A Field Study of Three Collocated Ambient PM$_{10}$ Samplers

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Abstract

The performances of three ambient PM$_{10}$ samplers were studied at three monitoring stations in Taiwan. It was found that differences in the daily measured PM$_{10}$ concentrations of the SA 1200 and Wedding high-volume samplers are now within ±10% since the former now has a closer cut-point to the latter than in the earlier SA 321A model. The Wedding beta gauge automatic sampler was found to be applicable in rainy and humid weather conditions in Taiwan. Its daily PM$_{10}$ concentrations are typically within ±10% of those of the Wedding high-volume sampler. The particle loading effect of Wedding high-volume and beta gauge samplers was found to be important. To avoid sampling errors due to the loading effect with ambient PM$_{10}$ samplers, they must be cleaned regularly at an interval depending on the ambient particulate level.

1 Introduction

Because of their ability to penetrate and deposit in the tracheobronchial and alveolar regions of the respiratory tract, particulate matter smaller than 10 μm in aerodynamic diameter (so-called PM$_{10}$) poses a significant health risk to humans. The US Environmental Protection Agency (US EPA) has promulgated new size-specific national ambient air quality standards for particulate matter, or PM$_{10}$ standards, to replace the previous standards for total suspended particulate (TSP) [1]. The Taiwan Environmental Protection Agency (Taiwan EPA) has also adopted similar PM$_{10}$ standards but kept the TSP standards. According to the Taiwan national ambient air quality standards, the current 24-h and annual average PM$_{10}$ standards are 125 and 65 μg/m$^3$, respectively. For comparison purposes, the corresponding TSP standards are 250 and 130 μg/m$^3$, respectively.

The US EPA has set performance specifications and test procedures for PM$_{10}$ sampling methods in Title 40 of the Code of Federal Regulations (40 CFR Part 53, US EPA [2]). A candidate PM$_{10}$ sampler must be tested according to the test procedures and meet the performance specifications (US EPA [2]) in order to be approved as an EPA-designated reference or equivalent method. Table 1 shows the performance specifications regarding the sampling effectiveness and cut-point of PM$_{10}$ samplers. The cut-point is defined as the aerodynamic diameter at which the sampling effectiveness is 50%. An EPA-designated PM$_{10}$ sampler must have a 10 ± 0.5 μm cut-point for each wind speed of 2, 8 and 24 km/h. The PM$_{10}$ sampler is also tested by comparing it with the sampling effectiveness of an ideal sampler based on a specified mass concentration distribution.

The ideal sampler has a sampling effectiveness curve based on measurements of particle deposition as a function of aerodynamic diameter in the respiratory tract below the larynx during oral breathing through a mouthpiece [3].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Sampling effectiveness</td>
<td>Expected mass concentrations calculated from the sampling effective curves for all three windspeeds (2, 8 and 24 km/h) must be within ±10% of that calculated for the specified ideal sampler</td>
</tr>
<tr>
<td>Liquid particles</td>
<td>10 ± 0.5 μm aerodynamic diameter</td>
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<tr>
<td>Solid particles</td>
<td>Sampling effectiveness for 25-μm particles must be no more than 5% above that obtained for liquid particles of same size</td>
</tr>
<tr>
<td>Cut-point</td>
<td>10 ± 0.5 μm aerodynamic diameter</td>
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The Taiwan EPA has recently installed many automatic Wedding beta gauge PM$_{10}$ samplers to monitor hourly PM$_{10}$ concentrations island-wise in Taiwan. The Taiwan EPA is concerned whether these samplers will measure daily PM$_{10}$ concentrations accurately under highly humid and often rainy conditions in Taiwan. In particular, the Wedding beta gauge PM$_{10}$ samplers will be run unattended except during periodic flow-rate calibration and inlet cleaning.

There are also many Sierra-Andersen Model 1200 (SA 1200) and Wedding high-volume PM$_{10}$ samplers currently being used in Taiwan. SA 1200 sampler, which was described in McFarland and Ortiz [4], is a modified version of the Sierra-Andersen Model 321A sampler (SA 321A) [5]. The inlet of the SA 1200 is a single-stage multi-jet impactor whereas that of the SA 321 A is a double-stage impactor. Both samplers have a flow rate of 1.13 m$^3$/min. The Wedding high-volume sampler, which has a cyclonic inlet size fractionation, also has a flow rate of 1.13 m$^3$/min and is identical with the GMW 9000 sampler originally developed by Wedding and Weigand [6]. Slight modifications were the replacement of the oiled plastic surface with an oiled sintered metal surface, and the redesign of the inlet to provide convenient access for periodic cleaning. Both SA 321 A samplers and Wedding samplers were fully tested in many different wind tunnel facilities as shown in Ranade et al. [1] and in the field under different conditions by Rodes.
et al. [7] and Purdue et al. [8]. The SA 1200 sampler was tested by McFarland and Ortiz [4] in the laboratory but has never been tested in the field.

The automatic Wedding beta gauge sampler is a sampler capable of measuring hourly PM$_{10}$ concentrations continuously. It consists of a 10-µm cut-point inlet, a 100-µCi 14C source, a solid-state semiconductor detector and a critical flow device to control the sampling flow rate at 18.9 l/min. A detailed description of and field tests with this sampler were presented by Wedding and Weigand [9].

2 Previous Work

Substantial disagreement between SA 321A and Wedding samplers were found in field tests especially when the impaction surface of the SA 321A sampler was not oiled, as pointed out by Rodes et al. [7] and Purdue et al. [8]. For example, according to the so-called Phoenix III study at Phoenix by Purdue et al. [8], unoiled SA 321A samplers produced PM$_{10}$ concentrations that were 58% higher than those with uncleaned Wedding samplers.

John et al. [10] investigated three different possible mechanisms in order to explain the oversampling of unoiled SA 321A samplers in the Phoenix III study. These included re-entrainment by air flow, re-entrainment by particle collision and deagglomeration of particles on the impaction plate. They found that re-entrainment of 10-µm deposited ammonium fluorescein particles due to air flow alone was negligibly small. Re-entrainment of 10-µm deposited fluorescein particles was observed when clay particles (mode aerodynamic diameter, 13 µm; geometric standard deviation, 2.0) were sampled through an SA 321A sampler. Such re-entrainment was induced by collisions between impacting clay particles and deposited fluorescein particles on the impaction surface.

Deagglomeration of large particles, which occurs when large particles impact on the unoiled surface or when large deposited particles are bombarded with other incoming particles, was found to be the principal mechanism of oversampling by an SA 321A sampler.

Cleaning and reoiling the impaction surface of a sampler can reduce re-entrainment and deagglomeration effects, which lower the measurement PM$_{10}$ concentrations. Oiling the impaction surface can also lead to a loading or soiling effect [7-8, 10].

2.1 Loading Effect

Cleaning and reoiling the impaction surface of a sampler can reduce re-entrainment and deagglomeration effects, which lower the measurement PM$_{10}$ concentrations. Oiling the impaction surface of a sampler can decrease re-entrainment and deagglomeration effects, which lower the measurement PM$_{10}$ concentrations. Oiling the impaction surface of a sampler can decrease re-entrainment and deagglomeration effects, which lower the measurement PM$_{10}$ concentrations.

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3 Experimental Procedure

The field tests were conducted at three monitoring stations from March to June 1993. The first station is located in a polluted city where the daily average PM$_{10}$ concentration is very high, typically about 150 µg/m$^3$. The second station is located in a cleaner region where daily average PM$_{10}$ concentration is about 80 µg/m$^3$. The third station is in a very clean region where daily average PM$_{10}$ concentration is only about 30 µg/m$^3$. At the first two stations, all three PM$_{10}$ samplers were tested. At the third station, only the two high-volume samplers were tested.

Depending on the station, the height of the sampling inlets was typically 10–16 m above the ground. Each different sampler
had a slightly different height. For example, at the first station, the heights were 16, 14.2 and 14 m above the ground for the Wedding beta gauge, Wedding high-volume and SA 1200 sampler, respectively. The horizontal distance between samplers was 2–4 m to avoid flow interference. It is believed that such an arrangement would not introduce spatial differences between samplers.

The impaction surface of the SA 1200 sampler was cleaned and sprayed with silicone grease before each sampling day. It was intended that the measured \( PM_{10} \) concentrations of the SA 1200 sampler would be used as a standard in this comparison study. Typical particle mass loadings were 0.24, 0.13 and 0.05 \( g/\text{day} \) for the high-volume samplers and 0.004, 0.002 and 0.0008 \( g/\text{day} \) for the beta gauge sampler at the first, second and third stations, respectively. The mass loading was computed based on the measured \( PM_{10} \) concentrations of the SA 1200 sampler. Such an estimation is reasonably correct knowing that the daily average total particulate concentration in Taiwan is typically twice the \( PM_{10} \) values.

The particle collection surfaces of the Wedding high-volume and beta gauge samplers were cleaned once every 2 weeks at the first station and once every 4 weeks at the second station. The collection surface of the Wedding high-volume sampler at the third station was also cleaned once every 2 weeks. During the field study at the first and third stations, the weather was mostly sunny, the daily average temperature typically being 20–28°C, and the daily average relative humidity was typically 70% to less than 80%. However, during the first half of the study at the third station, there were scattered showers or drizzle every day. The daily average relative humidity was typically higher than 80% with hourly relative humidity values as high as 90–100% immediately before or after the rain. During the rainy days at the second station, the daily average concentrations dropped from 80 to 57 \( \mu g/\text{m}^3 \) because of aerosol scavenging by rain.

The filter-papers for high-volume samplers, which were glass-fibre filters, were conditioned for 24–48 h in a humidity-controlled chamber (relative humidity 40 ± 5%, temperature 20 ± 3°C) before and after sampling. During the days with scattered showers or drizzle, the filter-papers were conditioned long enough until the filter weights no longer changed. However, in the case of heavy and continuous rainy days, the filter samples were too wet and the experiment had to be discontinued. Each sampling period commenced from 10 a.m. to the same time the next day. The daily average concentrations for the Wedding beta gauge sampler were computed based on 24 hourly readings for each sampling period. These concentrations were compared with those for the high-volume samplers, which were obtained by dividing the sample weights by the total sampled air volume at 25°C and 1 atm. The experiment also recorded the hourly weather data, including rain intensity, wind speed, wind direction, relative humidity and temperature.

### 4 Experimental Results

#### 4.1 Wedding High-Volume Sampler

Both the Wedding and SA 1200 high-volume samplers are reference samplers designated by the US EPA. Anderson samplers have a long history of sampling higher \( PM_{10} \) concentrations than Wedding samplers. Each modified version of Anderson sampler results in a smaller cut-point and closer measured \( PM_{10} \) concentrations when compared with a Wedding sampler.

#### 4.2 Wedding Beta Gauge Sampler

The hourly \( PM_{10} \) concentrations recorded by the Wedding beta gauge sampler were found to be stable and reasonable, especially in good weather conditions. Typical daily experimental data acquired at the second station at a rainy day are shown in Figure 2. It shows that even on rainy days, the Wedding beta gauge is capable of capturing detailed hourly variation of \( PM_{10} \) concentrations. The aerosol increased from less than 60 \( \mu g/\text{m}^3 \) in the morning to nearly 160 \( \mu g/\text{m}^3 \) at night, and was then scavenged by the showers between 22:00 and 1:00. After the rain, hourly \( PM_{10} \) concentration dropped from the maximum value of 160 \( \mu g/\text{m}^3 \) to 80 \( \mu g/\text{m}^3 \) and the relative humidity increased from 80% to nearly 100% in the same period. The daily average \( PM_{10} \) concentration was calculated to be 90 \( \mu g/\text{m}^3 \). On the same day, the \( PM_{10} \) concentrations measured by the SA 1200 and Wedding high-volume samplers were slightly different, 99.7 and 89.6 \( \mu g/\text{m}^3 \), respectively. The differences in the measured concentrations depend on inlet cleaning, weather conditions and the differences in inlet designs. It is therefore concluded that the Wedding beta gauge
Fig. 2: Typical hourly PM\textsubscript{10} concentration variation as recorded by the Wedding beta gauge sampler on a rainy day at the third station.

Fig. 3: Comparison of daily average PM\textsubscript{10} concentrations between Wedding high-volume and Wedding beta gauge samplers at (a) first station and (b) second station. W(BETA), Wedding beta gauge sampler.

Fig. 4: Loading effect expressed as fractional difference between Wedding and SA 1200 high-volume samplers versus cumulated mass. (a) Third station; (b) first station; (c) second station.

can be used not only in good weather conditions but also rainy conditions in Taiwan.

A comparison of daily PM\textsubscript{10} concentrations with the Wedding high-volume and beta gauge samplers at the first and second stations is shown in Figure 3(a) and (b). Except on highly polluted days when the daily PM\textsubscript{10} concentrations with the Wedding beta gauge are more than 10% lower than those with the Wedding high-volume sampler, Figure 3(a) shows that Wedding beta gauge sampler is capable of measuring daily PM\textsubscript{10} concentrations within ±10% of those of the Wedding high-volume sampler of the time. The larger than 10% difference at high PM\textsubscript{10} concentrations may be caused by the greater loading effect of the Wedding beta gauge, which has a much smaller flow rate and hence smaller inlet cross-section than the Wedding high-volume sampler. At the second station where daily
The measured daily PM$_{10}$ concentrations with the Wedding high-volume sampler now has measured PM$_{10}$ concentrations much closer to those of the Wedding high-volume sampler because the two samplers now have closer cut-points. The difference is now less than 10% when the particle collection surfaces of the two samplers remain clean. The loading effects of both Wedding high-volume and beta gauge samplers were determined. The intercept of the Wedding high-volume sampler is from $-0.013$ to $-0.033/g$, which is comparable to the previously determined value of $-0.0223/g$. The intercept of the Wedding beta gauge sampler is from $-2.7/g$ to $-2.84/g$. It is suggested that the inlet of a Wedding beta gauge sampler be cleaned once every week at a polluted area in order to limit its measured error to within 10% due to loading effect.

5 Conclusions
A comparison test of three collocated samplers was conducted at three monitoring stations in Taiwan. The test results indicate that compared with the earlier SA 321 A model, the Andersen SA 1200 high-volume sampler now has measured PM$_{10}$ concentrations much closer to those of the Wedding high-volume sampler because the two samplers now have closer cut-points. The difference is now less than 10% when the particle collection surfaces of the two samplers remain clean.

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References


