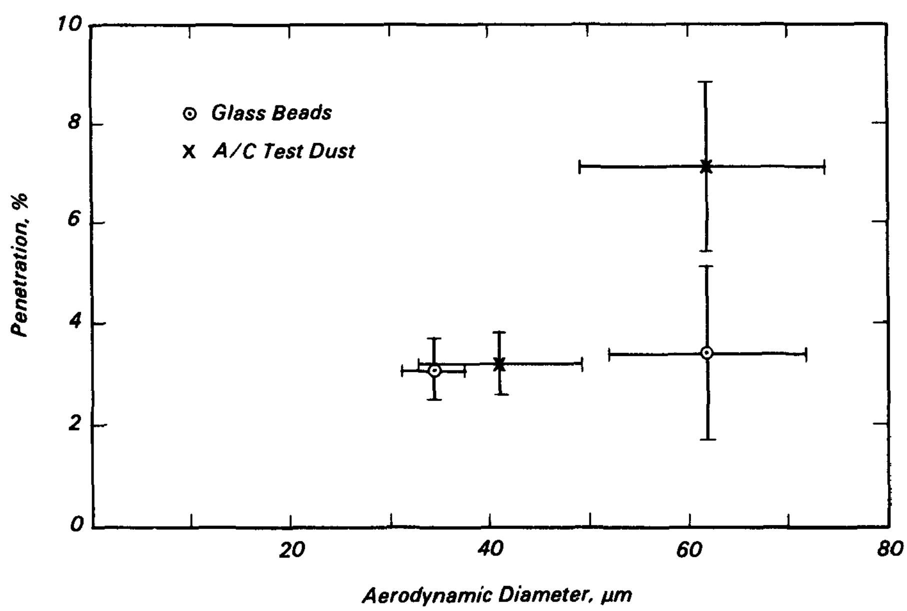

Figure 5. *Penetration of the size-selective hi-vol by large glass beads and A/C test dust.*

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The complete report, entitled "Validation of Samplers for Inhaled Particulate Matter," (Order No. PB 83-191 395; Cost: $11.50, subject to change) will be available only from:
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