



Original Article

Field comparison between electrostatic charge and light scattering monitors for continuous monitoring of airborne PM_{1.0}, PM_{2.5}, and PM₁₀ mass concentrations

Panich Intra^{1*}, Artit Yawootti¹, and Thanesvorn Siri-achawawath²

¹ *Research Unit of Applied Electric Field in Engineering, College of Integrated Science and Technology, Rajamangala University of Technology Lanna, Mueang, Chiang Mai, 50220 Thailand*

² *Innovative Instrument Co., Ltd., 72 PAV Building, Soi Ladprao 42, Ladprao Road, Sam Sen Nok, Huai Khwang, Bangkok, 10310 Thailand*

Received: 2 November 2016; Revised: 7 December 2016; Accepted: 1 January 2017

Abstract

This study evaluates and simultaneously compares two monitors, an electrostatic PM mass and a light scattering, DustTrak 8533 mass monitor, TSI Incorporated, for PM_{1.0}, PM_{2.5} and PM₁₀ measurements at ambient conditions at the Research Unit of Applied Electric Field in Engineering (RUEE), Rajamangala University of Technology Lanna (Doi Saket), Pa Pong, Doi Saket, Chiang Mai, Thailand during May 6–9, 2015. The two different instruments showed good results that were highly correlated. It was found that the comparison between the EPMM and the DustTrak 8533 values were R^2 of 0.8144, 0.9364, and 0.7657, and a slope of 0.7965, 1.0260, and 0.9556 for PM_{1.0}, PM_{2.5}, and PM₁₀, respectively. Relative humidity and temperature played an important role in PM mass concentration and its electrical properties. Particularly, EPMM proved its advantages in measuring and detecting PM_{1.0}, PM_{2.5}, and PM₁₀ particulate air pollution for mass concentrations in the range from 0.01 to 500 $\mu\text{g}/\text{m}^3$ because it was not affected by hygroscopic growth of the PM.

Keywords: particulate matter, PM, mass monitor, electrostatic charge, light scattering laser

1. Introduction

Health concerns over airborne particulate matter (PM) have brought attention to the monitoring and measuring of this fraction. So far, the U.S. Environmental Protection Agency (U.S. EPA) promulgated a regulation for the PM mass concentrations (EPA, 1997). One of the valuable tools for measuring PM mass concentration in real-time, both outdoors and indoors, is an automatic and continuous PM mass monitor. There are several automatic PM mass monitors available, wide-ranging in type, cost, flexibility, resolution, and accuracy.

Some of these automatic monitors include beta ray absorption, light scattering, quartz microbalances, and electrostatic charge monitors (Babich *et al.*, 2000; Choi *et al.*, 2014; Intra *et al.*, 2013; Koch *et al.*, 1999, 2005; Lee *et al.*, 2001, 2005; Lippmann *et al.*, 2000; Misra *et al.*, 2001). Each automatic PM monitor has been used more or less success-fully by specific researchers, who needed to collect accurately the real mass concentration of PM in ambient air conditions over a given time period (Chung *et al.*, 2001; Heal *et al.*, 2000; Liu *et al.*, 2002; Patashnick & Rupprecht, 1991). The mass, size, spectra, and chemistry of urban PM are not fixed over a given measurement time period, and their physical and chemical properties are sensitive to environmental variables. Therefore, it is important to compare the various automatic PM mass monitoring methods and instruments in controlled laboratory experiments and under a gambit of field environments.

*Corresponding author

Email address: panich_intra@yahoo.com

Real-time light scattering monitors are widely used because they are easy to operate, portable, provide a continuous output of instant time-resolved data, lower costs than comparable instruments, and they have operational advantages over the federal reference method (FRM) and federal equivalent method (FEM). Heal *et al.* (2000) showed that the DustTrak mass monitor had excellent functionality in terms of ease of portability and real-time data acquisition. DustTrak measures PM mass concentration in an air stream as a function of the light scattered by the sampled PM. The relationship between this light-scattering and the PM mass concentration is usually pre-set in the factory, using a standard type of A1 test dust (Arizona Test Dust). However, the light scattering properties of PM might be varied as a result of differences in particle's refractive index, shape, density, size, and humidity and temperature (Thomas & Gebhart, 1994). Numerous real-time light scattering monitors and other commercial automatic PM mass monitors have been made and compared measuring PM_{2.5} and PM₁₀ mass concentrations under various conditions (Chung *et al.*, 2001; Heal *et al.*, 2000; Liu *et al.*, 2002). Chung *et al.* (2001) compared five continuous PM_{2.5} and PM₁₀ mass monitors with the federal reference method at Bakersfield, CA. The results showed that the beta attenuation monitor closely followed the 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. Liu *et al.* (2002) evaluated the performance of portable light scattering devices for PM_{2.5} in indoor, outdoor, and personal settings, including the Radiance nephelometer (neph) and the personal DataRAM (pDR) (without any size fractionation inlet), against measurements from both Harvard impactors (HI_{2.5}) and Harvard personal environmental monitors (HPEM_{2.5}). In their results, the nephs showed higher coefficients of determination ($R^2 = 0.81-0.93$) than the pDRs ($R^2 = 0.77-0.84$). Kingham *et al.* (2006) compared PM₁₀ mass concentration of three types of real-time aerosol monitors including the DustTrak Aerosol Monitor Model 8520 (TSI Inc.), the TEOM Series 1400, and the MiniVol Portable Air Sampler (Airmetrics). The results showed that the DustTrak correlated well with the TEOM ($R^2 = 0.79$), but not with the MiniVol ($R^2 = 0.53$) for PM₁₀. In a later work Huang (2007) compared PM_{2.5} mass concentration of a portable light scattering monitor (DustTrak) and beta gauge monitor (E-BAM) at various ambient relative humidity levels. The results showed that the mean PM_{2.5} mass concentration 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. In a previous work, Yawootti *et al.* (2015) developed an automatic electrostatic PM mass monitor (EPMM) and evaluated it simultaneously with a commercially available TEOM series 1400ab ambient particulate monitor, Thermo Fisher Scientific Inc. We measured PM₁₀ mass concentration at ambient air conditions. The two different instruments showed good results that were highly correlated. The comparison between the EPMM and TEOM data values resulted in R^2 of 0.8352 and 0.9697, and a slope of 0.8401 and 0.9087 for 1-hour and 24-hours, respectively. However, few comparisons have been made of other commercial automatic PM mass monitors for real-time measurement of PM_{1.0}, PM_{2.5} and PM₁₀ mass concentration. In particular, differences in real-time measured PM_{1.0}, PM_{2.5}, and PM₁₀

mass concentrations between the electrostatic charge and the light scattering methods on a site-by-site and season-by-season basis for environmental sampling has not been studied extensively in recent years. This comparison particularly will be useful in refining and redesigning the EPMM and help improve complying with regulatory measurements using these devices.

In this study, the developed electrostatic PM mass monitor and a commercially available DustTrak 8533 mass monitor, TSI Inc., were installed at the same place and the two monitors were compared in the field using linear regression analysis on the collected data using the reduced major axis (RMA) method for PM_{1.0}, PM_{2.5} and PM₁₀ mass concentration. The location was at the Research Unit of Applied Electric Field in Engineering (RUEE), Rajamangala University of Technology Lanna (Doi Saket), 98 M. 8 Pa Pong, Doi Saket, Chiang Mai, Thailand, during May 6 to 9, 2015.

2. Description of Developed Electrostatic PM Mass Monitor

Figure 1 shows the schematic diagram of the electrostatic PM mass monitor (EPMM), developed in this study. The EPMM composed of a diffusion dryer, a PM charger, a PM impactor, a PM detector, an electrometer circuit, a flow system, a DC high voltage power supply, a data acquisition and processing system, and a wireless communication system. In the EPMM, mass flowmeter, Dwyer series RMA-21, and vacuum pump, an oil-less diaphragm vacuum pump, GAST model 15D1150/1190, were used to regulate and control the PM flow rate. It was operated at PM flow rate of about 5 L/min. Sample stream was first passed through the diffusion dryer to dried with the silica gel, any remaining water vapor from air samples was successfully removed. After the dryer, dried PM was directly introduced into the PM charger to electrostatically charge them by ion-particle collisions via diffusion charging and field charging mechanisms by a corona discharge field in the charging zone of the charger. It was then passed through an ion trap zone of the charger to remove the high electrical mobility of free ions after the charging; free ions can potentially reach the PM detector and ruin the measurement (Intra & Tippayawong, 2013). Figure 2 shows the schematic diagram of the corona-needle charger with ion trapper. Commercial DC high voltage power supplies, Spellman model MM10P1.5/12 and MM0.5P1.5/12, were used to maintain the corona voltage and ion-driving voltage in the charger. After the charger, charged PM was then passed through PM impactor inside the PM detector to remove particulates outside the measurement size range based on their aerodynamic diameter, particulates with diameters larger than 1.0, 2.5 and 10 μm for PM_{1.0}, PM_{2.5}, and PM₁₀, respectively (Intra *et al.*, 2012). The charged PM then measured electrically in the open-ended cup with a filter to collect the charges downstream of the PM impactor (Intra & Tippayawong, 2015). Figure 3 shows the schematic diagram of the PM detector. It consisted of a Faraday housing, a filter holder, a high efficiency particulate air (HEPA) filter, a Teflon® insulator and electrometer housing. The Faraday housing helped to eliminate electrical noise from the measurement of ultra-low currents produced by the charges that were collected on the internal filter (Intra & Tippayawong, 2015).

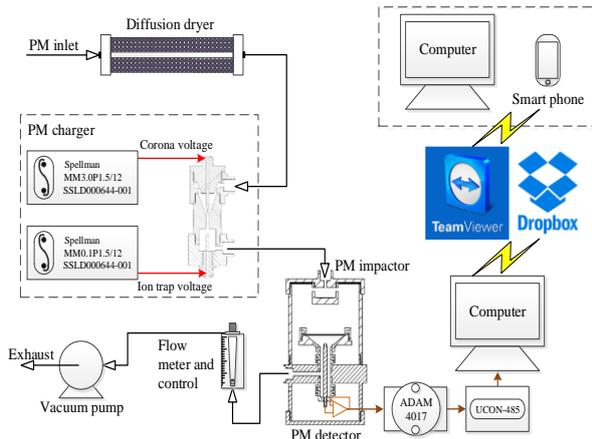


Figure 1. Schematic diagram of the EPMM.

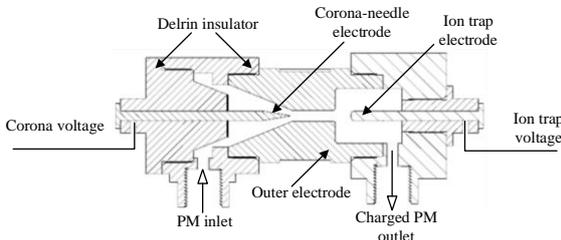


Figure 2. Schematic diagram of the corona-needle charger with ion trapper.

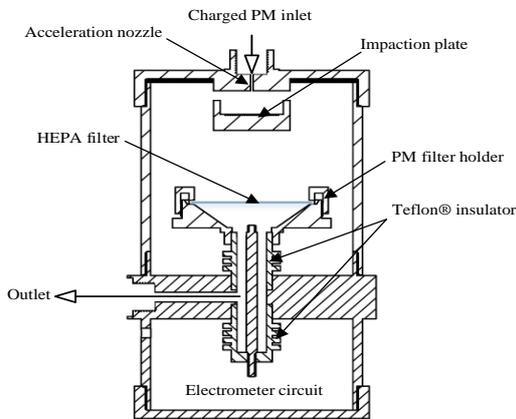


Figure 3. Schematic diagram of the PM impactor and detector.

Charges collected in the filter could move to the electrometer circuit through the connecting electrode located inside the Faraday housing. Figure 4 shows the schematic diagram of the electrometer circuit. The electrometer circuit was a simple current-to-voltage converter, where the voltage drop caused by a current flowing through a resistor was measured (Intra *et al.*, 2013). This circuit gave an output voltage of 5 mV per 10 fA of input signal current. Its output voltage, in the range of 5 mV to 5 V, linearly translated into current measurements of 10 fA to 10 pA. The PM mass concentration, m_p , on the filter in the PM detector as a function of the charged PM current, I_p , and PM diameter, d_p , could be calculated by (Yawootti *et al.*, 2015).

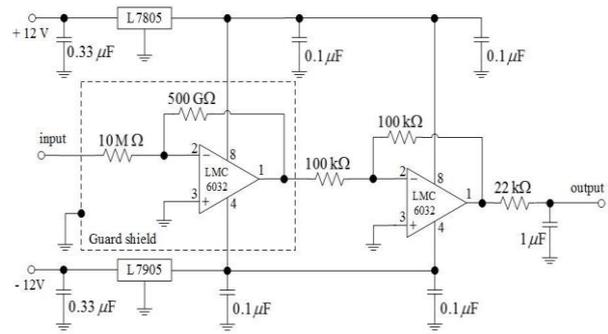


Figure 4. Schematic diagram of the electrometer circuit.

$$m_p = \frac{\pi}{6} \frac{I_p}{eQ_p} \int \frac{\rho_p(d_p)d_p^3}{n_p(d_p)} dd_p \quad (1)$$

Where m_p is the total mass concentration of PM ($\mu\text{g}/\text{m}^3$), e is the value of elementary charge on an electron (1.61×10^{-19} C), ρ_p is the PM density, n_p is the mean charge per particle and Q_p is the PM flow rate (m^3/s). Equation (1) can be rewritten in the power law form (Yawootti *et al.*, 2015)

$$m_p = \frac{\pi \rho_p d_p^3}{6 n_p e Q_p} I_p^n \quad (2)$$

In this study, the PM mass concentrations for PM1.0, PM2.5, and PM10 were determined empirically through regression analysis of the data gathered. The PM1.0 mass concentration in $\mu\text{g}/\text{m}^3$ is given by

$$m_p = 52.28 I_p^{0.9607} \quad (3)$$

The PM2.5 mass concentration in $\mu\text{g}/\text{m}^3$ is given by

$$m_p = 59.93 I_p^{0.9042} \quad (4)$$

The PM10 mass concentration in $\mu\text{g}/\text{m}^3$ is given by

$$m_p = 64.98 I_p^{0.8757} \quad (5)$$

The output voltage from the electrometer circuit was then sent to the 16-bit, 8 channel analog input module, ADAM-4017, controlled and data sampled by an external personal computer via RS-485 to USB converter interface, UCON-485. Software running on an external computer was developed based on Visual Basic programming. The software was capable of displaying the variation of time and PM mass concentration and the average of the 1-min, 1-hour and 24-hour PM mass concentration, respectively. The EPMM was also capable to be connected to the GPRS/3G modem via TCP/IP through the internet and a public cellular network for wireless continuous monitoring. The EPMM had a mass resolution of about $0.01 \mu\text{g}/\text{m}^3$, mass concentration range of about 0.01 to $500 \mu\text{g}/\text{m}^3$ and a measurement time range of about 0.1 to 3,600 sec.

3. Field Study Setup

3.1 Instrument description

The EPMM was compared side by side with a DustTrak 8533, TSI Inc. for measuring PM_{1.0}, PM_{2.5}, and PM₁₀ mass concentrations at ambient conditions. The TSI Inc. DustTrak 8533 is a compact commercial instrument that includes an impaction inlet, a laser diode, a focusing optics, a photo-detector, a vacuum pump, and control electronics (TSI, 2003). DustTrak drawn a continuous PM stream through the impaction inlet where particles with aerodynamic diameter greater than 10 μm are removed (impaction inlets with 1 and 2.5 μm cuts are also available). The sample stream then passed through a sensing chamber where it was intersected by light (0.78 μm wavelength) emitted from the laser diode. Particles in the sample stream scatter light in all directions; the amount of light measured by the photo-detector oriented at an angle of 90° to both the laser and the sample stream was converted to a proportional mass concentration by internal electronics. The proportionality constant used by the DustTrak sampler was determined by calibration against a gravimetric measurement of the International Organization for Standardization (ISO) 12103-1, A1 test dust (Arizona Test Dust) (TSI, 2003). DustTrak has a mass resolution of $\pm 0.1\%$ of reading of 0.001 mg/m^3 (whichever was greater), mass concentration range between 0.001 and 150 mg/m^3 and a detection range between 0.1 and 10 mm (PM_{0.1} to 10) (TSI, 2003). Table 1 shows the comparison between EPMM and DustTrak 8533.

3.2 Site description

In this work, the field study was done at a station located at the Research Unit of Applied Electric Field in Engineering (RUEE), Rajamangala University of Technology Lanna (Doi Saket), 98 M. 8 Pa Pong, Doi Saket, Chiang Mai, Thailand. The geographical coordinate information of the EPMM at that location is 18°93'34.13" N and 98°25'26.42" E. The elevation of the field study site was about 313 m above sea level and the topography of the field study site was about 70% of the area consists of mountains covered with forests. Both the EPMM and the DustTrak 8533 were collocated inside a trailer with their sample inlets located approximately 1 m above the trailer roof. To avoid potential interferences, the distance between two inlets of both continuous mass monitors was greater than 1 m. Inside the trailer temperature

was controlled at about 25 °C to maintain suitable operation conditions for the electronic units and the monitors. During the field test, the ambient relative humidity ranged from about 40 to 60 % and the ambient temperature ranged from about 35 to 42 °C.

3.3 Statistical analysis

Linear regression relationships were calculated using the reduced major axis (RMA) method to determine the relationship between the EPMM and DustTrak 8533 monitors in this work. The RMA regression to be the appropriate method for comparing the air pollutant concentration data since it does not assume that accuracy of the independent variable is error free (Ayers, 2001; EPA, 1987). Standard linear regression using the least-squares method, which does make this assumption, is not a suitable tool with which to determine the equivalence of PM mass concentration monitors. For each possible pairing of instruments at each site using unprocessed data and on log-normally transformed (\log_e) values were calculated by RMA regressions (Ayers, 2001).

4. Results from the Field Study

In this study, the total observations times were 72 hours during May 6–9, 2015, three test periods from 10:00, May 6 to 10:00, May 7, 2015; 10:00, May 7 to 10:00, May 8, 2015 and 10:00, May 8 to 10:00, May 9, 2015 for PM_{1.0}, PM_{2.5} and PM₁₀, respectively. The starting field sampling was set at 10.00 due to the working hours. It should be noted that the PM mass concentration showed two peaks: one corresponding to the morning peak i.e. between 8:00 am to 11:00 am, and the other one corresponding to evening peak i.e. between 5:00 pm – 9:00 pm in the diurnal cycle. The data used in this study were 1-min and 1-hr mass concentration levels (in micrograms per cubic meter) of PM_{1.0}, PM_{2.5}, and PM₁₀. The 1-min average mass concentrations of PM_{1.0}, PM_{2.5} and PM₁₀ were calculated from data collected every 0.1 sec. The 1-hr averages PM_{1.0}, PM_{2.5} and PM₁₀ mass concentration data were calculated from data recorded at every 1-min average; 1440 data points were collected for these test periods from EPMM and DustTrack 8533. The averages of the 1-min and 1-hr mass concentration of PM_{1.0}, PM_{2.5} and PM₁₀ were calculated to plot the time series to investigate the trend of the PM mass concentration.

Table 1. Comparison between EPMM and DustTrak 8533.

Specifications	EPMM	DustTrak 8533
Measurement technique	Electrostatic	Light scattering
Particulate size	PM _{1.0} , PM _{2.5} and PM ₁₀	PM _{1.0} , PM _{2.5} and PM ₁₀
Mass concentration range	0.01 – 500 $\mu\text{g}/\text{m}^3$	1 – 150,000 $\mu\text{g}/\text{m}^3$
Resolution	0.01 $\mu\text{g}/\text{m}^3$	1 $\mu\text{g}/\text{m}^3$
Measurement time	0.1 – 3,600 sec	1 – 60 sec
Data averaging	Every 0.1 sec	Every 1 sec
Particulate flow rate	5 L/min	3.0 L/min
Operating temperature range	10 – 60°C	0 to 50°C
Output	RS232/RS485, USB, TCP/IP	USB (Host and Device) and Ethernet.
Dimensions (L x W x H)	50 x 35 x 20 cm	13.46 x 21.59 x 22.35 cm
Weight	15 kg	2 kg
Electrical Requirements	100 – 240VAC 50 Hz	24 VDC at 2.5A

Figure 5 shows the comparison of 1-min average mass concentrations of PM1.0, PM2.5 and PM10, respectively, for EPMM and DustTrack 8533 during May 6–9, 2015. There was good agreement for the comparison. The measured mass concentrations of ambient PM1.0 for both monitors were found to be in the range of 17.93 to 40.26 $\mu\text{g}/\text{m}^3$. The maximum PM1.0 mass concentrations were between 40.26 and 40.00 $\mu\text{g}/\text{m}^3$, the minimum PM1.0 mass concentrations were found from 17.93 and 18.00 $\mu\text{g}/\text{m}^3$, and the standard error of about 0.10 and 0.09 $\mu\text{g}/\text{m}^3$ for the EPMM and DustTrack 8533, respectively. The measured mass concentrations of ambient PM2.5 for both monitors were in the range of 19.00 to 66.80 $\mu\text{g}/\text{m}^3$. The maximum PM2.5 mass concentrations were about 66.80 and 65.00 $\mu\text{g}/\text{m}^3$ for the EPMM and DustTrack 8533, respectively. The minimum PM2.5 mass concentrations were about 20.78 and 19.00 $\mu\text{g}/\text{m}^3$ for the EPMM and DustTrack 8533, respectively. Standard errors were about 0.29 and 0.31 $\mu\text{g}/\text{m}^3$ for the EPMM and DustTrack 8533, respectively. Measured mass concentrations of ambient PM10 for both monitors were found in the range of about 28.00 to 69.00 $\mu\text{g}/\text{m}^3$. Maximum PM10 mass concentrations were found to be about 55.71 and 69.00 $\mu\text{g}/\text{m}^3$ for the EPMM and DustTrack 8533, respectively. Minimum PM10 mass concentrations were found to be about 29.85 and 28.00 $\mu\text{g}/\text{m}^3$ for the EPMM and DustTrack 8533, respectively. Standard errors were about 0.16 and 0.17 $\mu\text{g}/\text{m}^3$ for the EPMM and DustTrack 8533, respectively.

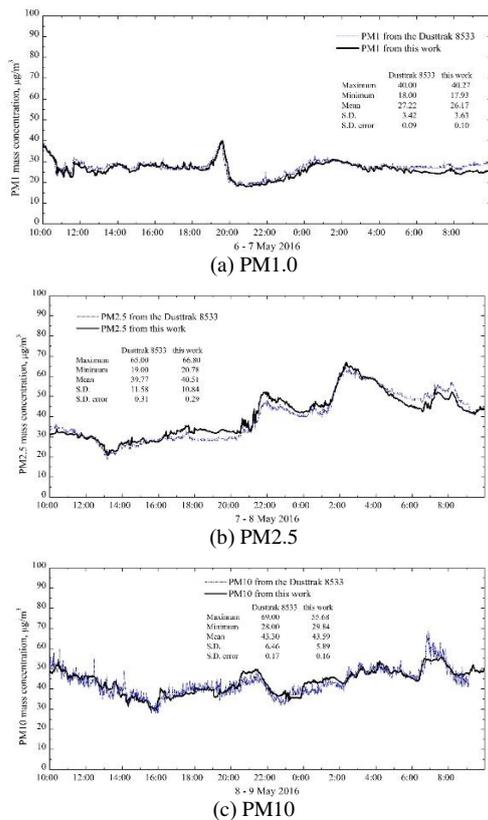


Figure 5. Comparison of PM1.0, PM2.5 and PM10 mass concentrations for EPMM and DustTrack 8533 at Rajamangala University of Technology Lanna (Doi Saket) during May 6–9, 2015.

Figure 6 shows the relationship between 1-hr average mass concentrations of PM1.0, PM2.5 and PM10 for EPMM and DustTrack 8533, respectively, during May 6–9, 2015. RMA regression analysis was used to determine the relationship of the slope of the regression between the EPMM and DustTrack 8533. It is well known that RMA regression analysis is the method the U. S. EPA uses to determine correlations between reference and candidate methods for particulate sampling and monitoring. The two instruments agreed well and were highly correlated (EPA, 1997). Comparing the data between the EPMM and DustTrack 8533 gave R^2 of about 0.8144, 0.9364, and 0.7657 with RMA regression slopes of about 0.7965, 1.0260, and 0.9556 and the intercept of about -2.3087, 3.9729, and 6.0089 for PM1.0, PM2.5, and PM10, respectively. It should be noted that the correlation and slope of the reference method and the candidate PM method measurements must be ≥ 0.97 , and 1.00 ± 0.10 , respectively. Additionally, the maximum precision and accuracy for the candidate PM10 method must be 15%, and 5%, respectively (EPA, 1997; Liu *et al.*, 2014). Results showed that the average EPMM mass concentration was about 26.17, 40.51, and 43.59 $\mu\text{g}/\text{m}^3$ for PM1.0, PM2.5, and PM10, respectively, and the average DustTrack 8533 mass concentration was about 27.22, 39.77, and 43.30 $\mu\text{g}/\text{m}^3$ for PM1.0, PM2.5, and PM10, respectively.

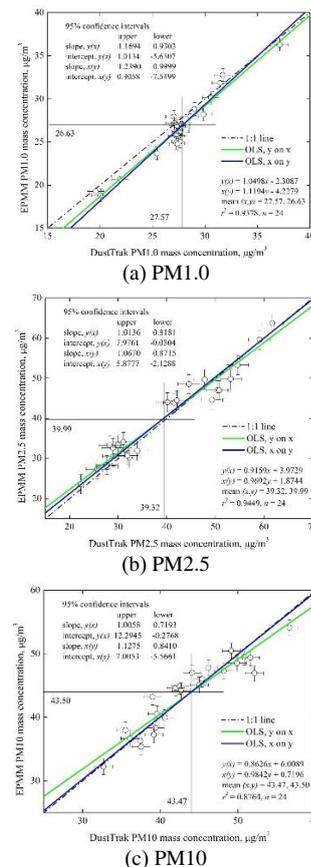
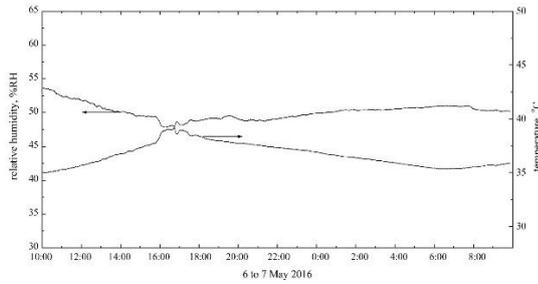
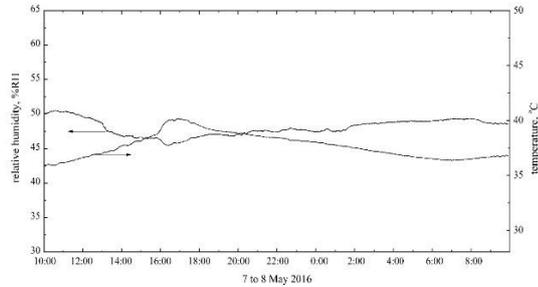


Figure 6. Relationship between PM1.0, PM2.5 and PM10 mass concentrations for EPMM and DustTrack 8533 at Rajamangala University of Technology Lanna (Doi Saket) during May 6–9, 2015.

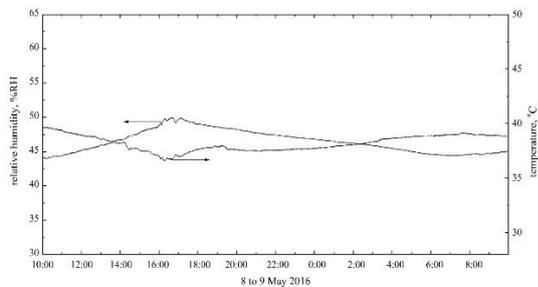
Figure 7 shows how the relative humidity and temperature of the EPMM changed over the time period of the test. The range for the operating relative humidity was from about 40 to 55 % and the operating temperature ranged from about 35 to 42 °C. It should be noted that relative humidity played an important role in PM mass concentrations and the associated electrical properties of the PM (Young *et al.* , 2007).



(a) 6 – 7 May 2016



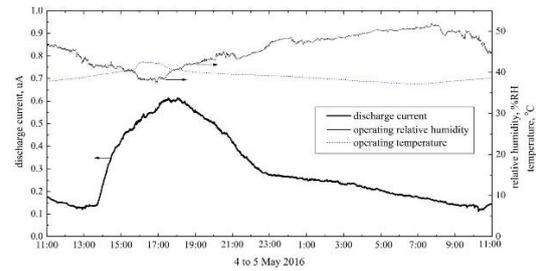
(b) 7 – 8 May 2016



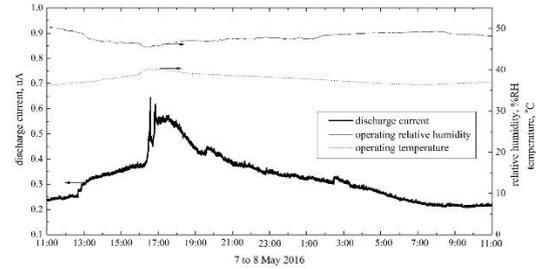
(c) 8 – 9 May 2016

Figure 7. Change of operating relative humidity and temperature of EPMM with measuring time.

Figure 8 shows the relationship between discharge current, operating relative humidity and temperature of EPMM without the diffusion dryer for observing the relative humidity and temperature effects. The discharge current of the EPMM charger was different for changing relative humidity and temperature. In the EPMM charger the water vapor present in the air affected the corona onset field strength, the mobility of the charge carriers, and the plasma chemistry inside the EPMM charger. Further study on how inherent particulate properties and ambient relative humidity can influence electrical properties of PM should be conducted.



(a) without the diffusion dryer



(b) with diffusion dryer

Figure 8. Relationship between discharge current, operating relative humidity and temperature of EPMM with/ without the diffusion dryer.

Figure 9 shows the relationship between PM mass concentrations and discharge current of the EPMM charger. The PM mass concentration decreased linearly with a decrease in the discharge current of the EPMM charger with R^2 of about 0.9856 and a RMA regression slopes of about 31.722. In the DustTrak, photometric mass measurements have been reported that the over-estimate the mass concentration readings of the PM when they were compared to a reference method under high humidity ambient conditions. This could largely be attributed to water-uptake, resulting in a hygroscopic growth of the PM. When the PM increases in size they scatter more light which in turn results in higher readings of the mass concentration of the PM for the photometric instrument (Brauer, 1995; Day *et al.* , 2000; McMurry & Stolzenburg, 1989;). In addition, a heated inlet sample conditioner can reduce photometric mass measurements when compared to an identical photometric instrument without a heated inlet during side-by-side sampling in humid outdoor environments (Peters *et al.* , 2008). A difference of 30% to 35% was observed between data collected with the heated inlet active as opposed to inactive with identical side-by-side instruments.

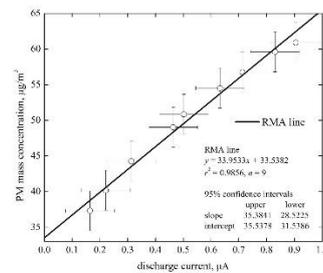


Figure 9. Relationship between PM mass concentrations and discharge current of the EPMM charger.

5. Conclusions

For PM_{1.0}, PM_{2.5}, and PM₁₀ measurements at ambient conditions the performance of the EPMM was evaluated and simultaneously compared with a commercially available DustTrak 8533 mass monitor, TSI Inc., at the Research Unit of Applied Electric Field in Engineering (RUEE), Rajamangala University of Technology Lanna (Doi Saket), Pa Pong, Doi Saket, Chiang Mai, Thailand, during May 6–9, 2015. Three test periods were chosen, from 10:00, May 6 to 10:00, May 7, 2015; 10:00, May 7 to 10:00, May 8, 2015 and 10:00, May 8 to 10:00, May 9, 2015 respectively. The mass concentration for 1-min averages PM_{1.0}, PM_{2.5} and PM₁₀ were calculated from data recorded at every 0.1 sec; 1440 data points were collected for these test periods both for EPMM and DustTrack 8533. During the test, the ambient relative humidity ranged from about 40 to 60 % and the ambient temperature ranged from about 35 to 42°C. In this study, a simple linear regression for slope and regression coefficient was used to determine the relationship between the EPMM and DustTrak 8533 monitors. The two different instruments showed highly correlated results. The comparison between the EPMM and the DustTrak 8533 showed a regression coefficient R^2 of 0.8144, 0.9364, and 0.7657, and a slope of 0.7965, 1.0260, and 0.9556 respectively for PM_{1.0}, PM_{2.5}, and PM₁₀. Relative humidity and temperature played an important role in PM mass concentration and its electrical properties. In particular, EPMM has an advantage in measuring and detecting PM_{1.0}, PM_{2.5}, and PM₁₀ particulate air pollution for mass concentrations in the range from 0.01 to 500 $\mu\text{g}/\text{m}^3$, as it did not give flawed readings because of hygroscopic growth of the PM, and is therefore a more reliable instrument for the application presented in this study.

Acknowledgements

Authors gratefully acknowledge the National Science and Technology Development Agency (NSTDA) (Research contract no. P-14-50757) for financial support. Authors wish to thank Dr. R. Zawadzki of Governors State University, U.S.A., for the valuable contribution during the preparation of the manuscript.

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