Field Comparison of Real-Time $PM_{2.5}$ Readings from a Beta Gauge Monitor and a Light Scattering Method

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Abstract

In this study, $PM_{2.5}$ 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 $PM_{2.5}$ 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 $PM_{2.5}$ readings of the light scattering monitor were also higher than those of the manual sampler. Results indicated that the relative humidity affected $PM_{2.5}$ reading of the light scattering monitor and $PM_{2.5}$ reading increased as the relative humidity rose. In contrast, when the inlet heater of the beta gauge was switched on, the mean $PM_{2.5}$ 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 $PM_{2.5}$ mass readings of the beta gauge monitor.

Keywords: Beta gauge monitor; Light scattering monitor; $PM_{2.5}$; Relative humidity.

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INTRODUCTION

The measurement of $PM_{2.5}$ 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 $PM_{2.5}$ mass concentrations under various conditions (Niu *et al.*, 2002; Yanosky *et al.*, 2002; Chang, 2005; Kulkarni, 2006; Prasserttachato *et al.*, 2006). Yanosky *et al.* (2002) compared $PM_{2.5}$ 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 $PM_{2.5}$ 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 $\mu g/m^3$, and a correlation coefficient of 0.99. Geller *et al.* (2004) determined $PM_{2.5}$ 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 $PM_{2.5}$ concentration in indoor and ambient air monitor using a light scattering technology. However, several studies showed that $PM_{2.5}$ 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 $PM_{2.5}$ 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 $PM_{2.5}$ utilizing parametric variables was described by analyzing $PM_{2.5}$ mass concentrations at over 300 locations in the eastern United States during 2000 (Paatero *et al.*, 2003). $PM_{2.5}$ mass concentrations collected by Federal Reference Method every third day at a series of sites were analyzed. The parametric variables in the model of $PM_{2.5}$ 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 $PM_{2.5}$ 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 $PM_{2.5}$ readings of two real-time aerosol monitors. The $PM_{2.5}$ 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 $PM_{2.5}$ mass readings was further examined by turning on the heater. The $PM_{2.5}$ 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 $PM_{2.5}$ 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 $PM_{2.5}$ cut-size WINS impactor (BX-804, Met One Instruments Inc. Oregon) downstream of a PM_{10} inlet head (BX-802, Met One Instruments Inc. Oregon) at a sampling flow rate of 16.7 L/min. ^{14}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, $PM_{2.5}$ 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^3 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, $PM_{2.5}$ mass concentration of particles can be obtained from the generated voltage.

The $PM_{2.5}$ mass readings of the EB and DT were recorded every 15 minutes. Two test periods generated 192 $PM_{2.5}$ 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 $PM_{2.5}$ 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 $PM_{2.5}$ 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 $PM_{2.5}$ 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 $PM_{2.5}$ mass readings by the EB and DT, with a gradient of 0.79, an intercept of 1.43 $\mu g/m^3$, and a coefficient of determination of 0.74. The ratio of the mean $PM_{2.5}$ mass reading of the DT to that of the EB without heating was 1.22. Fig. 2 plots $PM_{2.5}$ 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 $PM_{2.5}$ 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 $PM_{2.5}$ readings of the DT, CC and EB when the inlet heater of the EB was turned off at various relative humidities. The $PM_{2.5}$ readings of the DT ranged from 32 to 75 $\mu g/m^3$, and those of the EB ranged from 25 to 62 $\mu g/m^3$. Test data revealed that the $PM_{2.5}$ 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 μg/m^3 at various relative humidities. $PM_{2.5}$ concentrations detected by the real-time monitors were also compared to that measured using a manual sampler, which was found to be 20.3 μg/m^3, as shown in Fig. 3. The ratio of the average $PM_{2.5}$ mass reading by the DT and EB to that using the manual sampler was 2.32 and 1.89, respectively. $PM_{2.5}$ 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%.

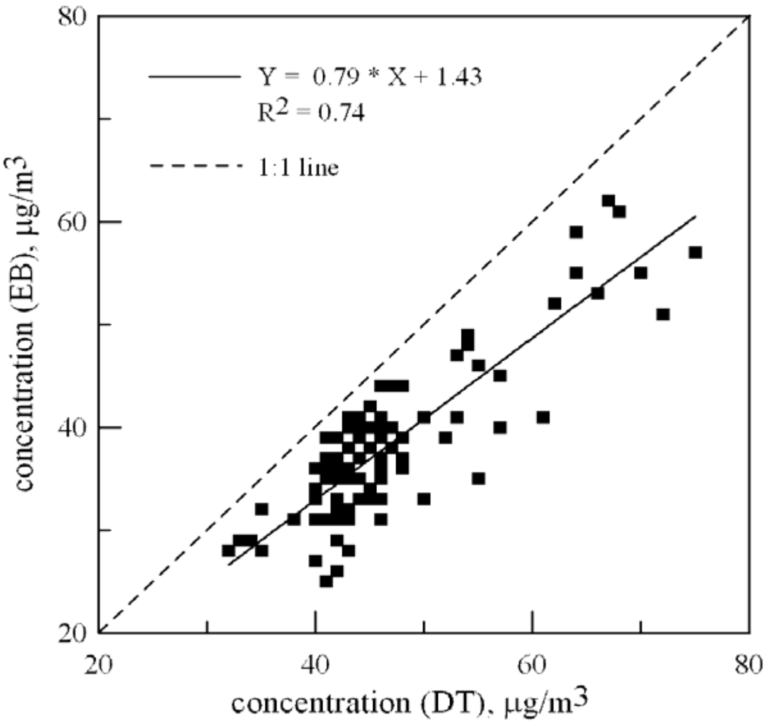

Fig. 1. Comparison of $PM_{2.5}$ readings between DT and EB without heating.

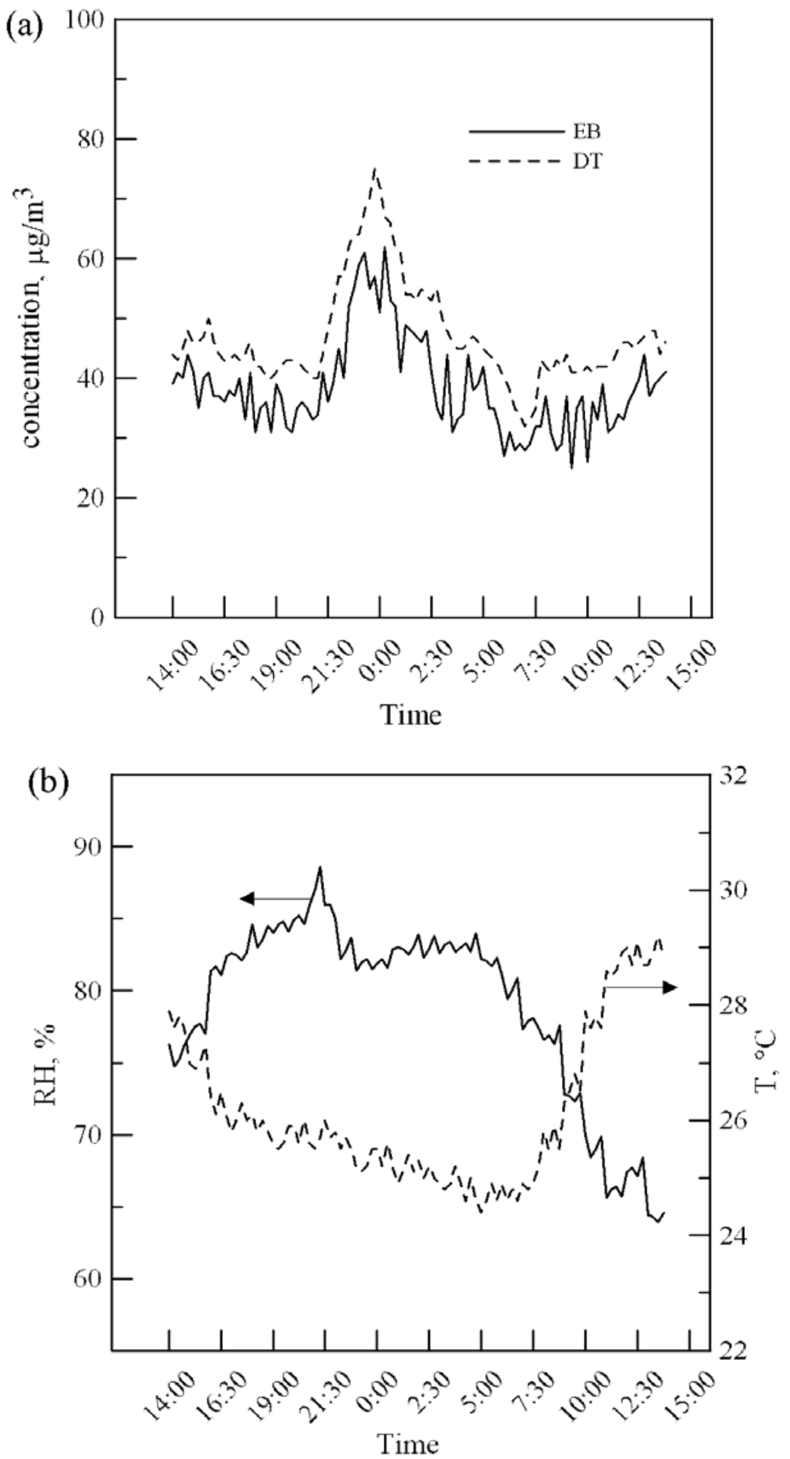

Fig. 2. (a) $PM_{2.5}$ reading vs. time (b) Relative humidity and temperature vs. time (EB without heating).

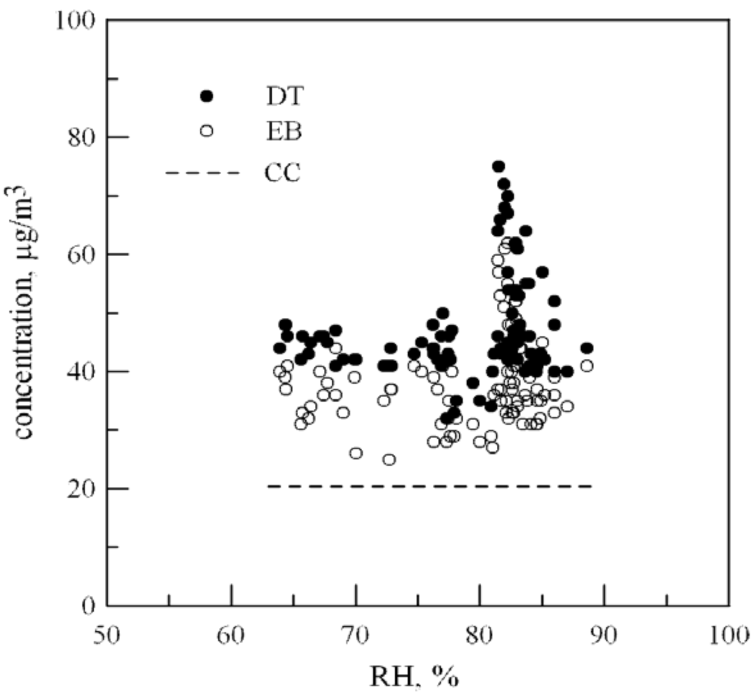

Fig. 3. $PM_{2.5}$ reading of DT, CC and EB without heating at various relative humidities.

When the inlet heater of the EB was turned on, $PM_{2.5}$ mass reading by the EB was much lower than that by the DT, as shown in Fig. 4. $PM_{2.5}$ 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 $\mu g/m^3$, and a coefficient of determination of 0.17. The ratio of the mean $PM_{2.5}$ mass reading of the DT to that of the EB with heating was found to be 1.76. Fig. 5 plots $PM_{2.5}$ 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 $PM_{2.5}$ mass readings from the DT were higher than those from the EB at various ambient RHs. Fig. 6 plots $PM_{2.5}$ readings of the DT, CC and EB when the inlet heater of the EB was turned on at various relative humidities. The results revealed $PM_{2.5}$ concentration of the manual sampler was 21.7 $\mu g/m^3$. The ratio of the average $PM_{2.5}$ mass reading by the EB to that using the manual sampler was 1.05, indicating that $PM_{2.5}$ 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 $PM_{2.5}$ 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 $PM_{2.5}$ mass reading of the DT.

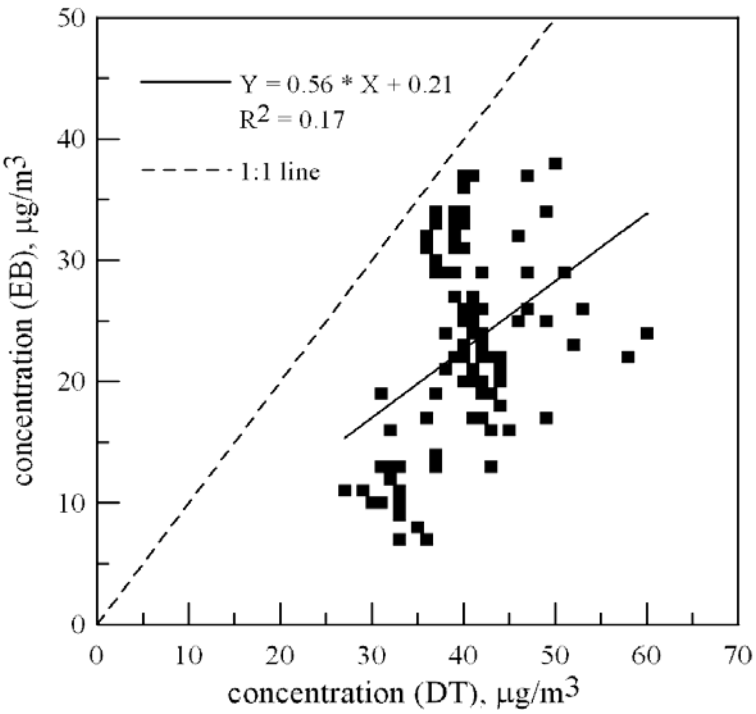

Fig. 4. Comparison of $PM_{2.5}$ readings between DT and EB with heating.

Fig. 7 shows the influence of relative humidity on $PM_{2.5}$ 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 $PM_{2.5}$ 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 $PM_{2.5}$ readings were related to ambient RHs with a gradient of 0.73, an intercept of -38.3 μg/m^3, and a coefficient of determination of 0.68. It should be noted that there are several variables which can affect $PM_{2.5}$ 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 $PM_{2.5}$ reading of the EB is eliminated, the increasing ambient RH results in an increasing $PM_{2.5}$ 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.

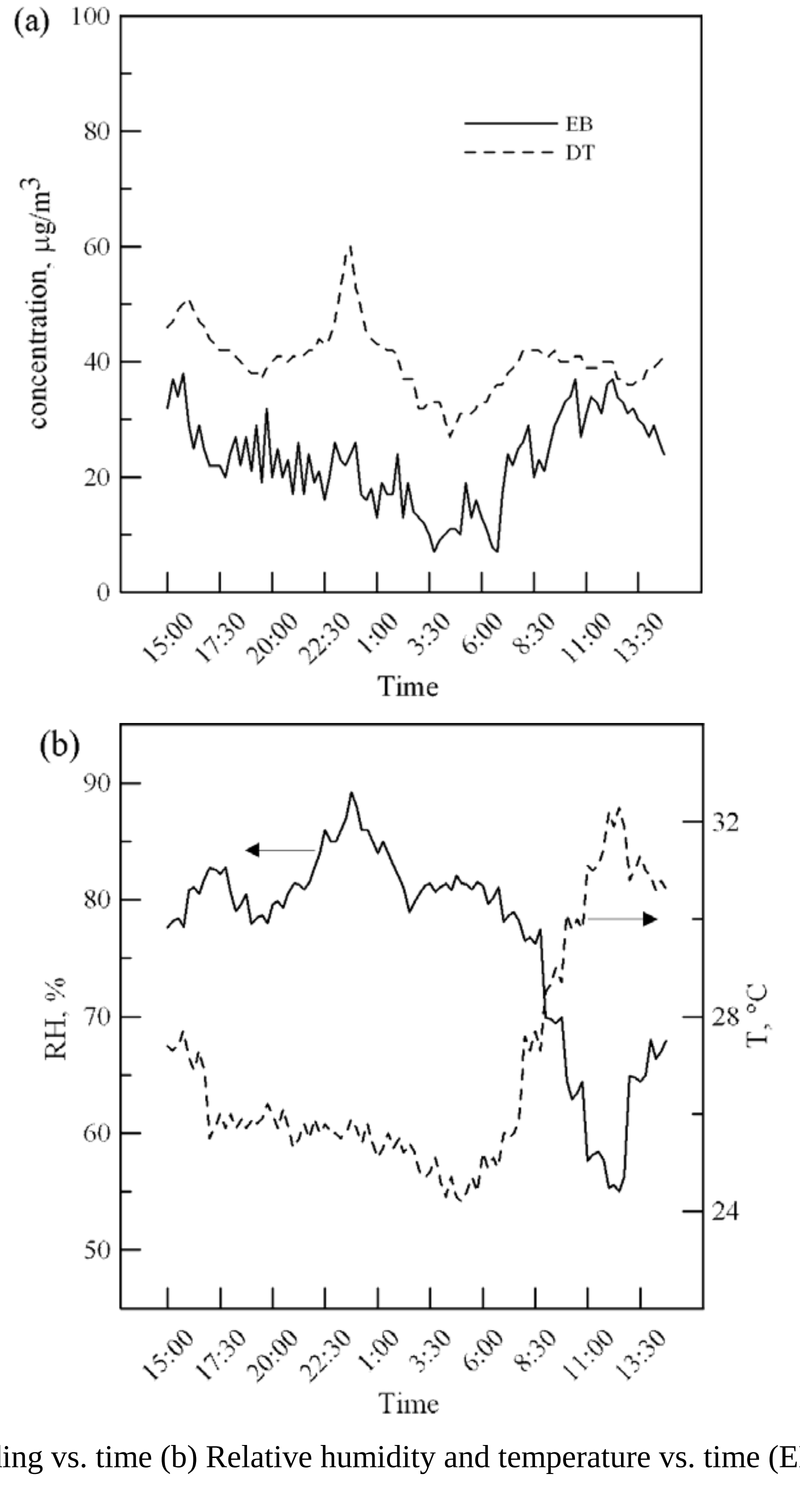

Fig. 5. (a) $PM_{2.5}$ reading vs. time (b) Relative humidity and temperature vs. time (EB with heating).

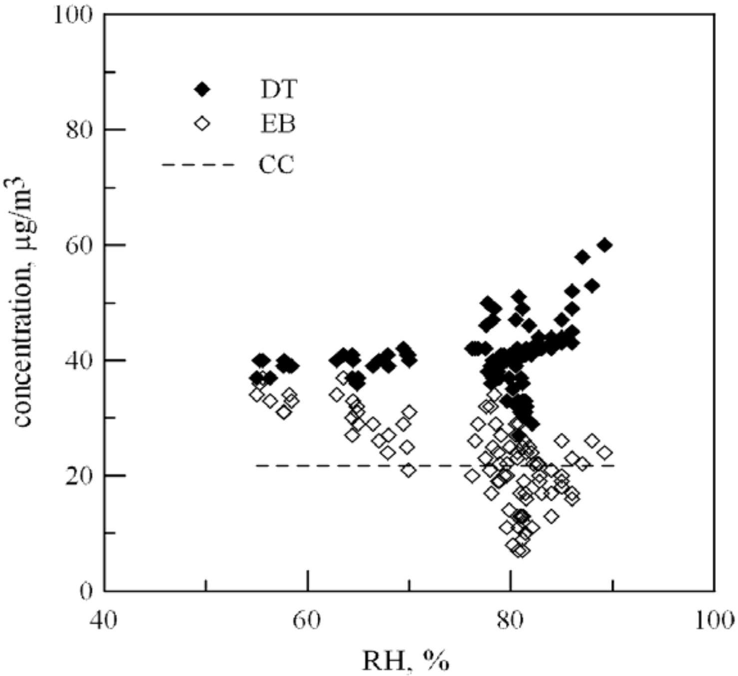

Fig. 6. $PM_{2.5}$ reading of DT, CC and EB with heating at various relative humidities.

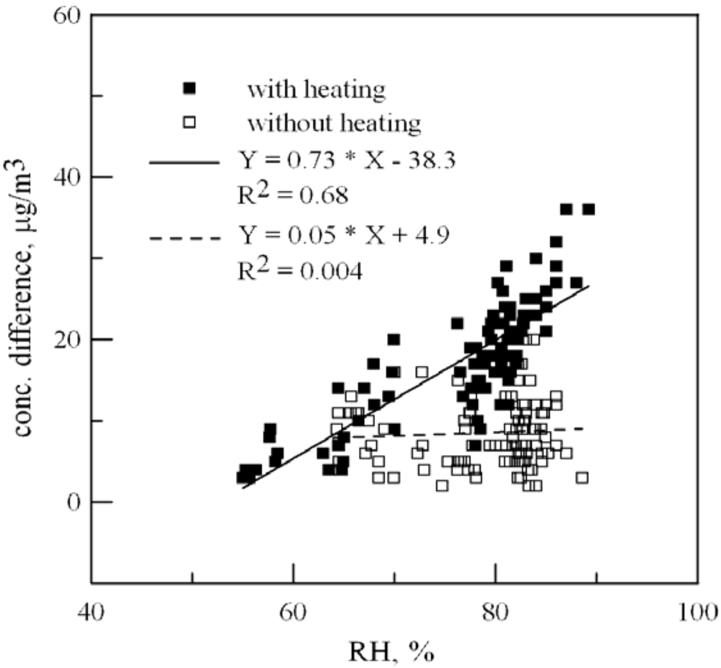

Fig. 7. Influence of relative humidity on $PM_{2.5}$ difference between DT and EB.

CONCLUSIONS

This investigation studied the influence of ambient relative humidity on $PM_{2.5}$ readings of two collocated real-time aerosol monitors. Relationships between $PM_{2.5}$ readings by a beta gauge monitor and by a light scattering monitor were evaluated at different ambient relative humidities. The results indicated that $PM_{2.5}$ 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 $PM_{2.5}$ 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. $PM_{2.5}$ readings of the real time monitors were also compared to those of a manual sampler. The mean $PM_{2.5}$ 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 $PM_{2.5}$ 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 $PM_{2.5}$ reading and $PM_{2.5}$ reading increased with an increasing relative humidity. Hence, $PM_{2.5}$ reading of the light scattering monitor should be validated in real-time for the various relative humidities.

ACKNOWLEDGMENTS

The author would like to thank the National Science Council of the Republic of China for financially supporting this research under Contract No. NSC 95-EPA-Z-264-001.

REFERENCES

Allen, G., Sioutas, C., Koutrakis, P., Reiss, R., Lurmann, F.W. and Roberts, P.T. (1997). Evaluation of the TEOM Method for Measurement of Ambient Particulate Mass in Urban Areas. *J. Air Waste Manage. Assoc.* 47: 682-689.

Chang, C.T. (2005). Characteristics and Emission Factor of Fugitive Dust at Gravel Processing Sites. *Aerosol Air Qual. Res.* 6: 15-29.

Chung, A., Chang, D.P.Y., Kleeman, M.J., Perry, K.D., Cahill, T.A., Dutcher, D., McDougall, E.M. and Stroud, K. (2001). Comparison of Real-Time Instruments Used to Monitor Airborne Particulate Matter. *J. Air Waste Manage. Assoc.* 51: 109–120.

Geller, M.D., Fine, P.M. and Sioutas, C. (2004). The Relationship between Real-Time and Time-Integrated Coarse (2.5–10 μm), Intermodal (1–2.5 μm), and Fine (< 2.5 μm) Particulate Matter in the Los Angeles Basin. *J. Air Waste Manage. Assoc.* 54: 1029–1039.

Hauck, H., Berner, A., Gomiscek, B., Stopper, S., Puxbaum, H., Kundi, M. and Preining, O. (2004). On the Equivalence of Gravimetric PM Data with TEOM and Beta-Attenuation Measurements. *J. Aerosol Sci.* 35: 1135-1149.

Kulkarni, M.M. (2006). Source Apportionment of Human Exposure to Particulates in Mumbai, India. *Aerosol Air Qual. Res.* 6: 281-294.

Lanki, T., Alm, S., Ruuskanen, J., Janssen, N.A. H., Jantunen, M. and Pekkanen, J. (2002). Photometrically Measured Continuous Personal $PM_{2.5}$ Exposure: Levels and Correlation to a Gravimetric Method. *J. Expo. Anal. Environ. Epidemiol.* 12: 172-178.

Niu, J., Lu, B.M.K., and Tung, T.C.W. (2002). Instrumentation Issue in Indoor Air Quality Measurements: The Case with Respirable Suspended Particulates. *Indoor Built Environ.* 11: 162–170.

Paatero, P., Hopke, P.K., Hoppenstock, J., Eberly, S.I. (2003). Advanced Factor Analysis of Spatial Distributions of $PM_{2.5}$ in the Eastern United States. *Environ. Sci. Technol.* 37: 2460-2476.

Prasserttachato, T., Podgorski, A., Luckner, J.H., Furuuchi, M., Gradon, L., Suvachittanont, S., and Szymanski, W. W. (2006). Sampling and Characterization of PM-Fractions of Ambient Particulate Matter in Bangkok Utilizing a Cascade Virtual Impactor. *Aerosol Air Qual. Res.* 6: 67-81.

Ramachandran, G., Adgate, J.L., Hill, N., Sexton, K., Pratt, G., and Bock, D. (2000). Comparison of Short-Term Variations (15-Minute Averages) in Outdoor and Indoor $PM_{2.5}$ Concentrations. *J. Air Waste Manage. Assoc.* 50: 1157–1166.

Tung T.C.W., Chao, C.Y.H., Burnett, J. (1999). A Methodology to Investigate the Particulate Penetration Coefficient through Building Shell. *Atmos. Environ.* 33: 881–893.

Yanosky, J.D.,Williams, P.L., and MacIntosh, D.L. (2002). A Comparison of two Direct-Reading Aerosol Monitors with the Federal Reference Method for $PM_{2.5}$ in Indoor Air. *Atmos. Environ.* 36: 107–113.

Received for review, January 7, 2007

Accepted, March 24, 2007