

## Field Comparison of Real-Time PM<sub>2.5</sub> Readings from a Beta Gauge Monitor and a Light Scattering Method

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### Abstract

In this study, PM<sub>2.5</sub> mass readings by a portable light scattering monitor (Dust Trak) were compared to those obtained using a collocated beta gauge monitor (E-BAM) at various ambient relative humidities. The mass readings of two automatic particle monitors were also compared with those of a manual sampler. The inlet heater of the beta gauge was actuated or switched off to determine whether ambient relative humidity has an effect on the beta gauge readings. This work demonstrated that PM<sub>2.5</sub> readings of the light scattering monitor were higher than those of the beta gauge monitor, regardless of whether the inlet heater was turned on or off. In addition, the mean PM<sub>2.5</sub> readings of the light scattering monitor were also higher than those of the manual sampler. Results indicated that the relative humidity affected PM<sub>2.5</sub> reading of the light scattering monitor and PM<sub>2.5</sub> reading increased as the relative humidity rose. In contrast, when the inlet heater of the beta gauge was switched on, the mean PM<sub>2.5</sub> mass reading of beta gauge monitor was close to that of the manual sampler, and it was lower than that of the light scattering monitor. The inlet heater appeared to avoid the relative humidity effect on PM<sub>2.5</sub> mass readings of the beta gauge monitor.

**Keywords:** Beta gauge monitor; Light scattering monitor; PM<sub>2.5</sub>; Relative humidity.

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## INTRODUCTION

The measurement of PM<sub>2.5</sub> mass concentration is important in assessing human exposure to air pollution. Numerous real-time particle monitors and gravimetric measurements have been made and evaluated to measure PM<sub>2.5</sub> mass concentrations under various conditions (Niu *et al.*, 2002; Yanosky *et al.*, 2002; Chang, 2005; Kulkarni, 2006; Prassertachato *et al.*, 2006). Yanosky *et al.* (2002) compared PM<sub>2.5</sub> mass concentration of two types of real-time aerosol monitor, DustTrak Aerosol Monitor and Aerodynamic Particle Sizer to a USEPA Federal Reference Method. Their results showed that PM<sub>2.5</sub> mass concentration of the DustTrak monitor were high correlated with the Federal Reference Method (coefficient of determination = 0.86), but the gradient of the regressions was 2.57. Similar results were found by Ramachandran *et al.* (2000), which indicated the coefficient of determination was 0.76 and the gradient was 1.94. The concentrations of respirable suspended particulates were also measured using the Dust Trak aerosol monitor and a gravimetric method in the indoor environment (Niu *et al.*, 2002). Their results indicated that the particle concentrations of the real-time monitor were approximately twice as large as those of integrated sampling method. Besides, Chung *et al.* (2001) compared five continuous monitors with the Federal Reference Method at Bakersfield, CA. The results demonstrated that the beta attenuation monitor closely followed Federal Reference Method with a linear regression gradient of 0.95, an intercept of 1.36  $\mu\text{g}/\text{m}^3$ , and a correlation coefficient of 0.99. Geller *et al.* (2004) determined PM<sub>2.5</sub> mass concentrations at four sites using a beta attenuation monitor and an annular denuder system. Their findings indicated that the particulate matter included a significant proportion of fine particles, which were thought to cause the greatest health effects.

Dust Trak is a real-time, small and portable monitor for measuring PM<sub>2.5</sub> concentration in indoor and ambient air monitor using a light scattering technology. However, several studies showed that PM<sub>2.5</sub> readings by the Dust Trak monitor were higher than those by the gravimetric method (Tung *et al.*, 1999; Ramachandran *et al.*, 2000; Niu *et al.*, 2002; Yanosky *et al.*, 2002). One possible reason for the high concentration of the Dust Trak will be the difference between the air relative humidity of the monitoring environment and that of the filter (Niu *et al.*, 2002). On the other hand, beta attenuation monitor (E-BAM, Met One Instruments Inc) used an automatic inlet heater to condition the sample air stream for reaching a setting relative humidity. The inlet heater was expected to eliminate the condensation effect on the filter, which may lead to influence the actual mass reading (Allen *et al.*, 1997; Hauck *et al.*, 2004). In addition, the short-term concentration of the personal PM<sub>2.5</sub> exposure was measured using a photometric sampler in the indoor and outdoor conditions (Lanki *et al.*, 2002). Results indicated that a good correlation (coefficient of determination = 0.861) for the 24-h concentration was observed between the photometric and gravimetric methods. The indoor concentrations were higher than outdoor concentrations. The average indoor /outdoor ratios at relative humidity below 60% and above

90% were 0.93 and 0.73, respectively. The artifact in outdoor concentrations caused by high relative humidity was found to be 22%. A model of PM<sub>2.5</sub> utilizing parametric variables was described by analyzing PM<sub>2.5</sub> mass concentrations at over 300 locations in the eastern United States during 2000 (Paatero *et al.*, 2003). PM<sub>2.5</sub> mass concentrations collected by Federal Reference Method every third day at a series of sites were analyzed. The parametric variables in the model of PM<sub>2.5</sub> concentration included temperature, humidity, pressure, ozone concentrations and wind velocity vectors. Results reported that the contributions of factor number nine increased with increasing humidity. It is worthwhile to know if the relative humidity has an effect on PM<sub>2.5</sub> mass readings of a beta gauge monitor and a light scattering method, especially for the frequent occurrence of high humidity in the ambient air in Taiwan.

This study investigated the relative humidity effect on PM<sub>2.5</sub> readings of two real-time aerosol monitors. The PM<sub>2.5</sub> mass readings of the beta gauge monitor were compared with those of the collocated light scattering monitor at the various ambient RHs. The influence of the inlet heater of the beta gauge monitor on PM<sub>2.5</sub> mass readings was further examined by turning on the heater. The PM<sub>2.5</sub> difference between the light scattering monitor and the beta gauge monitor with the heater was compared to that without the heater at various ambient RHs.

## METHODS

In order to compare PM<sub>2.5</sub> mass reading of two real-time monitors, beta gauge monitor (E-BAM, Met One Instruments Inc. Oregon) and Dust Trak monitor (Model 8520, TSI, USA) were collocated on the second floor of the Ji-Hsin Building in Yuanpei University, which was about 3.7 meters above the ground. Both of the beta gauge monitor (EB) and the Dust Trak monitor (DT) can be used as a portable and real-time sampler to measure the mass concentration of particles. The EB has a PM<sub>2.5</sub> cut-size WINS impactor (BX-804, Met One Instruments Inc. Oregon) downstream of a PM<sub>10</sub> inlet head (BX-802, Met One Instruments Inc. Oregon) at a sampling flow rate of 16.7 L/min. <sup>14</sup>Carbon source of the monitor emits beta-particles through a reference position of the filter tape to make a first count. When particle-laden air is passed through the filter and the particulate matter is deposited on the filter, a second count is carried out. After detecting the initial and final count rate through the reference position of the filter tape, PM<sub>2.5</sub> mass concentration can be obtained from some simple calculations. An optional inlet heater of the EB was developed to avoid the water condensation on the filter. The relative humidity setpoint of the inlet heater for the EB was fixed at 35%. The DT uses 90-degree light scattering to measure the mass concentration of particles in an air stream that passes through an impactor with a cutsize of 2.5 μm at a sampling flow rate of 1.7 L/min. The detection of the DT ranges from 0.001 to 100 mg/m<sup>3</sup> and the resolution is 1% of the reading. When the particle laden stream was drawn through the inlet impactor of the DT, a source of laser light was used to illuminate the

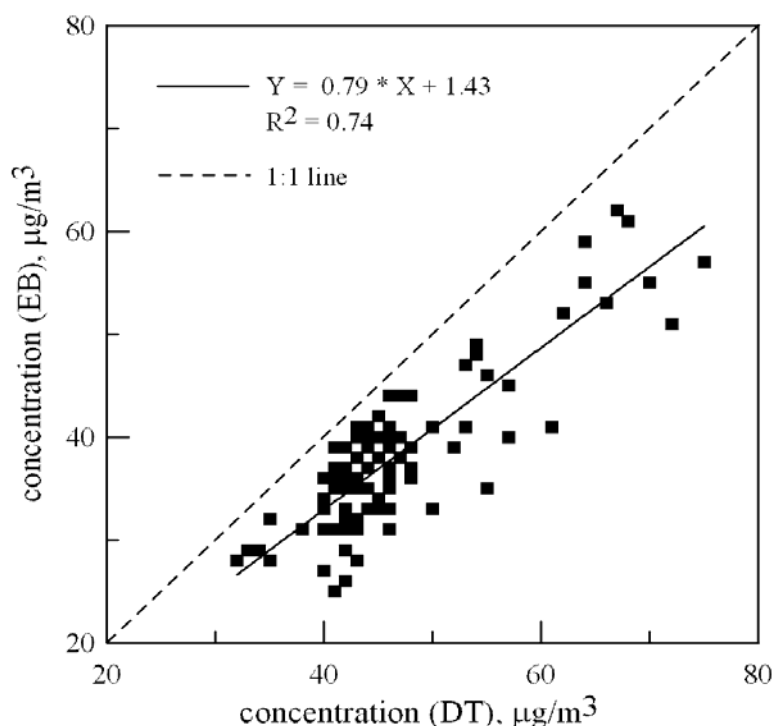
stream and the light was scattered from the particles. Some of the scattered light was focused onto a photo detector and then converted into a voltage. After some calculations, PM<sub>2.5</sub> mass concentration of particles can be obtained from the generated voltage.

The PM<sub>2.5</sub> mass readings of the EB and DT were recorded every 15 minutes. Two test periods generated 192 PM<sub>2.5</sub> data sets from 14:00, June 12 to 15:00, June 14, 2006. During these periods (period 1 and period 2), the ambient relative humidity, RH, ranged from 55.1 to 89.2% and the ambient temperature, T, ranged from 24.2 to 32.3°C. From June 12 to 13 (period 1), the inlet heater of the EB was switched off to investigate the influence of relative humidity on PM<sub>2.5</sub> mass reading, while the inlet heater was turned on for the period 2 (from June 13 to 14). Time-averaged sampling was also performed using a Chemcomb Cartridge (Model 3500, Rupprecht & Patashnick Co., Inc. NY) to determine PM<sub>2.5</sub> mass concentration. The components of the Chemcomb Cartridge (CC) included an impactor with the cutoff aerodynamic diameter at 2.5 µm, a glass-transition section, two honeycomb denuders, a spacer and a filter pack. The flow rate of the CC was 10 L/min. The honeycombs were coated using 1% (w/v) sodium carbonate, 1% (w/v) glycerol in a 1:1 (v/v) methanol/water solution for acid gases. For ammonia gas, 1% (w/v) citric acid in ethanol was used. A Teflon filter was placed downstream of the denuders to collect fine particles. The manual samplers and the real-time monitors were collocated with a 24-h sampling and the relative distance between the continuous and the manual samplers exceeded 1.5m. The sample of the CC was pre- and post-weighed using a Microbalance (Mettler Toledo Inc, Greifensee, Switzerland) after 24-hr equilibration at 23 ± 3°C and 40 ± 5% relative humidity. The samples of the CC were weighed twice for each sampling and the tolerance of the additional re-weighing was found to be within 10 µg.

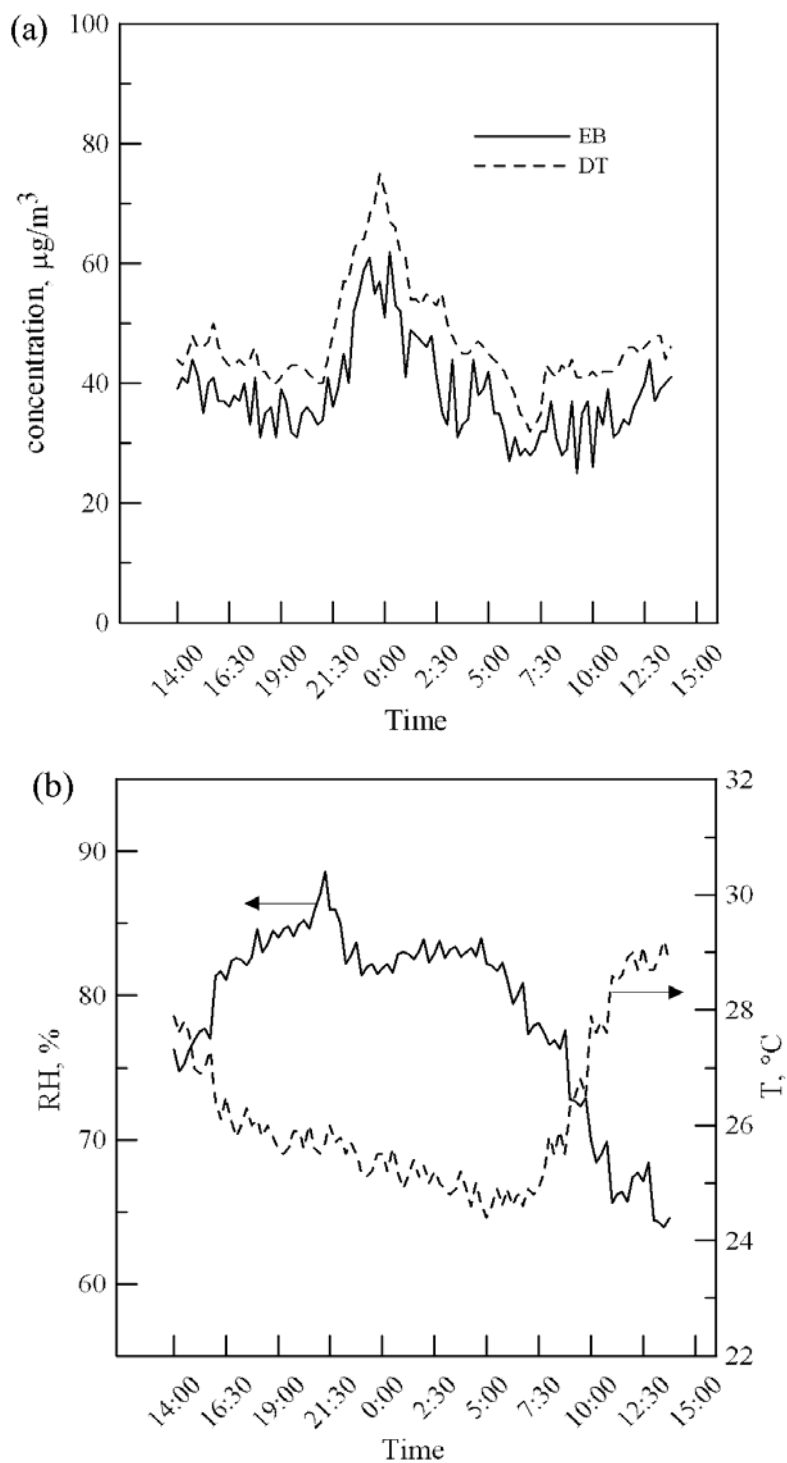
## RESULTS AND DISCUSSION

Fig. 1 plots that PM<sub>2.5</sub> mass reading by the EB versus those by the DT, when the inlet heater of the EB was turned off. A moderate correlation was observed between PM<sub>2.5</sub> mass readings by the EB and DT, with a gradient of 0.79, an intercept of 1.43 µg/m<sup>3</sup>, and a coefficient of determination of 0.74. The ratio of the mean PM<sub>2.5</sub> mass reading of the DT to that of the EB without heating was 1.22. Fig. 2 plots PM<sub>2.5</sub> mass readings of the DT and EB (Fig. 2 (a)), and ambient relative humidity and temperature (Fig. 2 (b)) for June 12-13. During the test, the ambient temperatures ranged from 24.4°C to 29.2°C, and the ambient RH ranged from 63.9% to 88.6%. For the test period of 21:15-01:45, higher PM<sub>2.5</sub> mass readings of the DT are observed than those of the EB when its ambient RH was ranged from 81.4 to 88.6%. Fig. 3 plots PM<sub>2.5</sub> readings of the DT, CC and EB when the inlet heater of the EB was turned off at various relative humidities. The PM<sub>2.5</sub> readings of the DT ranged from 32 to 75 µg/m<sup>3</sup>, and those of the EB ranged from 25 to 62 µg/m<sup>3</sup>. Test data revealed that the PM<sub>2.5</sub> mass readings from the DT, in general, were higher than those

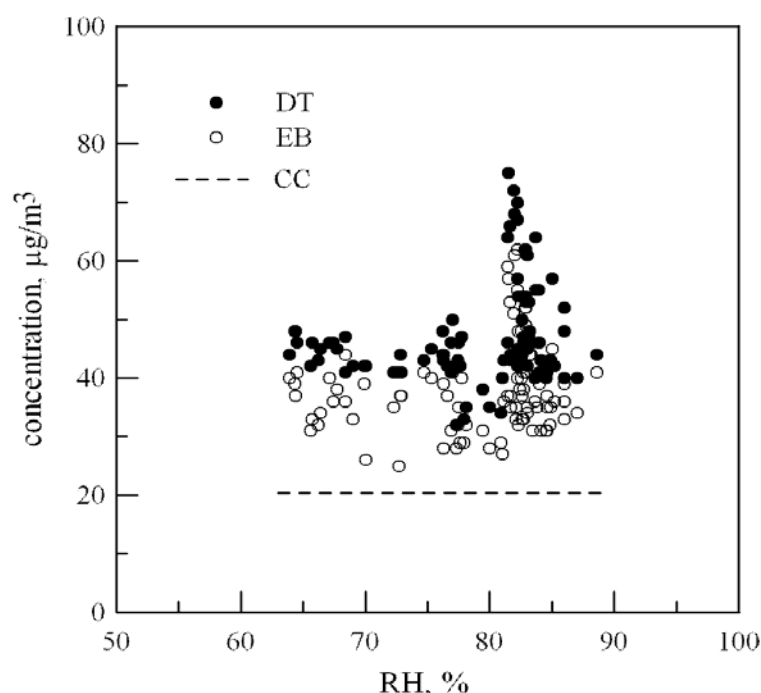
from the EB. The concentration difference between the DT and EB was found to be 2-21  $\mu\text{g}/\text{m}^3$  at various relative humidities.  $\text{PM}_{2.5}$  concentrations detected by the real-time monitors were also compared to that measured using a manual sampler, which was found to be 20.3  $\mu\text{g}/\text{m}^3$ , as shown in Fig. 3. The ratio of the average  $\text{PM}_{2.5}$  mass reading by the DT and EB to that using the manual sampler was 2.32 and 1.89, respectively.  $\text{PM}_{2.5}$  mass concentrations of both real-time monitors were higher than that of the manual sampler. It is probably due to the higher relative humidity for the real-time monitor than that for the manual sampler, which was usually conditioned under a relative humidity of 40%.



**Fig. 1.** Comparison of  $\text{PM}_{2.5}$  readings between DT and EB without heating.



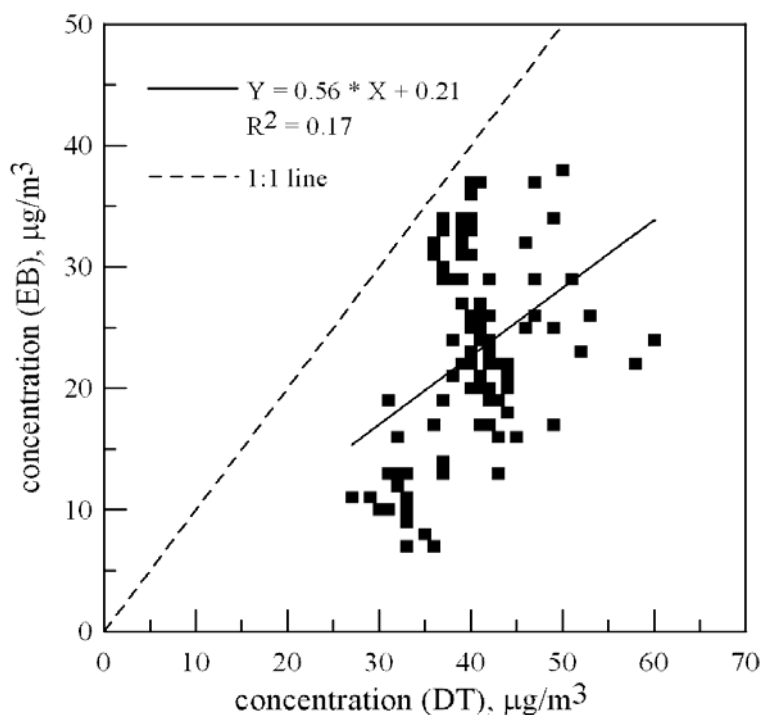
**Fig. 2.** (a) PM<sub>2.5</sub> reading vs. time (b) Relative humidity and temperature vs. time (EB without heating).



**Fig. 3.** PM<sub>2.5</sub> reading of DT, CC and EB without heating at various relative humidities.

When the inlet heater of the EB was turned on, PM<sub>2.5</sub> mass reading by the EB was much lower than that by the DT, as shown in Fig. 4. PM<sub>2.5</sub> mass reading by the EB has a lower gradient and a lower correlation than those by the DT, with a gradient of 0.56, an intercept of 0.21 µg/m<sup>3</sup>, and a coefficient of determination of 0.17. The ratio of the mean PM<sub>2.5</sub> mass reading of the DT to that of the EB with heating was found to be 1.76. Fig. 5 plots PM<sub>2.5</sub> mass readings of the DT and EB (Fig. 5 (a)), and the ambient relative humidity and temperature (Fig. 5 (b)) for June 13-14. The ambient RHs were from 55.1% to 89.2% and the ambient temperatures were from 24.2°C - 32.3°C. Results showed that PM<sub>2.5</sub> mass readings from the DT were higher than those from the EB at various ambient RHs. Fig. 6 plots PM<sub>2.5</sub> readings of the DT, CC and EB when the inlet heater of the EB was turned on at various relative humidities. The results revealed PM<sub>2.5</sub> concentration of the manual sampler was 21.7 µg/m<sup>3</sup>. The ratio of the average PM<sub>2.5</sub> mass reading by the EB to that using the manual sampler was 1.05, indicating that PM<sub>2.5</sub> mass reading of the EB with inlet heater was close to that of the manual sampler. The EB employed an automatic inlet heater to eliminate the condensation effect on the filter by the higher ambient RH, such that, the RH effect on the mass reading could be avoided. The weight contribution of water condensation on the filter was found to be 1.9% and 47% for the EB with and without heating, respectively. However, the ratio of the average PM<sub>2.5</sub> mass reading by the DT to that using the manual sampler was as high as 1.86. It demonstrates that the concentrations detected by the DT exceed those measured using the manual sampler, probably because of the condensational growth

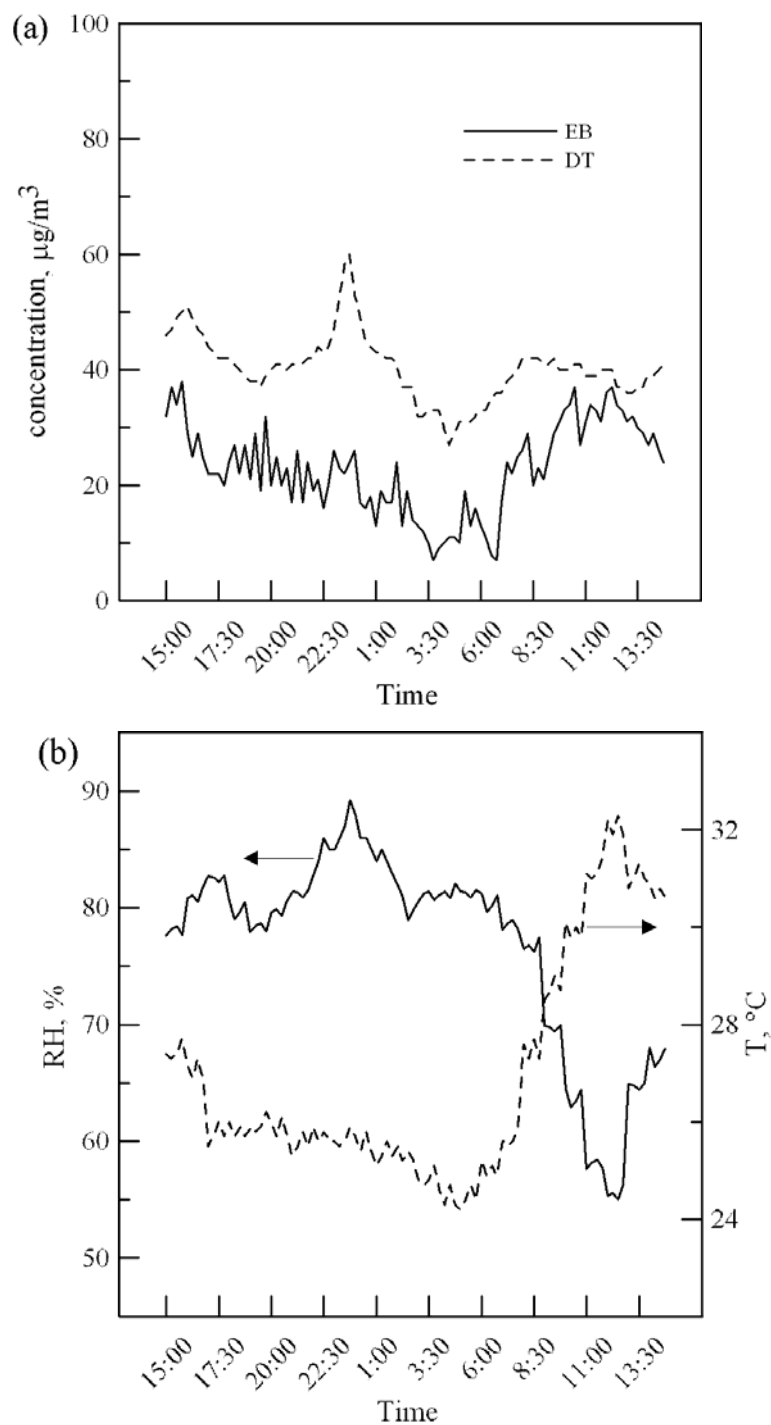
of hygroscopic particles by the higher ambient RH, which may increase PM<sub>2.5</sub> mass reading of the DT.



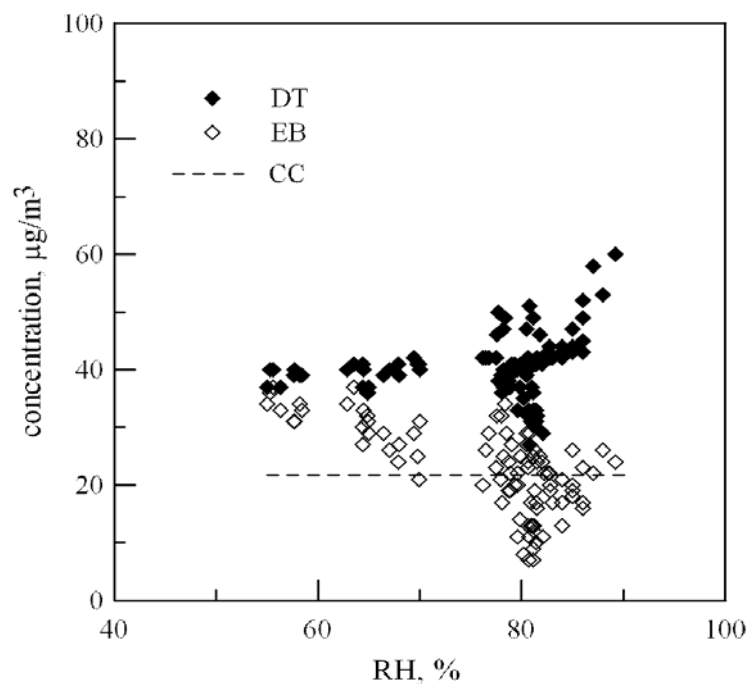
**Fig. 4.** Comparison of PM<sub>2.5</sub> readings between DT and EB with heating.

Fig. 7 shows the influence of relative humidity on PM<sub>2.5</sub> concentration difference between the DT and the EB with or without the inlet heater. When the heater of the EB was turned off, the concentration of the DT minus that of the EB was not obviously relevant with the relative humidity. It is due to that the relative humidity affected PM<sub>2.5</sub> reading for both the DT and EB real-time monitors. In comparison, as the heater of the EB was switched on, the concentration difference increased with an increasing relative humidity, as shown in Fig. 7. The difference in PM<sub>2.5</sub> readings were related to ambient RHs with a gradient of 0.73, an intercept of -38.3 µg/m<sup>3</sup>, and a coefficient of determination of 0.68. It should be noted that there are several variables which can affect PM<sub>2.5</sub> concentration differences between the DT and EB such as the sampling flow rate, particle characteristics, size-selective inlet and detecting system. This study indicates that when the effect of relative humidity on PM<sub>2.5</sub> reading of the EB is eliminated, the increasing ambient RH results in an increasing PM<sub>2.5</sub> reading of the DT. The measurements of the DT should be validated in real-time to reduce their monitoring bias for the different relative humidities.

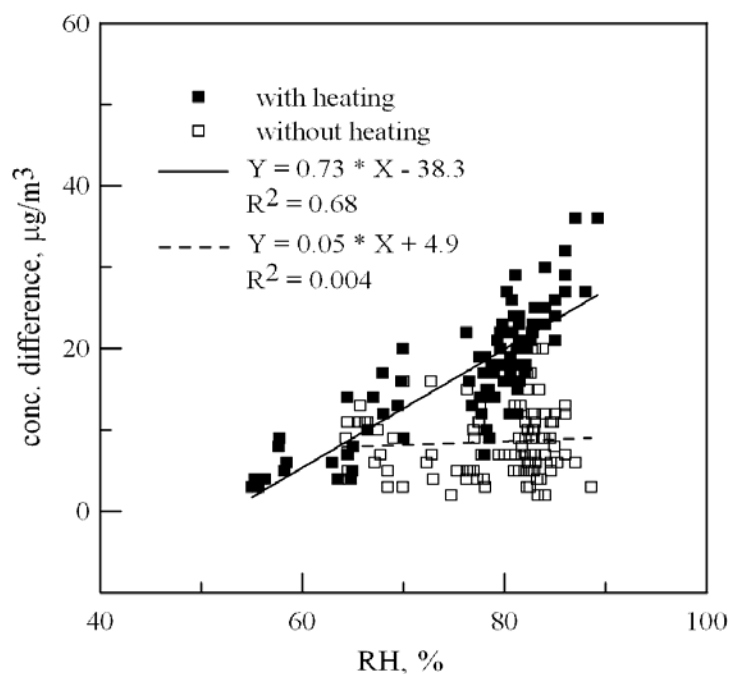




**Fig. 5.** (a) PM<sub>2.5</sub> reading vs. time (b) Relative humidity and temperature vs. time (EB with heating).



**Fig. 6.** PM<sub>2.5</sub> reading of DT, CC and EB with heating at various relative humidities.



**Fig. 7.** Influence of relative humidity on PM<sub>2.5</sub> difference between DT and EB.

## CONCLUSIONS

This investigation studied the influence of ambient relative humidity on PM<sub>2.5</sub> readings of two collocated real-time aerosol monitors. Relationships between PM<sub>2.5</sub> readings by a beta gauge monitor and by a light scattering monitor were evaluated at different ambient relative humidities. The results indicated that PM<sub>2.5</sub> readings of the light scattering monitor were higher than those of the beta gauge monitor, whenever the inlet heater of the beta gauge was turned on or off. The mean PM<sub>2.5</sub> reading of the light scattering monitor to that of the beta gauge with heating was found to be 1.76 and it was 1.22 for the case without heating. PM<sub>2.5</sub> readings of the real time monitors were also compared to those of a manual sampler. The mean PM<sub>2.5</sub> reading of the light scattering monitor to that of the manual sampler ranged from 1.89 to 2.32. However, when the inlet heater of the beta gauge monitor was turn on, the mean PM<sub>2.5</sub> mass reading of the beta gauge monitor was close to that of the manual sampler. The beta gauge monitor employed an inlet heater to eliminate the condensation effect on the filter and the relative humidity effect on the reading could be avoided. For the light scattering monitor, the relative humidity affected PM<sub>2.5</sub> reading and PM<sub>2.5</sub> reading increased with an increasing relative humidity. Hence, PM<sub>2.5</sub> reading of the light scattering monitor should be validated in real-time for the various relative humidities.

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