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TECHNICAL NOTE

Characterization of the Gent Stacked Filter Unit PM_{10} Sampler

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ABSTRACT. An integral part of several International Atomic Energy Agency sponsored coordinated research programmes involving the sampling and analysis of ambient airborne particules was the development of a PM_{10} sampler. Each participant was provided with such a sampler so that comparable samples would be obtained by each of the participating groups. Thus, in order to understand the characteristics of this sampler, we undertoke several characterization studies in which we examined the aerodynamic collection characteristics of the impactor inlet and the reproducibility of the sample mass collection. One of the samplers machined in Belgium was compared with one built from the same design in the U.S. and comparable results were obtained. The sampler was operated side-by-side with a commercial PM_{10} beta gauge and an IMPROVE-design 2.5 μm cut-point cyclone. Although the sampler was not wind tunnel tested as required for certification as a reference sampler, it does provide a collection efficiency that generally follows the guidelines for a PM_{10} sampler. AEROSOL SCIENCE AND TECHNOLOGY 27:726–735 (1997)

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INTRODUCTION

The international Atomic Energy Agency (IAEA) has several coordinated research programmes in which the participants are to collect and analyze samples of the ambient aerosol. In order to have comparable samples taken in the variety of locations around the world, the IAEA contracted with the University of Gent to design and construct a sampler that would generally follow the requirements of a PM_{10} sampler. The sampler design is described by Maenhaut et al. (1993).

The sampling head for the unit is shown in Fig. 1. The air enters the unit through an impactor stage designed to have a 50% collection efficiency at 10 μm equivalent aerodynamic diameter. It then is drawn through a stacked-filter unit (SFU). The SFU consists of a holder for two sequential filters constructed by the Norwegian Institute for Air Research (NILU). The initial filter is an 8 μm pore 47 mm Nuclepore® filter and the second filter is an 0.4 μm pore Nuclepore® filter. At a flow rate of 16 lpm, the unit should act as a dichotomous sampler. The flow through the 8 μm pores will result in collection of ~ 2.2 μm particles with 50% efficiency (Cahill et al., 1979). The < 2.2 μm particules are then collected on the 0.4 μm filter (Cahill et al., 1979). The complete unit design is shown in Fig. 2. The flow control system is simple in order to minimize the unit cost. However, the total volume of air sampled is directly measured by the dry test meter built into the system.

An important question is whether the system performs as it was designed to do. The behavior of the SFU was established by Cahill and co-workers (1977; 1979; 1990a, b). These studies (Cahill et al., 1990a, b) presented earlier side-by-side comparisons. The major change in the current sampler is the holder and inlet to the stacked filter unit. Thus, the primary initial concern was the verification of the performance of the impactor stage in the inlet. The other consideration is the reproducibility with which these systems can be constructed. The intial units were built at the University of Gent. Additional units were constructed at Clarkson University. At this time, over 75 of these units are operating worldwide.

EXPERIMENTAL PROCEDURES

Inlet Tests

The sampler was set up both in a parking lot near the Clarkson University Science Center and later on the top of the four story section of the Science Center. The impactor collection surface was covered

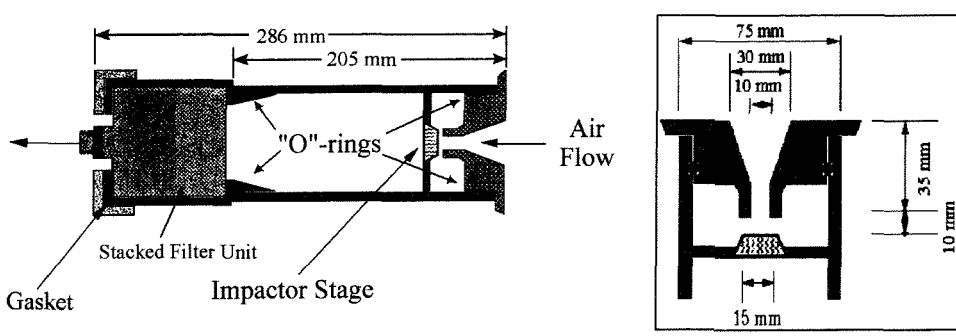

FIGURE 1. Schematic of the sampling head containing the 10 μm impactor inlet and the NILU SFU.

with a disk of mylar coated with a thin coating of Vaseline® and an 0.4 μm Nuclepore® filter was placed in the first filter location so that all of the particles would be collected. The filter and the impactor collection stage were then examined with an optical microscope. Image fields of particles were captured using a CCD video camera and a TrueVision TARGA-16® frame grabber board. Image analysis software (MOCHA®) was used to obtain the maximum and minimum axes. The particles were assumed to spheroids of revolution having a density of 2.5 g cm^{-3}. The aerodynamic diameter of the equivalent sphere can be calculated for each particle. The particle sizes can then be divided into a series of size bins and the number collected on the filter to the total particle concentration can be estimated. The total particles in a given size bin equals the number on the impaction stage plus the number on the filter and then corrected for the wall losses. The wall loss was estimated by using the wall loss curve for a similar design impactor built by Dr. Risto Hillamo at the Finnish Meteorological Institute and tested by Jappinen (1988).

Mass Collection Efficiency Tests

Two samplers, one from the University of Gent (UG) and one from Clarkson University (CU), were placed on the top of a four story building on the university of Illinois campus. The samplers were set up in the conventional manner with filters loaded in

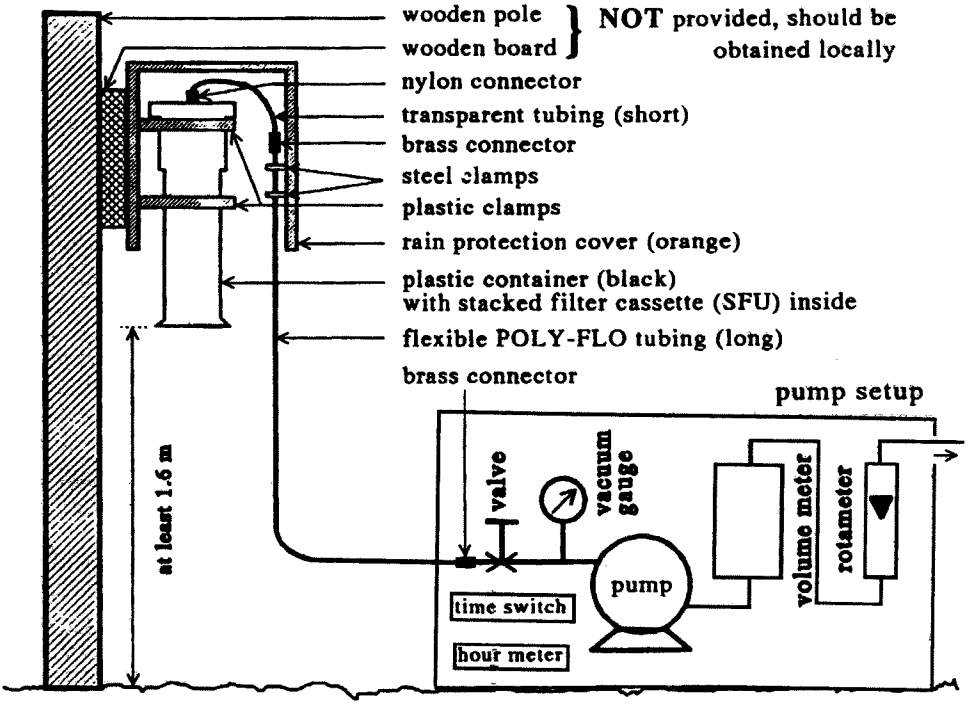

FIGURE 2. Schematic of the sampling system as typically deployed in the field including the pump, flow control system, and rain shield.

both stages of the SFU. The filters were equilibrated at 50% relative humidity and weighed on a microbalance prior to insertion into the SFU holder. After a 48 h collection period, the filter samples were retrieved, equilibrated, and reweighed. The difference in weights for each filter sample could be calculated and the masses of appropriate pairs of fine and coarse samples can then be compared.

Side-by-side sampling tests were also made in Sede Boker, Israel. Two of the SFU samplers were operated in parallel in two experiments. In the first, both samplers used Nuclepore® filters for both the coarse and fine samples. In the second, a 2 μm pore size Gelman Teflo® was substituted for the fine particle Nuclepore®. The coarse filter must be the 8 μm pore coated Nuclepore® because the size dependent particle separation process depends on the unique properties of the Nuclepore®-type filter. In addition, coated filters should be used to reduce particle bounce.

Several field tests were made to compare this SFU system with other samplers. In Sao Paulo, Brazil, the SFU was set side-by-side with a Phillips PM_{10} beta gauge system. Another SFU was placed at the aerosol sampling program (ASP) site at Lucas Heights, NSW, Australia (Liu et al., 1995; 1996) and compared with the 2.5 μm cut-point cyclone based on the IMPROVE sampler design (Malm et al., 1994).

RESULTS

Inlet Tests

A series of 11 samples were collected and analyzed. The results were averaged over the series of samples to provide mean collection efficiencies and an estimate of their variability. A plot of particle collection efficiency versus estimated aerodynamic diameter is shown in Fig. 3. The solid line is the theoretical PM_{10} sampler efficiency as

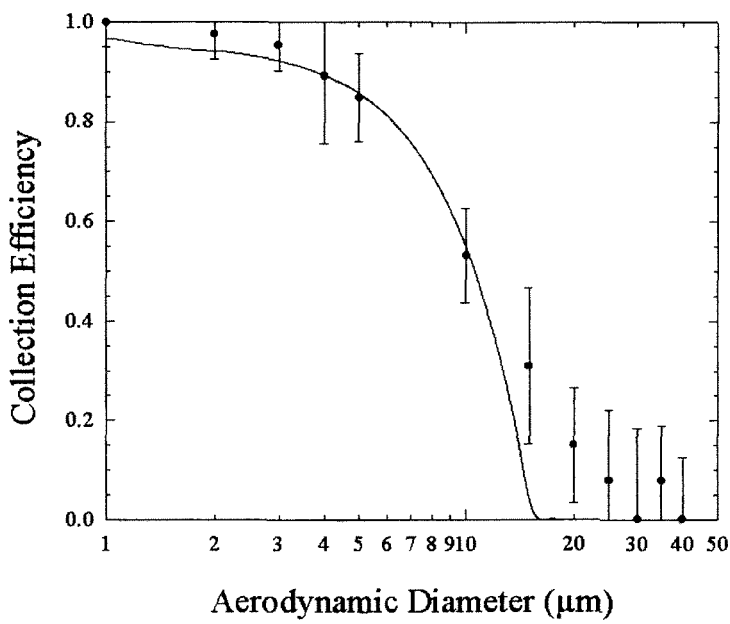

FIGURE 3. Collection efficiency as a function of aerodynamic diameter after applying the wall loss corrections. The error bars are the standard deviation of the 11 inlet samples. The line is the theoretical PM_{10} sampler efficiency as defined by the U.S. Environmental Protection Agency.

defined in the United States regulations for PM_{10} inlets (U.S. Code of Federal Regulations, 1996). The sampler inlet has a slight excess collection around 20 μm, but otherwise provides a reasonable match to the requirements for a PM_{10} sampler. Thus, the impactor behaves as expected from its design. The regulations also call for wind tunnel testing to determine the sensitivity of the system to wind speed. Such tests

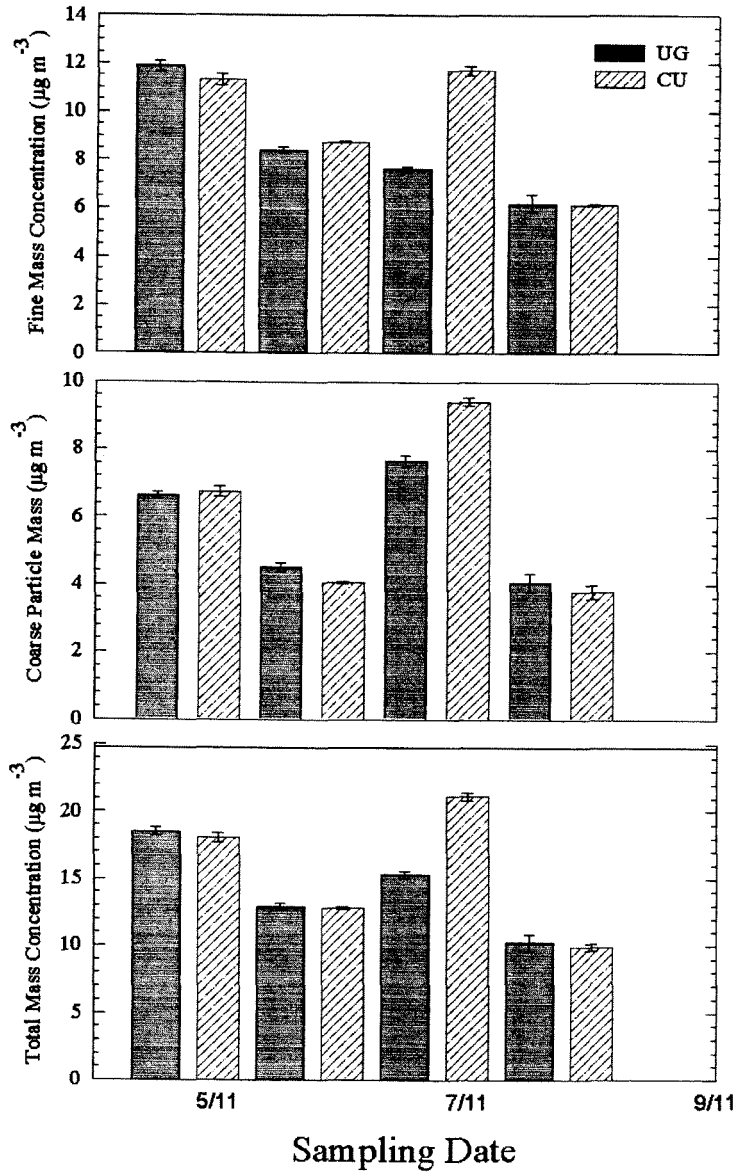

FIGURE 4. Comparison of the fine fraction mass (ng m^{-3}) [top], the coarse fraction mass (ng m^{-3}) [middle] and the total mass ng m^{-3} [bottom] for the two side-by-side samples manufactured in different laboratories.

were not made and, there is no information available on the inlet behavior as a function of wind speed. Thus, the sampler is not a reference PM_{10} sampler.

Mass Collection Efficiency Tests

The results for the four fine mass samples, the corresponding coarse mass samples, and the total mass (fine + coarse) for the four sampling intervals on the University of Illinois campus are given in Fig. 4. It can be seen that the agreement for three of the four samples is within the measurement error of the weighing. However, there is a discrepancy for the third sample pairs (9 Nov. 1994). There is no known explanation for the difference. It can be seen that the discrepancy is larger for the fine fraction samples than it is for the coarse fraction samples. It seems likely that the erroneous sample would be the one with lower mass values since it is easier to lose mass than to gain it. It may be that the fine filter was not fully seated in the SFU. Even more likely is that the bottom of the unit was not sealed tightly enough against the gasket and the SFU and thus, there is air leakage around the SFU rather than through the unit. It does show that even with care in preparing the filters in the sampler, there can occasionally be errors.

Figure 5 presents the comparison of the two samplers in Sede Boker, Israel with 0.4 μm Nuclepore® filters in both samplers. Figure 6 gives the results with the Teflo® filter substituted as the fine filter. There is excellent reproducibility between the two collocated samplers with identical filters. Their r^2 values are 0.881, 0.927, and 0.925 for the coarse, fine, and total PM_{10}, respectively. The slopes of the lines for the Nuclepore®/Nuclepore® samplers are 0.93 $\pm$ 0.09, 0.99 $\pm$ 0.02, and 0.97 $\pm$ 0.08, respectively. The intercepts are 0 within 1 σ.

For the Nuclepore®/Teflo® comparison at Sede Boker, Israel, the r^2 values are 0.987, 0.879, and 0.978, respectively, for coarse, fine, and total PM_{10}. The intercepts are again zero and the slopes are 0.84 $\pm$

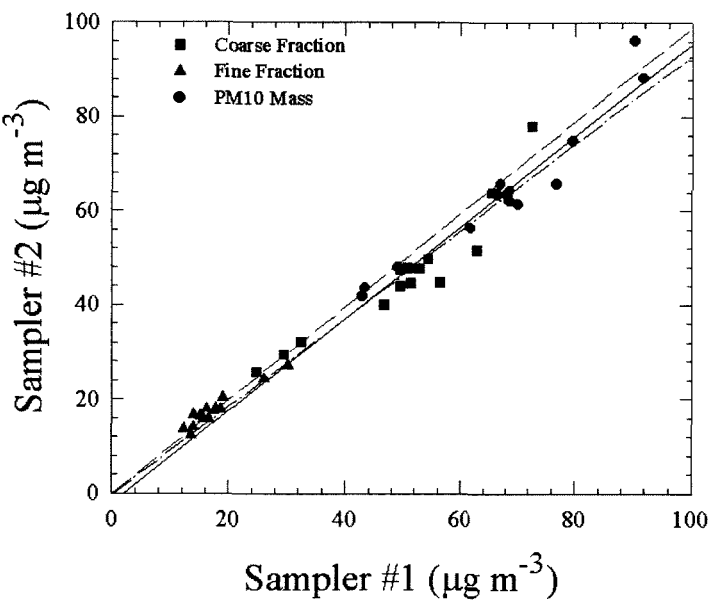

FIGURE 5. Comparison of the coarse fraction mass (μg m^{-3}) [top], fine fraction mass (μg m^{-3}) [middle] and total PM_{10} mass (μg m^{-3}) [bottom] for side-by-side samplers using 0.4 μm pore Nuclepore® filters as the fine fraction filters.

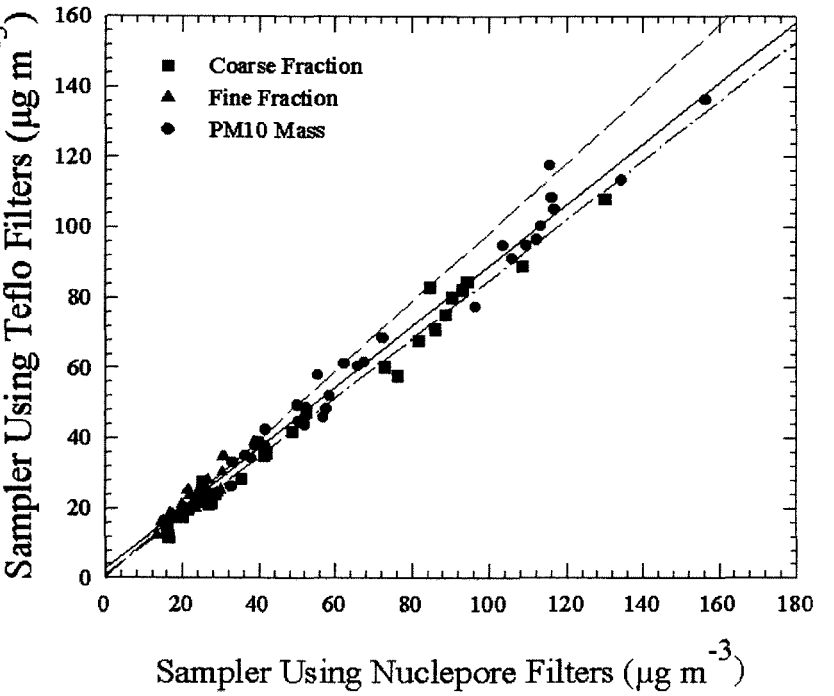

FIGURE 6. Comparison of the coarse fraction mass (μg m^{-3}) [top], fine fraction mass (μg m^{-3}) [middle] and total PM_{10} mass (μg m^{-3}) [bottom] for side-by-side samplers using a 0.4 μm pore Nuclepore® and a 2 μm pore Teflo® filter as the fine fraction filters.

0.02, 0.98 ± 0.07, 0.87 ± 0.02, respectively. The fine samples show excellent agreement showing that the substitution of the fine particle Nuclepore® for a Teflo® is acceptable. This substitution may be useful since the Teflo® filters have lower blank concentration values for most elements. Since there was good agreement for the coarse samples in the first experiment, it was hard to explain the poorer agreement during experiment 2.

Figure 7 shows the comparison of the IAEA/Gent SFU system with a Phillips PM_{10} beta gauge sampler. It can be seen that there is excellent agreement between the PM_{10} measured by both samplers. The slope of the curve is 0.99 ± 0.05 with a squared correlation coefficient of 0.859 and an intercept that is not statistically different from zero (-2.2 ± 15.3 μg m^{-3}). It should be noted that the Phillips sampler also was not wind tunnel tested and thus is not an U.S. Environmental Protection Agency reference sampler for PM_{10}.

Figure 8 shows the comparison of the IAEA/Gent SFU system with the 2.5 μm cut-point sampler designed to be equivalent with an IMPROVE sampler and used in the ASP sampling program (Cohen et al., 1994). The aerodynamic diameter cut point for collection of particles by the 8 μm Nuclepore® changes as a function of face velocity. Cahill et al. (1979) report that the 50% collection size is 2.5 μm for a flow rate of 14.5 l min^{-1}. The sampler was typically operated at 16 to 18 l min^{-1} resulting in an estimated 50% cut point of 2.2 μm. Thus, it is anticipated that the fine particle SFU mass would be less than that collected by the IMPROVE cyclone. The slope of

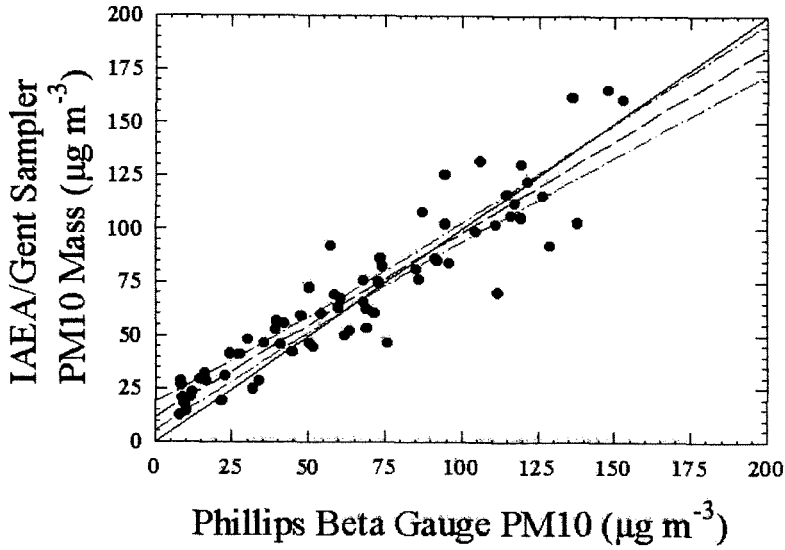

FIGURE 7. Comparison of PM_{10} ($\mu g\ m^{-3}$) measured with an IAEA/Gent SFU sampler and a Phillips PM_{10} inlet beta gauge.

the line in Fig. 8 is 0.76 ± 0.04 with a squared correlation coefficient of 0.793. Thus, the Gent sampler is collecting less of the fine particle mass than is the cyclone. However, from the prior studies, the total PM_{10} mass is being well measured.

There is a problem with the SFU when being used in areas with high atmospheric particle concentrations. There is a tendency for the filters to clog and a useful rule of thumb has been determined. Figure 9 shows the results of samples taken in Jakarta, Indonesia. The sum of the masses measured on the two filters is plotted against flow rate. It can be seen that if the sum of the masses collected on the 2 filters is $<$ 800–1000 μg, then the flow rates remain sufficiently high so that the sampler performance is reliable. When the total mass is larger, then the flow rate in SFU decreases and it ceases to function according to its design. Therefore, it is recommended that investigators in locations with high ambient particle mass concentrations sample only part of the time, but on a regular basis throughout the day (e.g., 1 h on, 1 h off) to obtain a lower total mass on the sampler while still obtaining a sample that is representative of the average conditions prevailing at the site. The timer provided on these units permits them to be cycled on and off.

There also were some difficulties of the fine filter clogging quickly in high humidity climates. It is assumed that there must be a substantial fraction of the fine particle mass that is hygroscopic and can become liquid solutions at high ambient humidities. The experiments described previously suggest that Teflo® filters can be substituted for the fine filters and eliminate the clogging problem. Experiments will be conducted to determine if the substitution of the fine filter type will mitigate this problem.

SUMMARY

In general the sampler performed well. The inlet behavior is in accordance with the design specifications and side-by-side reproducibility of samplers is very good. It appears that if the problem of filter overloading is carefully addressed, the sampler

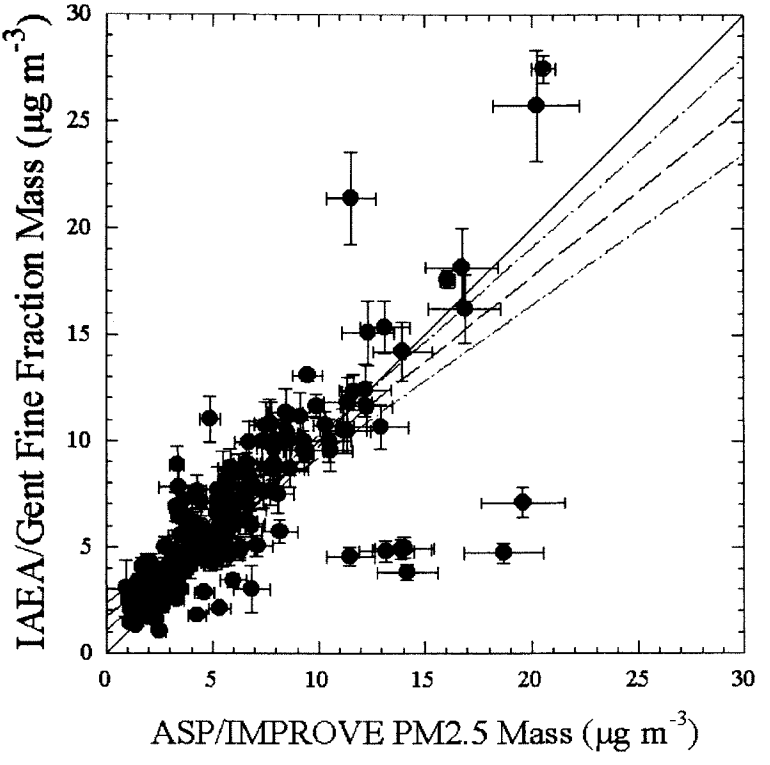

FIGURE 8. Comparison of fine particle mass (< 2.5 μg m^{-3}) measured with an IAEA/Gent SFU sampler and an ASP/IMPROVE cyclone sampler.

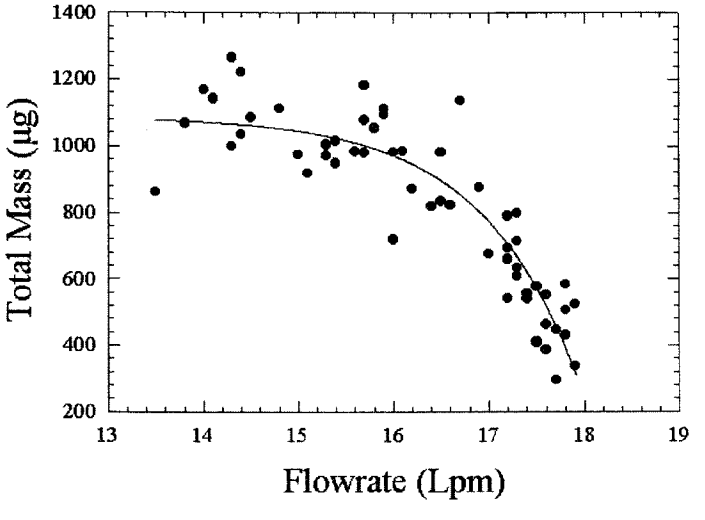

FIGURE 9. The effect of total mass collected in the SFU (fine plus coarse) on the flowrate through the IAEA/Gent SFU sampler.

will provide the aerodynamically well defined samples that will serve as a basis for comparative analysis of the airborne particle mass and composition data from the various sampling locations around the world using a relatively low cost sampler.

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