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WIND TUNNEL TEST REPORT NO. 29A

TEST OF THE RUPPRECHT AND PATASHNICK TEOM PM10 SAMPLER INLET AT 2 AND 24 KM/H

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ABSTRACT

Wind tunnel tests of the Rupprecht and Patashnick (R&P) 10-μm inlet for the TEOM Series 1400 PM-10 monitor have been conducted at 2 and 24 km/h. The purpose of the test was to compare the R&P inlet to the Sierra-Andersen (SA) 246b Dichotomous Sampler inlet. The test program was conducted in the EPA Aerosol Test Facility (ATF). The procedures used were those specified in 40 CFR Part 53 except that a reduced number of test particle sizes were used. All tests utilized liquid challenge particles, and tests were conducted at either 2 or 24 km/h.

Based on these limited tests, the R&P inlet appears to be functionally identical to the SA 246b Dichotomous Sampler Inlet. Using the standard PM_{10} data analysis procedure, the R&P inlet cut-point was estimated to be 9.8 μm at 2 km/h and 9.6 μm at 24 km/h (compared to 9.8 and 10.0 μm, respectively, for the SA 246b.)

Concurrently with the R&P Inlet test, the Saturation Monitor (SM) and Combustion Engineering Portable Indoor Particulate Sampler (PIPS) were tested. The results for these inlets are given in VanOsdell (1991).

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TEST OF THE RUPPRECHT AND PATASHNICK TEOM PM10 SAMPLER INLET AT 2 AND 24 KM/H

1 .O INTRODUCTION

This report documents a test whose primary purpose was to evaluate the R&P 10-µm inlet for the R&P TEOM Series 1400 Continuous PM-10 Monitor. The R&P inlet is essentially identical to the widely-used Sierra-Andersen (SA) 246b 10-µm inlet, which has been commercially available for a number of years. VanOsdell and Chen (1996) previously reported the results of a wind tunnel test of the SA 246b at the EPA ATF. Because the R&P inlet is a copy of the SA 246b, it was expected to be a fully satisfactory PM,, inlet. During this test, the R&P inlet was tested in the EPA ATF following an abbreviated PM_{10} test protocol that included 6 particle sizes at 2 and 24 km/h. By itself, this test was not sufficient to show that the R&P inlet met the criteria of 40 CFR Part 53 for reference and equivalent PM_{10} samplers. It was sufficient to find any significant differences in performance between the SA 246b and the R&P inlet.

Also tested during this test program were the Saturation Monitor (SM) and the Portable Indoor Particulate Sampler (PIPS) sampler heads. The SM, constructed of plastic pipe, was designed to be an inexpensive outdoor PM,, monitor. The PIPS was designed for indoor monitoring of particles in rooms, Two SMs and two PIPSs were run during each test of the R&P Inlet. Results for these inlets can be found in VanOsdell (1991).

2.0 CONCLUSIONS

Based on this test of the R&P 10-µm size-selective inlet, the following conclusions are drawn:

1. **The wind tunnel effectiveness performance of the R&P inlet is substantially the same as that of the SA 246b inlet at 2 and 24 km/h.**

2. **Given the physical similarity of the two inlets, the R&P inlet appears to meet the requirements of 40 CFR Part 53 for a PM_{10} inlet. Because 2 and 24 km/h are the extremes of the measurement range, it can be reasonably inferred that the R&P inlet would also perform satisfactorily at 8 km/h.**

3.0 EXPERIMENTAL PROCEDURES

The test procedures used in the EPA Aerosol Test Facility were the same as those used and reported previously (VanOsdell, Chen, and Newsome, 1988). Individual tests met the requirements of 40 CFR Part 53. Because the test program was designed primarily to compare the R&P inlet to the SA 246b only 2 wind speeds and about half the number of particle sizes called for in 40 CFR Part 53 were tested during the present work. A brief overview of the test procedures is given below, and details may be found in the report by VanOsdell, Chen, and Newsome (1988).

3.1 WIND TUNNEL ARRANGEMENT

Figure 1 gives an overview of the EPA Aerosol Test Facility and the wind tunnel. Flow in the wind tunnel was counterclockwise. There are few flow obstructions, and a number of access doors are provided to allow all sections of the wind tunnel to be cleaned. The test aerosol was generated on top of the wind tunnel where indicated, and injected through a distributor into the 1.83 m square cross-section region below. The sampler test area is also indicated in Figure 1. At the test area the wind tunnel cross-section is 1.52 m wide by 1.22 m high. The blower downstream of the sampler test area is capable of driving the wind tunnel at speeds up to 50 km/h (1550 m^3/min).

Some wind tunnel arrangement details not shown on Figure 1 were required to achieve acceptable particle and velocity uniformity at the 2 wind speeds. A plywood baffle was placed about 1 m upstream of the 1.83 m square cross-section particle injection zone to promote mixing. The baffle was 1.22 m square and mounted in the center of the wind tunnel transverse to the air flow. A counter-flow fan, 0.4 m in diameter and centered in the cross-section, was operated about 1 m downstream from the injection zone to provide additional mixing.

At 24 km/h, the large blower in Figure 1 powered the wind tunnel, and the filter/chiller was not turned on except to clean the wind tunnel air for 30 min before beginning each day's testing. The large blower could not be slowed enough to power the wind tunnel at 2 km/h. To operate at 2 km/h, the damper indicated on Figure 1 was closed and the filter/chiller fan used to power the wind tunnel. To prevent flow channeling along the wall of the wind tunnel during the 2 km/h tests, a center-hole baffle was placed 2 m downstream of the sampler test area (and about 1 m upstream of the filter/chiller inlet. This baffle blocked the wind tunnel except

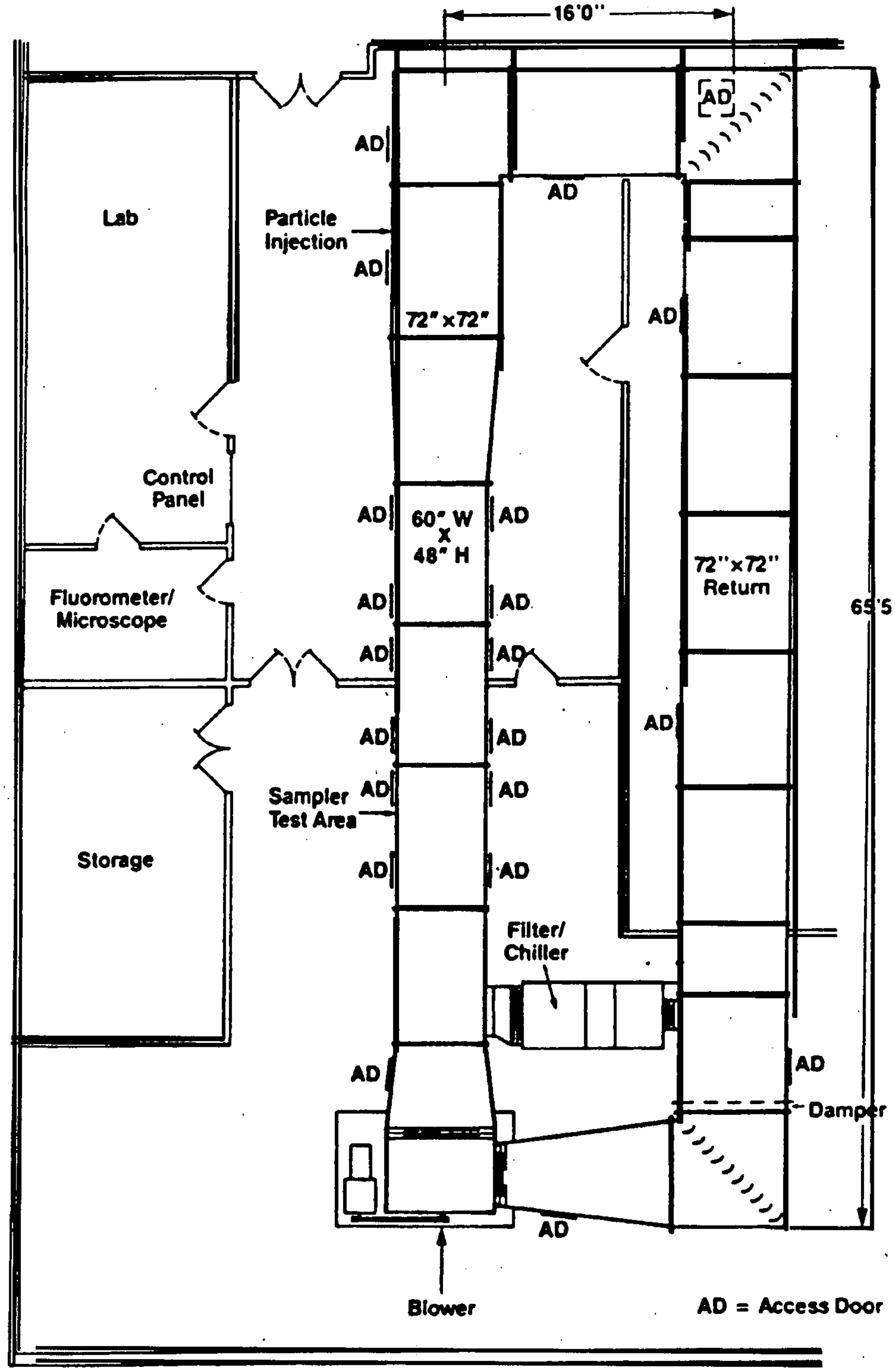

Figure 1. EPA Aerosol Test Facility and Wind Tunnel

for the 3O-cm square hole in its center, and provided a symmetric flow profile at 2 km/h.

The velocity uniformity and turbulence intensity have been previously measured, with the wind tunnel in the same physical configuration. The results are given in Table 1. The values at the center of the wind tunnel were checked before beginning this test and found to be within the ranges in Table 1. These flow parameters are within acceptable limits for PM_{10} testing.

Table 1. Wind Tunnel Set-Up for 2 and 24 km/h

Mean Wind Speed	Baffle Arrangement	Mixing Fan	Velocity Uniformity	Turbulence Intensity in Test Zone
2 km/h	1.22 m^2 centered	On	± 5%	3 - 4 %
24 km/h	1.22 m^2 centered	On	± 4%	4 - 5 %

Note: Velocity uniformity was calculated as the deviation from the mean within the test zone. Velocity was measured with a hot-film probe.

3.2 AEROSOL GENERATION

The test was conducted with monodisperse test aerosols generated using a vibrating orifice aerosol generator (VOAG). The aerosol material, oleic acid, was tagged with uranine, a fluorescent dye, and the oleic acid and uranine were both dissolved in an ethanol carrier. The concentration of nonvolatiles (oleic acid and uranine) in the ethanol varied as required to obtain the desired particle size after the ethanol evaporated. Typical VOAG operation utilized a 20 µm orifice, 0.165 mL/min feed rate, and a frequency of about 70 kHz. Particle size was calculated from the VOAG and particle solution parameters, and verified microscopically using Nye-Bar treated glass slides and a flattening coefficient determined by Olan-Figueroa et al. (1982). The liquid particles generated for the test had nominal diameters of 5, 7, 9, 10, 12, and 25 µm.

The test aerosol was blown down into the wind tunnel through a dispersion manifold, and dispersed across the wind tunnel cross-section within the 10 m between the injection site and test zone. The uniformity of particle dispersion and particle challenge concentration were evaluated during each test using an array of five isokinetic samplers placed within the test zone and operated simultaneously with the samplers being tested, The results of a day's tests were not useable if the particle mass collected by each individual isokinetic sampler that day was not within +/- 10 percent of the mean particle mass from the 5 isokinetic samplers, No tests during the present test program had to be rejected. The isokinetic samplers are described more fully below.

3.3 SAMPLER POSITION AND OPERATION

Figure 2 shows the arrangement of the samplers in the wind tunnel in a view along the direction of wind flow. The inlet of each sampler was positioned in the same axial plane of the wind tunnel (the same distance from the particle injection point.) That is, the upstream edges of the R&P inlet, the SMs, and the PIPSs were all in the same plane as the upstream ends of the isokinetic sampler nozzles. (The isokinetic samplers are indicated as I1 through 15. Dimensions above the wind tunnel floor are referenced to the center of the PIPS inlet hole, the bottom of the SM wind cap, and the center of the isokinetic samplers.

The isokinetic samplers were 47 mm fitter holders fitted with sharp-edged conical nozzles, and were operated isokinetically. The suction pipe at the back of each sampler was clamped to a support frame to hold the sampler in position with the nozzle inlet about 25 cm upstream of the support frame. At 2 km/h, the nozzles' inlets were 2.94 cm in diameter and the samplers were operated at 22.6 L/min. At 24 km/h, 1.22 cm diameter nozzles operated at 46.8 L/min were used. The flow rate through each sampler was controlled with a manual valve that was preset to the required flow rate. During a test, the total flow through each sampler was measured with a dry gas meter. The house vacuum manifold was used to draw the sample through the isokinetic samplers,

The R&P inlet was attached to a 3.2 cm OD aluminum riser tube and supported at the center of the wind tunnel as shown in Figure 2 A 47 mm fitter holder was mounted at the bottom of the tube, and a Gelman A/E glass fiber filter collected the aerosol that penetrated the inlet. The flow rate through the R&P inlet was controlled manually with a valve that was adjusted to the required 16.7 L/min prior to the test. During a test, the total flow was measured using a dry gas meter. Suction was provided by the house vacuum manifold.

The other samplers were also positioned as shown in Figure 2. They were held in place using 3-

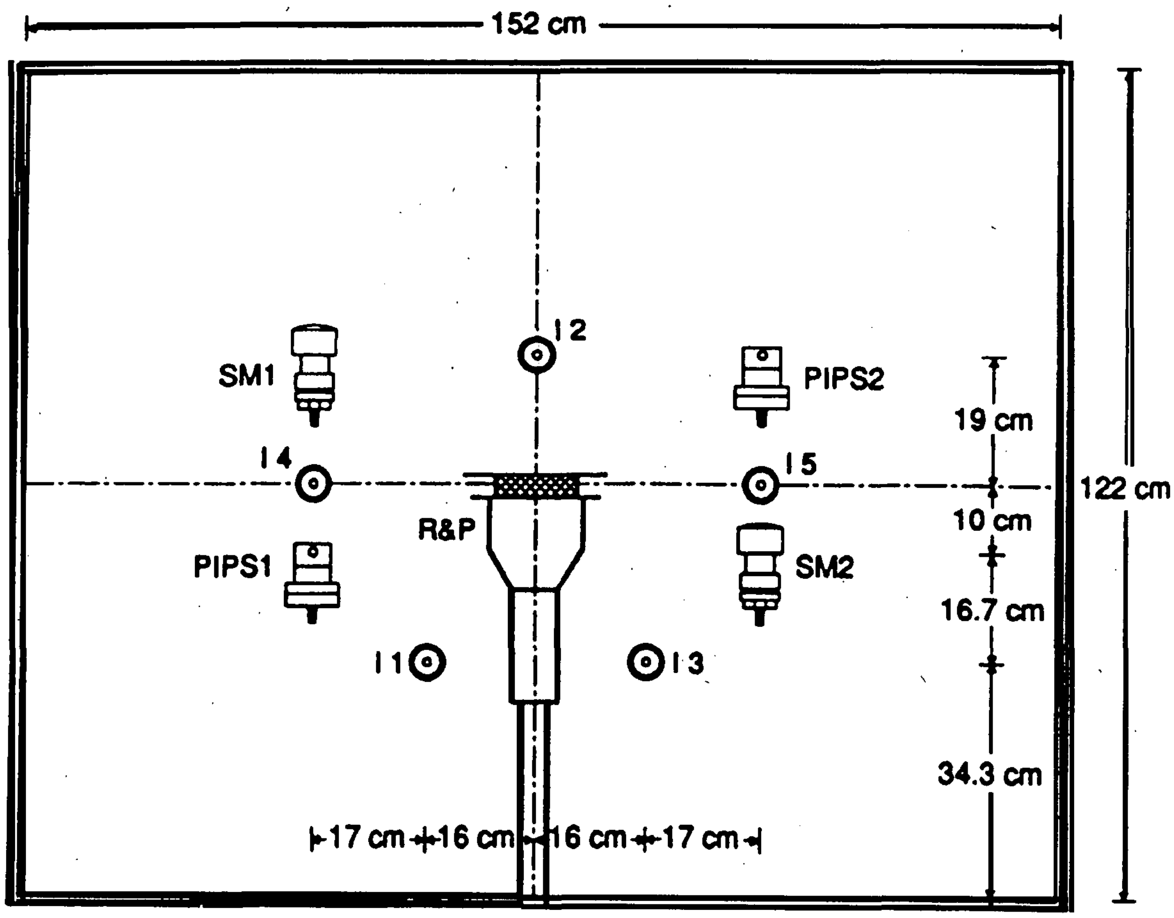

Figure 2. Arrangement of Samplers in the ATF Wind Tunnel

fingered laboratory clamps that were themselves clamped to the support frame. With flow rates of 5 L/min for the saturation monitors and 10 L/min for the PIPSs, their sampling did not affect flow near the R&P inlet.

3.4 INLET TESTS

Three sequential tests of the inlets were conducted on the same day using the same test aerosol for most particle sizes. The R&P inlet, two SMs, two PIPSs, and 5 isokinetic filter samplers were operated simultaneously during each of the tests. The duration of each test was set to ensure that the aerosol mass captured on the sampler filters was sufficient to provide a reliable measurement. Most runs lasted 1 hour, but the 5 and 25 µm particle runs at 24 km/h were 3 hours long.

The sampling effectiveness of the R&P inlet was computed as the ratio of the measured mass concentration to the mean of the mass concentration measured by the five isokinetic samplers shown in Figure 2.

3.5 ANALYSIS OF MASS COLLECTED ON FILTER SAMPLES

Following the EPA Aerosol Test Facility standard procedures, the filters from the samplers were placed in clean 2 oz. bottles to which 20 ml of 0.01 N NaOH were added. The uranine was extracted from the filters into the NaOH solution by soaking overnight following 20 minutes of ultrasonic mixing. The mass of test aerosol collected on the filters was determined fluorometrically using standard ATF procedures. The nozzles of the isokinetic samplers were washed and the uranine found in the wash was added to the uranine collected on the filter to obtain the total challenge aerosol mass. The inlet sections of the R&P inlet, SMs, and PIPSs were not washed.

3.6 DATA ANALYSIS

The raw effectiveness data from the samplers was analyzed using the PM_{10} data analysis procedure normally used at the ATF. The three effectiveness values for each test were averaged to obtain a value at each test particle size. These effectiveness values were then input to the PM_{10} data analysis computer program (VanOsdell, Chen, and Newsome, 1988). For each sampler and wind speed, the effectiveness data were adjusted to account for the presence of multiplets of the primary challenge particle. A robust-spline curve (in log-normal space) was then fit to the multiplet-corrected data The PM_{10}, data analysis procedure outlined in 40 CFR Part 53 requires that the effectiveness-particle size data be fit with a smooth curve and that the ends of the curve be smoothly extrapolated to 100 percent at 1 µm and 0 percent at 50 µm, and this requirement has been implemented mathematically in the data analysis program. (Because the curve fit is generated in log-normal space, values above 100 percent are suppressed.) The program usually fits effectiveness data well, especially in the region of the cut-point, and it provides an impartial estimate of an inlet's performance parameters. The robust spline curve-fit process does not impose any preconceived functional form on the data The D_{50}, expected mass collection for the PM,, ambient particle size distribution (40 CFR Subpart D, Part 53,Table D-3), and expected mass ratio were all computed based on the robust-spline curve.

4.0 RESULTS AND DISCUSSION

4.1 EFFECTIVENESS RESULTS

Figure 3 presents a direct comparison between the current test of the R&P inlet and a previous test of the SA 246b inlet (VanOsdell and Chen, 1990). (To facilitate comparisons with the results presented by VanOsdell and Chen (1990), the effectiveness values in Figure 3 have not been multiplet-corrected.) At both 2 and 24 km/h, the R&P and SA 246b effectiveness values agree extremely well, and show little wind speed dependence.

A summary of the test program results (after correction for multiplets) is presented in Table 2. The

Table 2. Summary of Multiplet Corrected R&P Test Results

	R&P Inlet
2 km/h D_{50} µm	9.82
2 km/h Expected Mass, µg/m³	148.0
2 km/h Mass Ratio to Ideal PM,, Sampler	1.028
24 km/h D_{50} µm	9.58
24 km/h Expected Mass, µg/m³	147.8
24 km/h Mass Ratio to Ideal PM_{10}, Sampler	1.027

Note: All values computed using standard PM10 Data Reduction Program. All effectiveness values were corrected for multiplets.

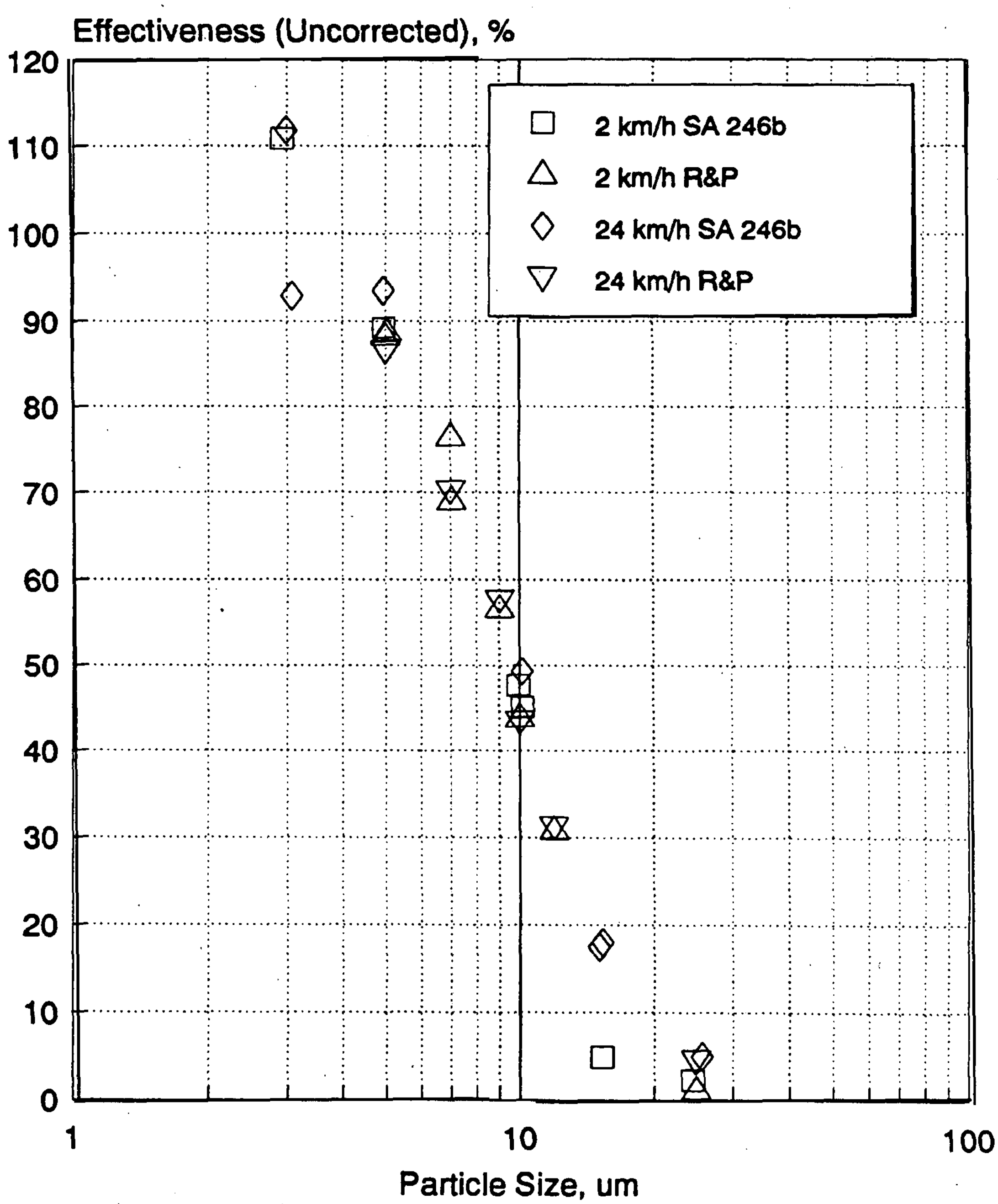

Figure 3. Comparison of SA 246b and R&P Inlets

Expected Mass and Mass Ratio to Ideal Sampler are values used to compare PM_{10}, samplers. The ideal sampler effectiveness performance curve and the ambient particle mass distribution are given in 40 CFR Part 53. The expected mass is obtained by multiplying the mass in each size fraction of the size distribution by the sampler's effectiveness at that size and summing over the size distribution. The ratio is self-explanatory. The complete data sets for each wind speed are given in the Appendix

Figure 4 shows the data and curve-fits for the R&P inlet at 2 and 24 km/h. The data are seen to be well-behaved, and the D_{50}, expected mass, and mass ratio values given in Table 2 provide good representations of the R&P sampler's behavior. Within the limits of this data set, the R&P IO-µm Inlet appears to easily meet the wind tunnel sampling requirements of 40 CFR Part 53. While the 8 km/h data were not gathered, the 2 and 24 km/h data span the limits of interest and are the most likely velocities for a sampler to fail the test procedure.

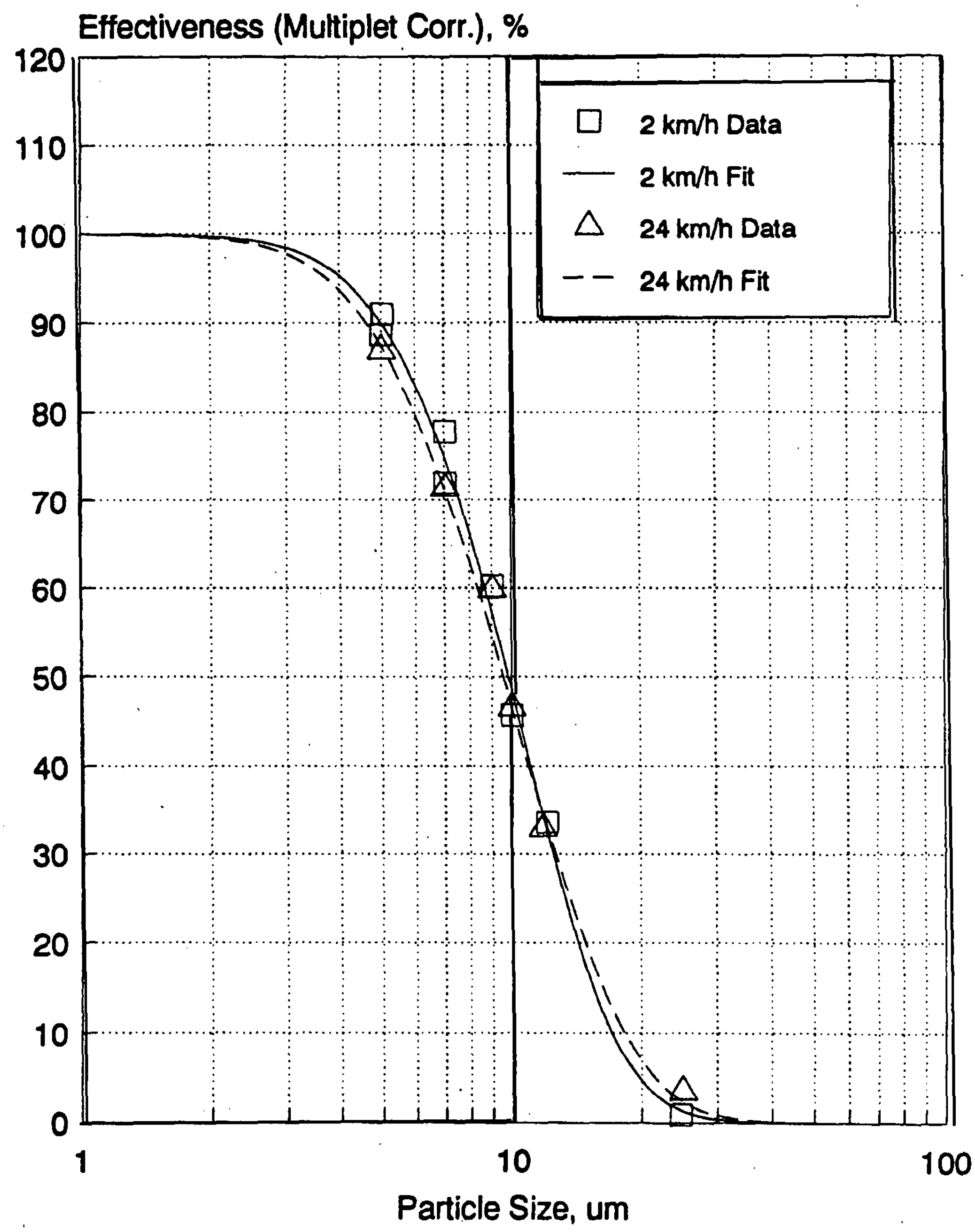

Figure 4. R&P 10-µm Inlet Performance at 2 and 24 km/h

5.0 REFERENCES

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APPENDIX

Table A-1. Effectiveness Data

Date	Aero. Dia. (µm)	Geo. Std. Dev.	% Doub	% Trip.	R&P Inlet Eff. (%)	Part. Conc. (µg/m³)	COV* Rake Meas. (%)
2 km/h Tests							
3/12/91	10.03	1.025	6.3	0.0	42.8	2.54	2.0
3/12/91	10.03	1.025	6.3	0.0	44.8	2.56	2.1
3/12/91	10.03	1.025	6.3	0.0	44.2	2.61	1.8
3/13/91	5.04	1.028	7.1	1.3	97.8	.27	5.3
3/13/91	5.04	1.028	7.1	1.3	82.6	.25	6.0
3/13/91	5.04	1.028	7.1	1.3	85.7	.26	4.0
3/18/91	24.71	1.015	2.3	0.0	1.7	2.34	6.4
3/18/91	24.71	1.015	2.3	0.0	1.0	1.08	5.0
3/18/91	24.71	1.015	2.3	0.0	0.9	2.14	5.8
3/19/91	5.01	1.035	2.3	0.0	97.8	.26	4.1
3/19/91	5.01	1.035	2.3	0.0	91.6	.25	2.5
3/19/91	5.01	1.035	2.3	0.0	95.3	.25	2.6
3/21/91	7.04	1.022	6.6	1.7	71.3	1.47	2.2
3/21/91	7.04	1.022	6.6	1.7	71.5	1.37	.9
3/21/91	7.04	1.022	6.6	1.7	64.5	1.31	.7
3/26/91	12.09	1.025	5.1	3.4	30.3	4.11	1.0
3/26/91	12.09	1.025	5.1	3.4	30.3	4.20	3.9
3/26/91	12.09	1.025	5.1	3.4	32.1	4.36	1.6
3/27/91	9.05	1.016	8.6	0.0	58.0	2.08	.8
3/27/91	9.05	1.016	8.6	0.0	57.4	2.03	2.0
3/27/91	9.05	1.016	8.6	0.0	54.7	2.10	.7
3/28/91	7.04	1.023	3.4	0.0	75.1	1.49	5.5
3/28/91	7.04	1.023	3.4	0.0	78.5	2.03	3.1
3/28/91	7.04	1.023	3.4	0.0	75.9	1.52	1.6

Date	Aero. Dia. (µm)	Geo. Std. Dev.	% Doub	% Trip.	R&P Inlet Eff. (%)	Part. Conc. (µg/m³)	COV* Rake Meas. (%)
24 km/h Tests							
4/15/91	5.00	1.035	2.3	0.0	86.5	.20	2.8
4/16/91	9.00	1.018	3.6	0.9	54.8	.31	5.0
4/16/91	9.00	1.018	3.6	0.9	57.4	.31	2.5
4/16/91	9.00	1.018	3.6	0.9	61.0	.29	4.0
4/17/91	11.83	1.015	4.8	1.9	31.9	.46	5.5
4/17/91	11.83	1.015	4.8	1.9	30.8	.48	1.4
4/17/91	11.83	1.015	4.8	1.9	31.3	.48	5.2
4/18/91	7.00	1.024	2.7	0.7	77.2	.41	5.7
4/18/91	7.00	1.024	2.7	0.7	65.7	.40	3.7
4/18/91	7.00	1.024	2.7	0.7	67.6	.41	3.1
4/24/91	24.99	1.007	6.8	2.2	4.6	.63	7.8
4/29/91	10.00	1.028	6.5	1.9	44.5	.47	4.8
4/29/91	10.00	1.028	6.5	1.9	41.0	.46	5.0
4/29/91	10.00	1.028	6.5	1.9	45.6	.50	5.0

*COV = Coefficient of Variation (Std. Dev./Mean) for concentration measurements by the 5 rake samplers