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Development and Evaluation of a PM_{10} Impactor-Inlet for a Continuous Coarse Particle Monitor

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Conventional PM_{10} inlets available operate at a flow rate of 16.7 l/min. The purpose of this study was to develop and test a PM_{10} inlet designed to operate at 50 l/min to be used with a recently developed continuous coarse particle monitor (Misra et al.). Laboratory tests using polystyrene latex particles established the inlet's 50% cutpoint at 9.5 μm. Further evaluation of PM_{10} inlet was performed in a wind tunnel at wind speeds of 3, 8, and 24 km/h. Tests showed that the 50% efficiency cutpoint as well as the very sharp particle separation characteristics of the inlet were maintained at these wind speeds. Field evaluation of the PM_{10} inlet was performed in Riverside and Rubidoux, CA. A 2.5 μm cutpoint round nozzle virtual impactor was attached downstream of the developed PM_{10} inlet. The Dichotomous PM_{10} Partisol Sampler, operating at a flow rate of 16.7 l/min was used as a reference sampler. The Dichotomous Partisol uses an FRM PM_{10} inlet operating at 16.7 l/min to remove particles larger than 10 μm in aerodynamic diameter. Commercially available 4.7 cm Teflon filters were used in both the Partisol and the PM_{10} inlet to collect particulate matter (PM). Results showed good agreement between coarse PM (2.5–10 μm) mass concentrations measured by means of the PM_{10} inlet and Partisol. Chemical analyses showed excellent agreement between coarse PM concentrations of Al, K, Si, Ca, and Fe obtained by the two samplers. The agreement also persisted for nitrate and sulfate. Finally, the excellent agreement between coarse concentrations of the PM_{10} inlet and Partisol persisted for wind speeds up to 19 km/h.

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INTRODUCTION

Since the advent of the particulate matter (PM) standards by the United States Environmental Protection Agency (US EPA), particle sampling has been a primary goal of both scientists and lawmakers. The addition of the $PM_{2.5}$ (fine particle) and the soon-to-be-developed PM_{10}–$PM_{2.5}$ (coarse particle) standards to the PM_{10} standard has created the need for reliable continuous coarse and fine PM measurement devices. One such device, a continuous coarse particle monitor (CCPM), is described by Misra et al. (2001).

An essential component of any modern PM monitoring device is a size preselective inlet. This is even more important when the size range to be removed prior to sampling consists of large particles. If the inlet allows even a small fraction of the undesirable PM into the measuring device, the error could be large. The reason for this is that large particles have large masses, which will heavily influence the measurement of a mass-based monitor.

Because of their large mass, hence inertia, coarse particles are difficult to sample and collect. When these heavy particles are accelerated in an impactor jet, their substantial inertia causes them to hit the impactor collection plate. Many times the particle will bounce off of this plate and become re-entrained in the air stream. This causes overestimation of the mass downstream of the inlet. Another problem that occurs because of the inertia of these particles is the underestimation or overestimation of particle mass that results from anisokinetic sampling. Unlike the PM in smaller size ranges, coarse PM is not as uniformly dispersed in the atmosphere. It settles and becomes resuspended due to localized events (i.e., high wind episodes). The original inlet employed to characterize the CCPM—which is described in more detail by Misra et al. (2001)—was subject to this error. That inlet consisted of a simple 90° elbow with a jet fashioned from a pipe with a preset diameter. Particles larger than about

10 μm impacted on the throat of that elbow. Among its problems were that it sampled from only one direction (thus was prone to substantial anisokinetic sampling errors if the wind direction was not in alignment with the inlet) and also needed to be regreased periodically in order to prevent bounce of large particles. Additionally, the inlet's efficiency curve was not as steep as most commercially available PM_{10} inlets.

Currently, several manufacturers have developed commercially available PM_{10} inlets, some of which have received designation from the US EPA to be used as federal reference methods. These inlets operate at sampling flow rates ranging from 16.7 to 1133 l/min. A comprehensive review of PM_{10} and other federal reference method inlets is given by Chow (1995). The SA (Thermo-Anderson, Smyrna, GA) or GMW (General Metal Works, Tisch Environmental, Village of Cleves, OH) Models 321A, 321B, 1200, and Wedding $IP_{10}PM_{10}$ operate at the highest flow rate. The SA 254 Medium-Volume PM_{10} Inlet operates at a flow of 113 l/min, and the SA 246B operates at a design flow of 16.7 l/min (Chow 1995). None of the devices listed above, however, is compatible with the CCPM's flow rate of 50 l/min.

To these ends, an efficient and low-maintenance PM_{10} inlet was designed and evaluated for a flow rate of 50 l/min. The inlet's design flow rate accommodates the CCPM developed by Misra et al. (2001). The goals of this newly developed inlet are to overcome anisokinetic sampling, sharpness of cutpoint, and limited capacity of other commercially available PM_{10} inlets.

MATERIALS AND METHODS

Description of the PM_{10} Impaction Inlet

The inlet used in these tests is a modification of a commercially available PM_{10} inlet, from Rupprecht and Patashnick (Model P/N 57-00596, R&P Inc., Albany, NY), which operates at a flow rate of 16.7 l/min. This inlet is described in detail in (US EPA 1996). To adapt the inlet so that it could operate at 50 l/min, the nozzle was modified by widening the nozzle diameter and also shortening the nozzle length so as to increase the jet-to-plate distance. The schematic of the inlet is shown in Figure 1a. The modifications along with the new dimensions are given in Figure 1b. The nozzle design parameters were modified so that the predicted cutpoint of the impactor is about 10 μm at the flow rate of 50 l/min.

The principal parameter determining particle capture is the Stokes number of a particle having a 50% probability of impacting, *St*, defined as the ratio of the particle stopping distance to the characteristic dimension of the impactor (Hinds 1982):

$$St = \frac{\tau U}{W} = \frac{\rho_p C_c d_p^2 U}{9\mu W}, \qquad [1]$$

where W is the diameter of the impactor's nozzle, U is the average velocity of the impactor jet, ρ_p is the particle density, μ is the dynamic viscosity of the air and C_c is the Cunningham slip correction factor, given by the following equation (Hinds 1982):

$$C_c = 1 + \frac{2}{Pd_p}\left[6.32 + 2.01\exp^{(-0.1095Pd_p)}\right], \qquad [2]$$

where P is the pressure at the location of the particle in the flow (in cm Hg) and d_p is the particle diameter in μm. The acceleration nozzle diameter of the impactor was 1.7 cm and the corresponding jet velocity for a flow of 50 l/min was 367 cm/s. The gap between the impaction jet and the collection plate was 1.1 cm. The Stokes number corresponding to 10 μm was approximately 0.135.

Laboratory Tests for Determination of Cutpoint

The schematic diagram of the experimental setup for testing the cutpoint of the PM_{10} inlet is shown schematically in Figure 2. Monodisperse aerosols in the range of 2.6 to 12 μm were generated by atomizing dilute aqueous suspensions of polystyrene latex particles (PSL, Bangs Laboratories Inc., Fisher, IN), using a constant output nebulizer (HOPE, B&B Medical Technologies, Inc., Orangevale, CA). The generated particles were drawn through a 2 l glass container in which they were mixed with dry room air in order to remove excess moisture. The dry aerosols were then passed through a series of Po-210 neutralizers (NDR Inc., Grand Island, NY) to bring the particle charge distribution to Boltzmann equilibrium. Particle penetration through the impactor was measured as a function of particle size by means of a nephelometer, DataRAM (RAM-1, MIE Inc., Billerica, MA), which was used to measure the mass concentrations of the monodisperse aerosols upstream and downstream of the PM_{10} inlet. The upstream and downstream measurements were repeated at least three times. The contributions from background ambient concentrations before and after the PM_{10} inlet were recorded and subtracted from those of the input and concentrated aerosols prior to determining the collection efficiencies at the given particle size. It should be noted that indoor air levels were on the order of 7–12 $\mu g/m^3$, and substantially smaller than those of the generated aerosols (prior to entering the PM_{10} inlet), which varied from 95 to about 300 $\mu g/m^3$. Therefore the contributions of the indoor aerosol to the overall concentrations measured upstream of and downstream of PM_{10} inlet were considered negligible.

Wind Tunnel Tests

The performance of the PM_{10} inlet was evaluated in the wind tunnel facility of School of Public Health, UCLA. The wind tunnel is described in detail by Hinds and Kuo (1995). In its original design, the wind tunnel has a 1.6×1.6 m cross-section and was operated at two wind speeds (3 and 8 km/h). The blower downstream of the sampler test area was capable of driving the wind tunnel speed up to 8 km/h (Kennedy et al. 2001). The cross-section of the wind tunnel was modified later to achieve a wind speed of 24 km/h. A plywood baffle was placed about 0.5 m upstream of the aerosol generation system to promote mixing. The vibrating aerosol orifice (VOAG) (Model 3450,

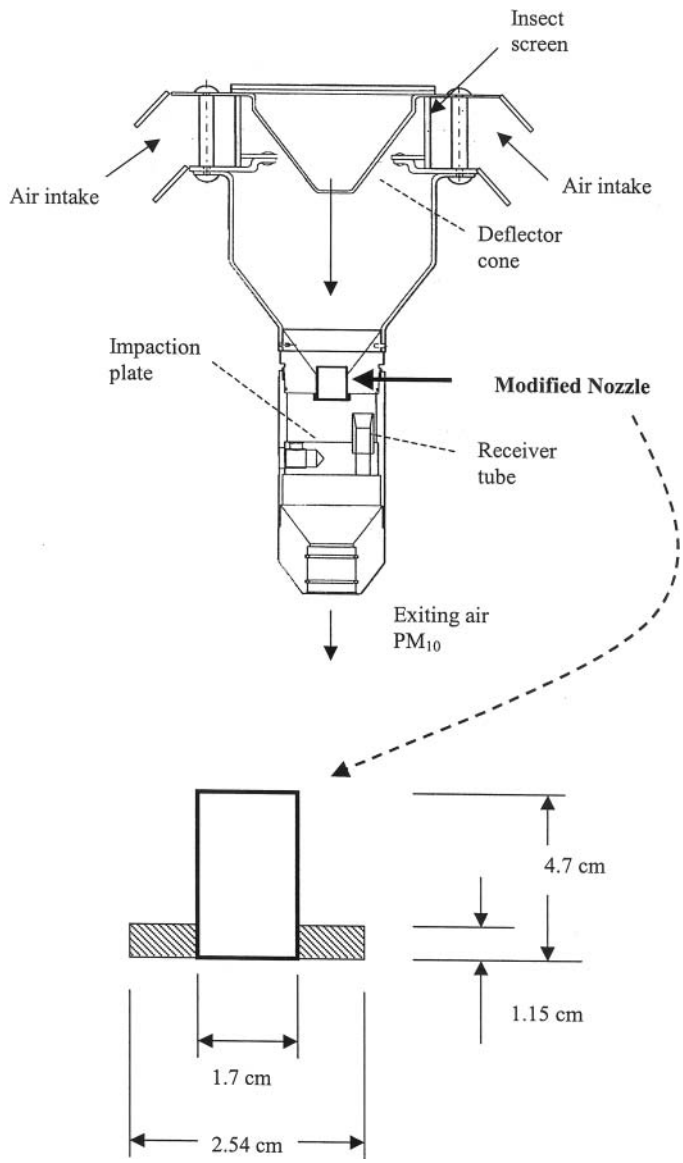


Figure 1. (a) Modified PM_{10} inlet for CCPM. (b) Dimensions of modified acceleration jet nozzle.

TSI Inc., St. Paul, MN) was itself mounted on a shaft, which moved both up and down and sideways to promote uniform injection. Three isokinetic samplers were placed around the PM_{10} inlet. The PM_{10} inlet was placed such that it was equidistant from the three isokinetic samplers. Two of these samplers were lateral to the PM_{10} inlet while the third one was above the PM_{10} inlet. The positioning of the isokinetic samplers corresponded to uniformity in concentration around the inlet. The earlier work by Hinds and Kuo (1995) describes the positioning of isokinetic samplers in detail.

The sampling characteristics of the PM_{10} inlet were determined by comparing the mass concentration obtained by the PM_{10} inlet to that measured by isokinetic samplers. Seven different particle sizes—5, 7, 9, 10, 12, 15, and 20 μm—were selected to evaluate the performance of the PM_{10} inlet.

A vibrating orifice aerosol generator (VOAG) (Model 3450, TSI Inc., St. Paul, MN) was used to generate monodisperse particles. It is known that when a solution containing a nonvolatile solute is sprayed through an orifice, the solvent eventually evaporates from the droplets and nonvolatile particles of solute are obtained. The diameters for these nonvolatile solute particles are given by

$$D_p = C^{1/3} D_d, \qquad [3]$$

where C is volumetric concentration of the nonvolatile solute in the solution and D_d is the initial droplet diameter.

A vibrating orifice produces one droplet per cycle and the D_d is given by

$$D_d = (6Q/\pi f)^{1/3}, \qquad [4]$$

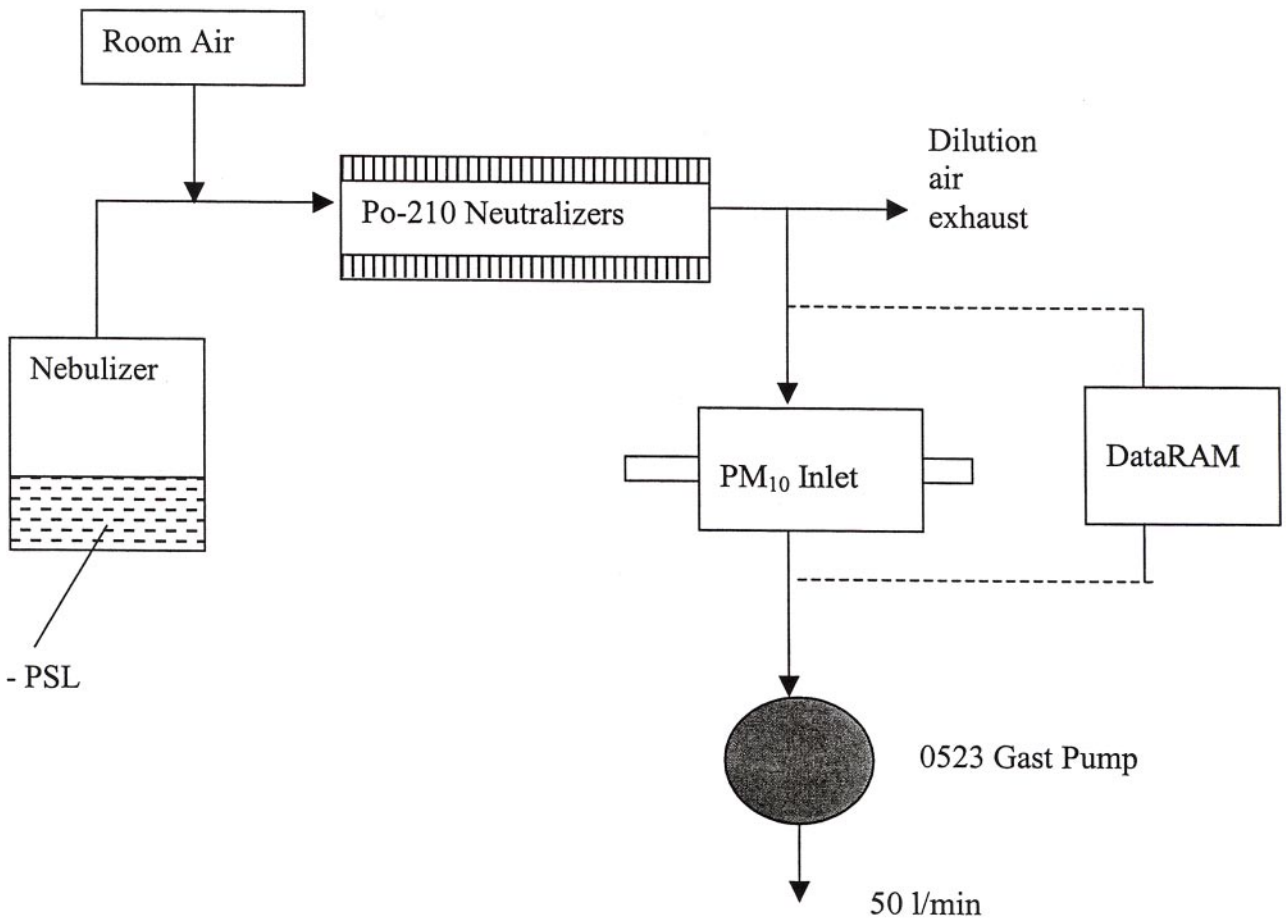


Figure 2. Schematic of the experimental set-up used for the laboratory characterization of the ultrafine PM separator.

where Q is the liquid flow rate and f is the disturbance frequency (Berglund and Liu 1973). The droplet size primarily depends on the orifice size for a given solution feed rate and the frequency. For these experiments, a 20 μm orifice was used for generating particle sizes of 5 and 7 μm, while a 35 μm orifice was chosen for generating particles in size ranges of 9, 10, 12, 15, and 20 μm. Typical VOAG operating parameters were 0.150 ml/min of feed rate at 65–70 kHz utilizing a 20 μm orifice. A feed rate of 0.3 ml/min at an operating frequency of 35 kHz was found to be optimum for a 35 μm orifice.

Uranine-tagged oleic acid was used as a nonvolatile solute for generating particles with acetone as the solvent. Approximately 2 g of uranine dye was dissolved in 50 mL of methanol to prepare the tracer solution and was left overnight to dissolve the dye in the solution with concomitant settling of the undissolved uranine dye. Then 20–40% of this solution was added to the oleic acid-acetone solution to generate particles of a desired size using Equations (3) and (4). The monodispersity of the generated aerosols was confirmed by observing the generated particles under a microscope, which also corroborated the size of the particles.

The isokinetic samplers and the PM_{10} inlet were positioned at the same distance from the sample injection point (same axial plane). These samplers were constructed from 2.5 cm in-line stainless steel filter holders (P/N 1209, Gelman Sciences Inc., Ann Arbor, MI) fitted with 8.5 mm ID brass probes that extended 32 mm from the face of the filter holder and sampled at a flow rate of 10 l/min for wind speeds of 3, 8, and 24 km/h. Millipore membrane filters (SMWP 02500, Millipore, Bedford, MA) were placed downstream of each of the isokinetic samplers to collect the generated monodisperse uranine-tagged oleic acid particles. A 4.7 cm Millipore membrane filter (SMWP 04700, Millipore, Bedford, MA) was placed after the PM_{10} inlet in order to collect the oleic acid particles. Each of the experiments was characterized by particle size and wind speed and lasted for about 10–15 min, which was sufficient to obtain detectable mass on the filters.

Detection of the deposited uranine-tagged oleic acid particles on the Millipore filters was performed using a fluorescence detector (Model FD-500, Programmable Fluorescence Detector, GTI, Concord, MA). Prior to their fluorescence detection, the extraction of the uranine was done using a buffer solution. The

buffer solution was prepared by dissolving 12.4 g of boric acid in 1000 mL of water (solution A) and 19.05 g of sodium borate in 1000 mL of water (solution B). Diluting 50 mL of solution A and 59 mL of solution B to 200 mL using distilled water yielded the buffer solution.

The Millipore filters were then extracted in glass vials using the buffer solution. Most of the extractions were done using 5–10 mL of solution. Standard uranine dye solutions of 0.005, 0.01, 0.025, 0.05, 0.075, and 0.1 ppm were used to plot the calibration curve.

For each wind speed, comparison between the mass concentrations obtained by means of the three isokinetic samplers and the PM_{10} inlet was performed. For each particle size, the averaged value of the mass concentration for the three isokinetic samplers was used. Finally, the particle penetration through the PM_{10} inlet was plotted against the particle diameter for each wind speed.

Field Evaluation of the PM_{10} Inlet

The performance of the PM_{10} inlet was evaluated in Riverside and Rubidoux, CA in the months of May and July, 2001. For these tests, a virtual impactor with a cutpoint of 2.5 μm at 50 l/min was attached downstream of the PM_{10} inlet. This is the same virtual impactor used in the continuous coarse PM monitor (CCPM) described by Misra et al. (2001) to separate coarse from fine PM. The concentrated coarse PM in the minor flow of this impactor is drawn into a Tapered Element Oscillating Microbalance (TEOM Mode 1400A, Rupprecht and Pataschnick Inc., Albany, NY) for near-continuous measurement of coarse mass concentration. A thin film of silicone grease (Chemplex 710, NFO Technologies, Kansas City, KS) was applied to the impaction plate of the PM_{10} inlet to prevent particle bounce. Coarse PM follows the minor flow, while particles smaller than the cutpoint of the virtual impactor follow the major flow. The minor flow in these experiments was set at 2 l/min to achieve a nominal enrichment factor of 25. This minor flow also corresponds to the inlet flow of the CCPM. Concentrated coarse particles, including a small fraction of fine PM (about 4%), were drawn in the minor flow (2 l/min), which was pulled by an oil-less pump (Model DOA-V191-AA, Gast Manufacturing Inc., Benton Harbor, MI). The remaining 48 l/min (major flow) through the virtual impactor was drawn by a separate, oil-less, lightweight, rotary vane pump (Model 0523-101Q-G588DX, Gast Manufacturing Inc., Benton Harbor, MI). Concentrated coarse particles in the minor flow stream were collected on a 4.7 cm Teflon filter (2 μm pore size, Gelman Science, Ann Arbor, MI). Measurements of concentration-enriched coarse particle mass were compared to measurements with a Dichotomous Partisol-Plus sampler (Model 2025 Sequential Air Sampler, Rupprecht and Patashnick Co. Inc., Albany, NY). The Dichotomous Partisol uses a Federal Reference Method (FRM) PM_{10} inlet operating at 16.7 l/min to remove particles larger than 10 μm in aerodynamic diameter. The remaining PM_{10} aerosol is drawn through a virtual impactor, or, "dichotomous splitter," located after the inlet. Two separate flow controllers maintain the coarse particle stream at 1.67 l/min and the fine particle stream at 15 l/min. Coarse and fine PM were collected on two 4.7 cm Teflon filters, placed in the minor and major flows of the Partisol virtual impactor, which are housed in reusable cassettes.

The Teflon filters of PM_{10} inlet and Partisol samplers were pre- and postweighed using a Mettler Microbalance (MT5, Mettler-Toledo, Inc, Hightstown, NJ) after 24 h equilibration under controlled humidity (35–40%) and temperature (22–24°C). The experiments were performed with simultaneous sampling from the PM_{10} inlet and the Dichotomous Partisol. The sampling time was around 120 min for each experiment to ensure sufficient mass was collected on the filters.

The coarse concentration of PM_{10} inlet was determined after dividing by the appropriate sample flow and subtracting 2.5% of fine concentration from it, which corresponded to the ratio of minor flow to the total flow of the PM_{10} inlet virtual impactor. Similarly, the coarse concentration of Dichotomous Partisol was determined after dividing by the appropriate sample flow and subtracting 10% of fine concentration from it, which corresponded to the ratio of minor flow to the total flow of the Partisol virtual impactor.

In addition to mass concentrations, comparisons were made between coarse PM concentrations of selected trace elements as well as particulate nitrate and sulfate measured by the PM_{10} inlet and Partisol. Ten of twenty-one pairs of PTFE filter samples collected by the PM_{10} inlet and Partisol were analyzed by means of X-ray fluorescence (XRF) to determine concentrations of selected elements and metals. The remaining 11 pairs were extracted with 0.15 ml of ethanol and 5 ml of ultrapure water (ethanol was used in order to wet the hydrophobic Teflon filter). The samples were sonicated for 15 min and analyzed for sulfate and nitrate ions by means of ion chromatography (IC). Samples that were lower than three times the lower limits of detection (LOD) of either XRF or IC were excluded.

RESULTS AND DISCUSSION

Experimental Determination of Cutpoint

Particle penetration, the ratio of downstream to upstream mass concentration, through the PM_{10} inlet is plotted as a function of aerodynamic diameter in Figure 3. The data shown in this figure indicate that particle penetration is 90% or higher for particles in the range of 2.5–8 μm. Penetration decreases sharply to about 50% at 9.5–9.7 μm and further to less than 10% for particles larger than 11 μm in aerodynamic diameter. An estimate of the "sharpness" of the particle penetration curve of an impactor can be defined by means of a geometric standard deviation (σ_g), which is the square root of the ratio of the aerodynamic particle diameter corresponding to 16%

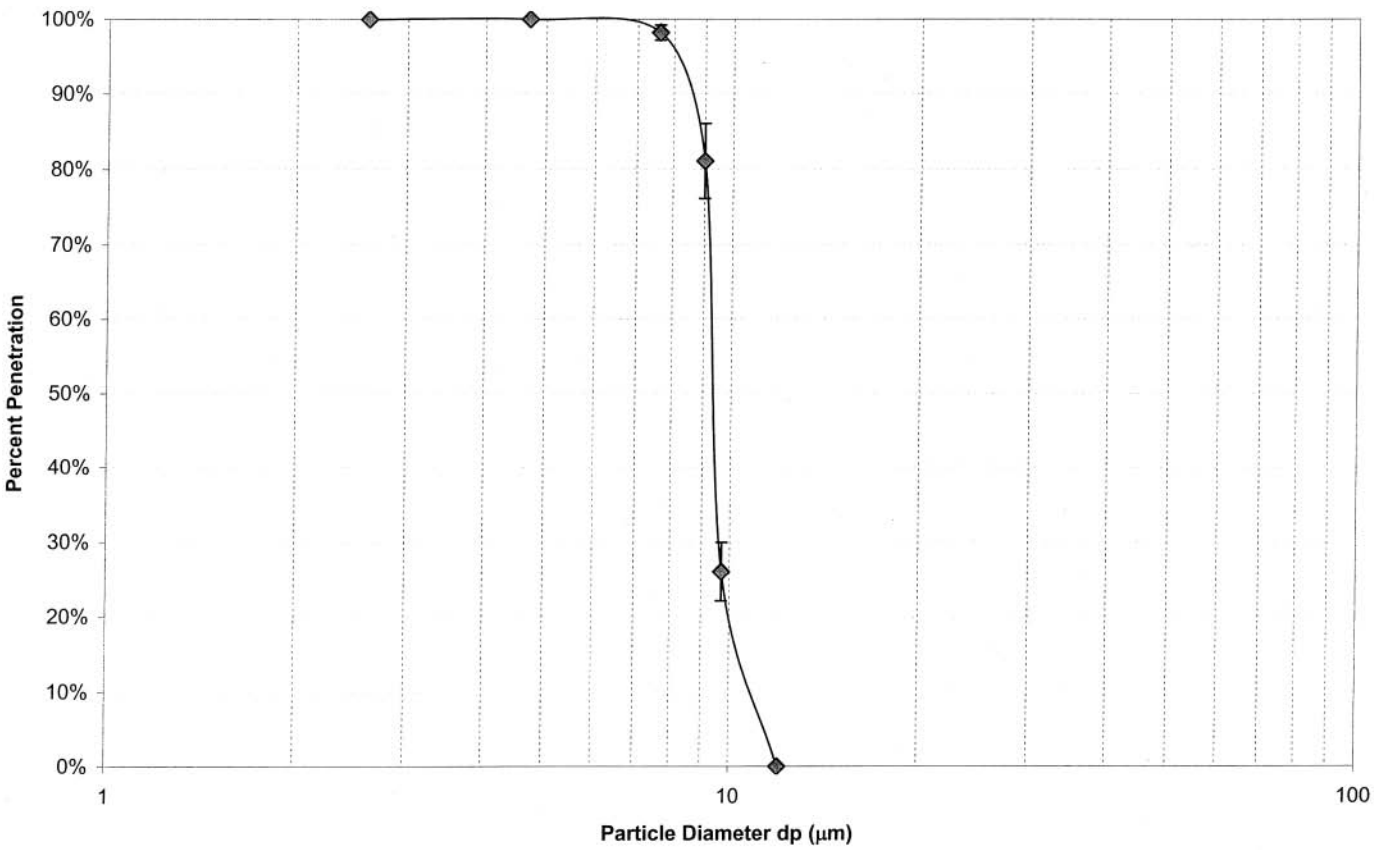


Figure 3. PM_{10} inlet penetration efficiency curve.

penetration to that corresponding to 84% penetration (Marple and Willeke 1976). Based on this definition, the value of σ_g is approximately 1.1 (roughly the square root ratio of 11 μm/9 μm) for the PM_{10} inlet, thereby indicating very sharp aerodynamic particle separation characteristics.

Wind Tunnel Evaluation of the PM_{10} Inlet

The results of the wind tunnel test are summarized in Figure 4. As evident from the figure, the particle penetration characteristics of the PM_{10} inlet are unaffected by the wind speeds. The penetration for all the wind speeds tested, viz., 3, 8, and 24 km/h, show a very close agreement. This is a particularly important result because it demonstrates that the inlet can be used throughout the various ambient conditions found in all normal environments. The wind tunnel tests show that the 50% cut is slightly shifted left at around 9–9.5 μm. The shift may be due to the limited resolution in the data of Figure 4, considering that experiments were conducted for particles with aerodynamic diameters of 9 and 10 μm and that data in between were fitted by the graph.

Field Evaluation of the Inlet

The results of the field evaluation of the PM_{10} inlet are shown in Figures 5 to 8. Figure 5 shows comparison between coarse PM mass concentrations obtained from the Partisol and the PM_{10} inlet. The figures display a very good agreement between the two samplers. The geometric mean ratio of PM_{10} inlet to Partisol coarse PM concentration is around 0.94. Coarse PM concentrations determined by both samplers appear to be also well correlated with $R^2 = 0.91$. It should be mentioned that for all the mass calculations, the contributions of the fine PM were subtracted from the coarse PM, both for Partisol and the PM_{10} inlet. The calculations were performed using Equations (5) and (6):

$$\begin{aligned}&\text{Actual Coarse Mass (Partisol)}\\&\quad = \text{Coarse Mass (Partisol)} - 0.1\\&\qquad \times \text{Fine Mass (Partisol)},\end{aligned} \tag{5}$$

$$\begin{aligned}&\text{Actual Coarse Mass (PM}_{10}\text{)}\\&\quad = \text{Coarse Mass (PM}_{10}\text{)} - 0.025 \times 50\\&\qquad \times \text{Fine Mass (Partisol)}/16.7.\end{aligned} \tag{6}$$

The Teflon filters after gravimetric analysis were analyzed for elements using XRF. Five major crustal metals were chosen to see the correlation between their coarse PM concentrations between the two samplers. Figure 6 and Table 1 show the comparisons and correlations between coarse concentrations of Al, Si, K, Ca, and Fe obtained by the two samplers.

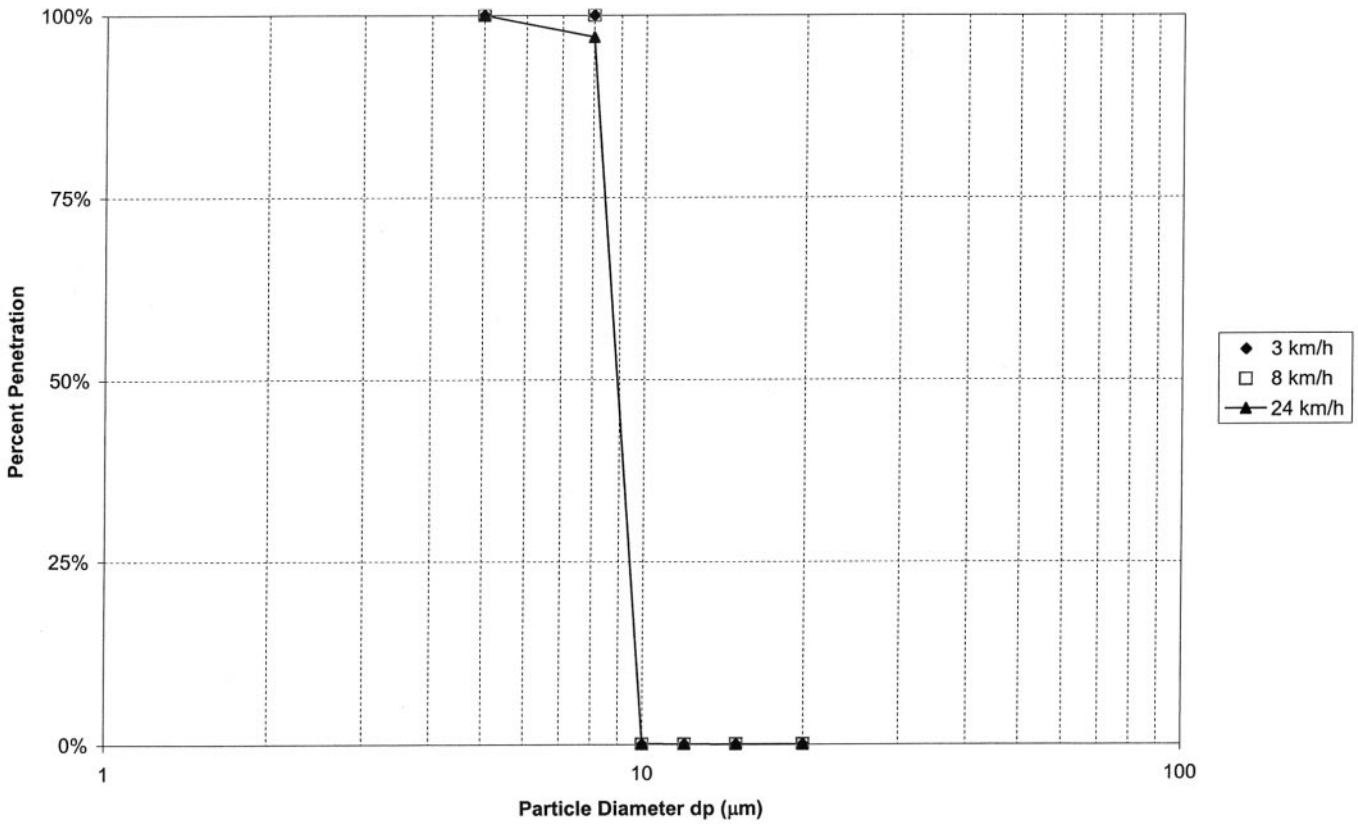


Figure 4. Plot of penetration versus particle diameter for various wind speed.

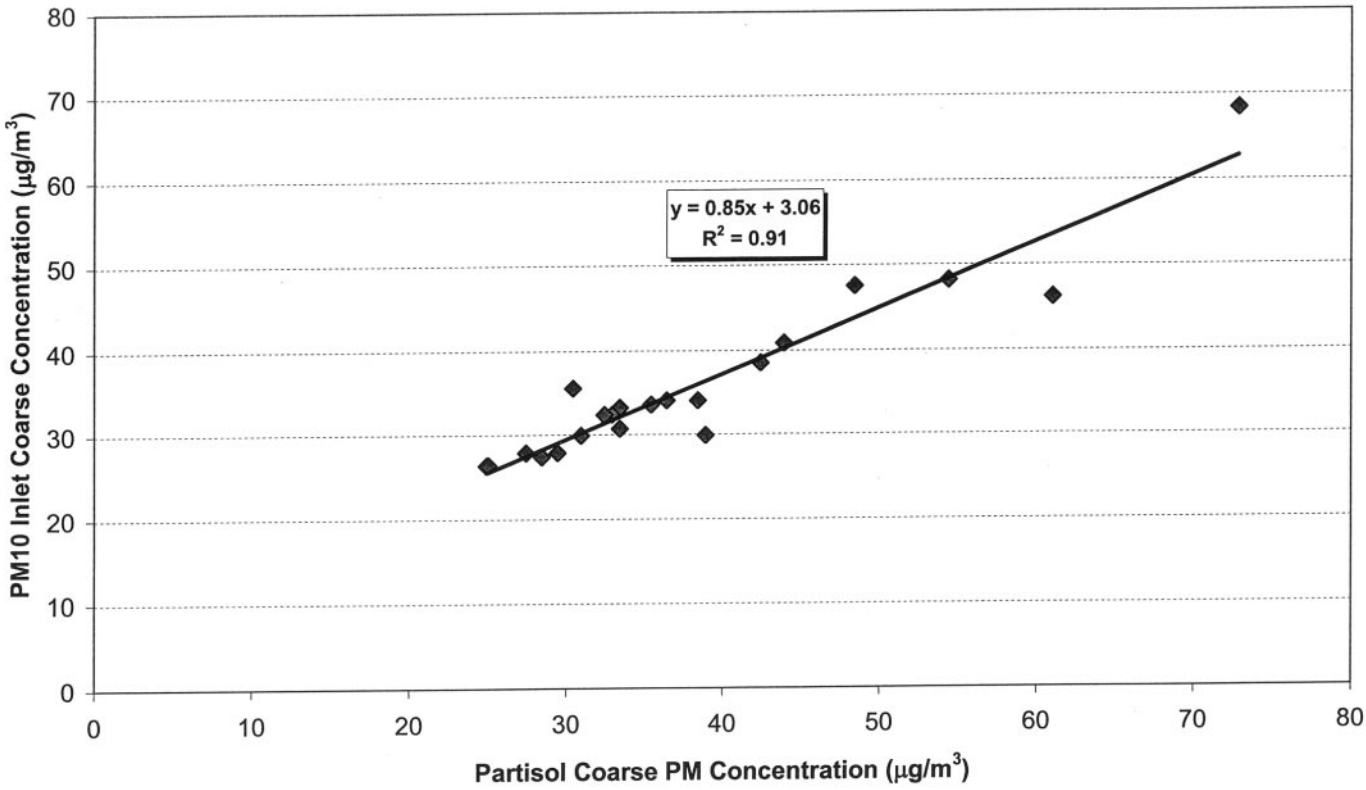


Figure 5. Coarse PM concentrations determined by the 50 l/min PM_{10} inlet and the R&P Partisol.

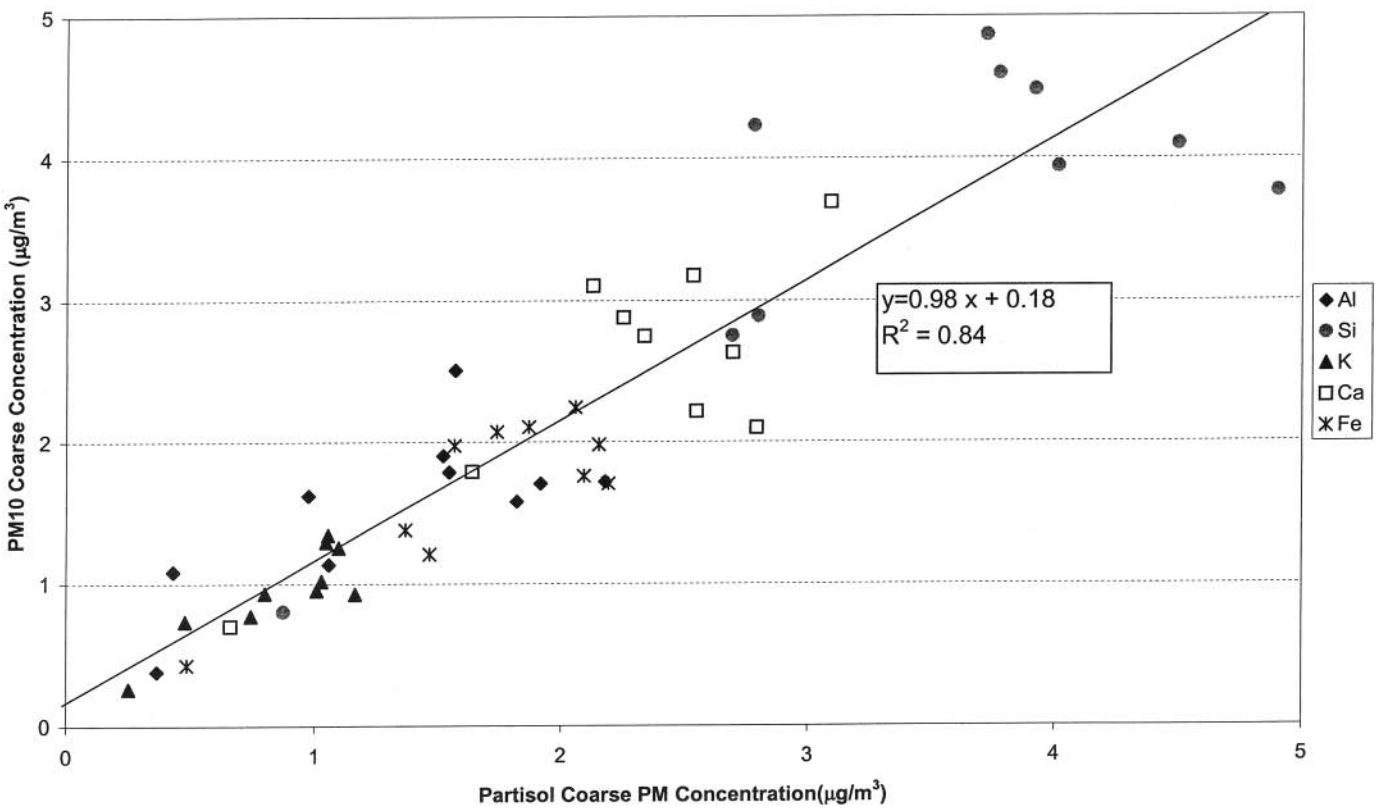


Figure 6. Overall comparison between coarse PM concentration of five crustal metal measured by Partisol and PM_{10} inlet.

The average (±standard deviation) ratio of the PM_{10} inlet to Partisol coarse concentration for a given element and metal are shown in Table 1, along with the correlation coefficient between these concentrations obtained for the specific metal. Figure 6 depicts an overall comparison of all the five crustal metals. The results summarized in Table 1 as well as the data plotted in Figure 6 reveal excellent agreement between the metal concentrations of the two samplers. The mean PM_{10} inlet-to-Partisol coarse PM concentrations vary from 0.98 to 1.19. The concentrations between the two samplers also appear to be highly correlated for each metal and element, with R^2 varying from 0.79 to 0.92.

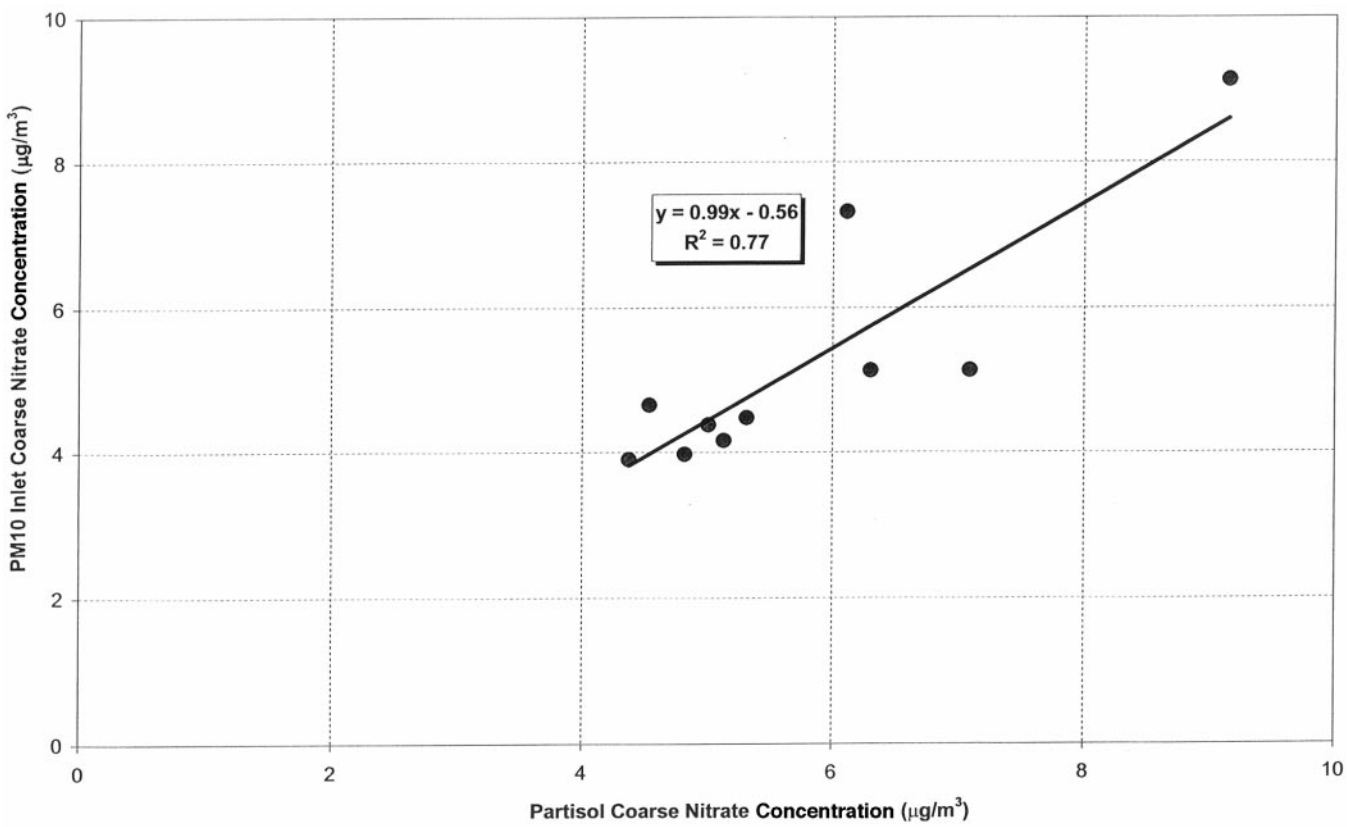
Table 1
Comparison between coarse PM concentrations of various crustal metals measured by the PM_{10} inlet and Partisol

Element	Ratio of PM_{10}/Partisol coarse concentration (Average ±S.D.)	Coefficient of determination (R^2)
Aluminum	1.19 (±0.23)	0.81
Silicon	1.06 (±0.22)	0.79
Potassium	1.09 (±0.19)	0.86
Calcium	1.07 (±0.18)	0.92
Iron	0.98 (±0.16)	0.85

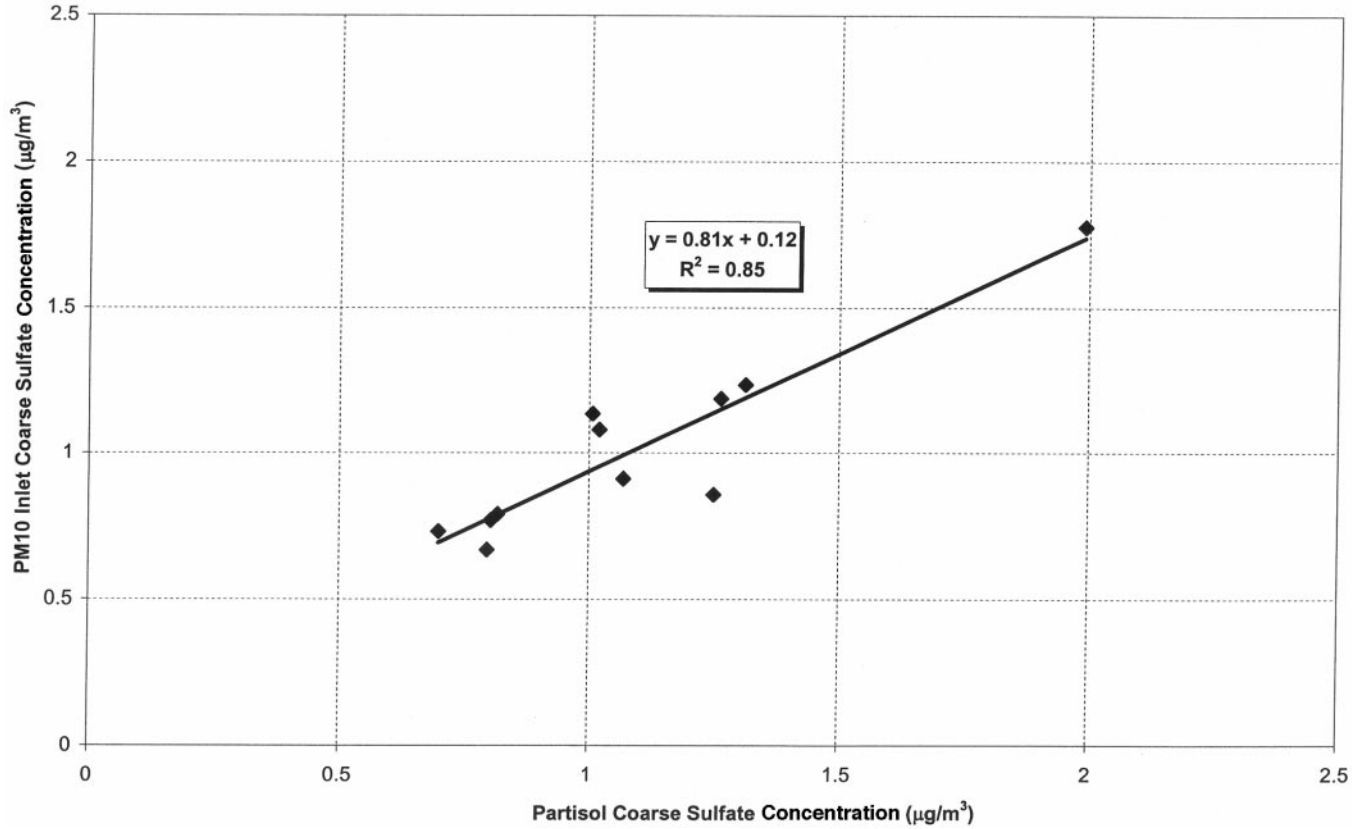
As seen in Figure 6, the overall PM_{10} inlet-to-Partisol ratio based on all metal concentrations is virtually identical to 1.

The comparison of coarse PM nitrate and sulfate concentrations measured by Partisol and the PM_{10} inlet are shown in Figures 7a and 7b, respectively. Fine PM contributions were subtracted using Equations (5) and (6), as in the case of the concentrations determined for metals. The results plotted in Figures 7a and 7b show also very good agreement between these two samplers, with the average PM_{10} inlet-to-Partisol concentration ratios being 1.13 (±0.15) and 1.08 (±0.14) for nitrate and sulfate, respectively.

Finally, the coarse PM concentration ratios of PM_{10} inlet and Partisol were plotted against the wind speed. The average ratio of PM_{10} inlet to Partisol coarse PM concentration is around 0.91 (±0.11). The slightly smaller PM_{10} inlet concentrations may be due to its somewhat smaller cutpoint (about 9.5 μm estimated from Figure 3) compared to that of the Partisol inlet. The results shown in Figure 8 clearly indicate that the ratio is independent of the wind speed, thereby indicating that there is no systematic bias in the coarse particle concentrations measured by the PM_{10} inlet when sampling is conducted at high wind speeds. This result further supports the findings of the wind tunnel tests and establishes the applicability of using the new 50 l/min PM_{10} inlet in conditions of winds as high as 24 km/h.



(a)



(b)

Figure 7. (a) Plot of coarse PM nitrate concentrations between the PM_{10} inlet and Partisol. (b) Plot of coarse PM sulfate concentrations between PM_{10} inlet and Partisol.

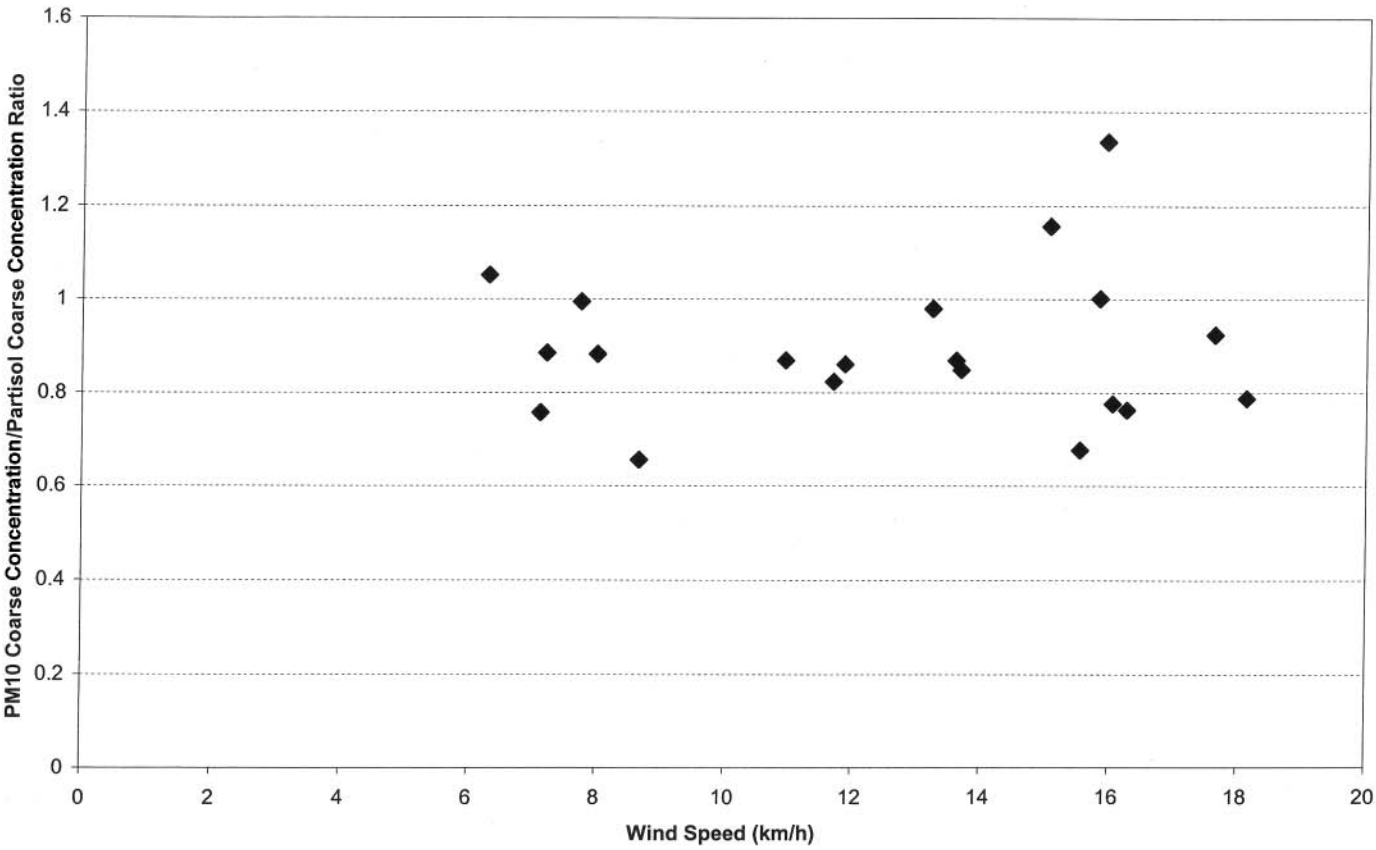


Figure 8. Plot of ratio of PM_{10}/Partisol coarse concentrations versus wind speed.

SUMMARY AND CONCLUSION

A PM_{10} inlet was developed and evaluated for the continuous coarse particle monitor developed by Misra et al. (2001). Laboratory evaluation was done using polystyrene latex particles and the cutpoint was found to be approximately 9.5 μm. The steepness of the penetration curve, the value of σ_g, was calculated to be as 1.1. This indicated reasonably sharp aerodynamic particle separation characteristics. The PM_{10} inlet sampling characteristics were then evaluated in a wind tunnel. Tests were performed at three different wind spends, viz., 3, 8, and 24 km/h. For these tests 5, 7, 10, 12, 15, and 20 μm particles were generated. Results showed that the particle penetration characteristics of the PM_{10} inlet were unaffected by the wind speeds. The penetration for all the wind speeds tested, viz., 3, 8, and 24 km/h, showed a very close agreement. The 50% cutpoint appeared to have shifted slightly left to around 9 μm. Field evaluation of the PM_{10} inlet was performed in Riverside and Rubidoux, CA in the months of May and July, 2001. For the field evaluation, a 2.5 μm cutpoint round nozzle virtual impactor was attached downstream of the developed PM_{10} inlet. Dichotomous Partisol was used as a reference sampler. Partisol has a preselective FRM PM_{10} inlet to remove particles larger than 10 μm aerodynamic diameter. Results showed excellent correlation between coarse PM concentrations measured by the PM_{10} inlet and the Partisol with slope of 0.94 with $R^2 = 0.93$. XRF analysis of filters was done and coarse PM concentrations of five different crustal metals measured by the PM_{10} inlet and Partisol were determined. Excellent agreement between the two samplers was obtained, with the average PM_{10} inlet to Partisol coarse concentration ratio for various crustal metals being between 0.98 and 1.19. The overall coarse PM metal concentration ratio for these five crustal metals was 0.98. Nitrate and sulfates were analyzed via ion chromatography. Coarse PM nitrate concentration agreed very well (e.g., within 15%) between the PM_{10} inlet and the Partisol. Finally, the coarse PM concentration ratios of PM_{10} inlet and Partisol were plotted against the wind speed and the results clearly showed that this ratio was independent of the wind speed. This further strengthens the wind tunnel tests and establishes the applicability of using the new 50 l/min PM_{10} inlet in conditions of wind speeds at least as high as 24 km/h.

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