A new calibration device of particulate matter mass concentration monitor

Junchen Zou1*, Wei Fan1, Yaohua Cui1, Bing Bao1, Wenhui Zhou1, Xingang Zhou1, Chenglin Lv1, Jiangtao Liu1, Zhenqi Ma1, Yong Wang2 and Guosheng Gai3

1Henan Institute of Metrology, Zhengzhou, China
2Henan Institute of Product Quality Supervision and Inspection, Zhengzhou, China
3College of Material and Mineral Resource, Xi’an University of Architecture and Technology, Xi’an, China

*Corresponding author e-mail: junchen526@163.com

Abstract. All manuscripts must be in English, also the table and figure texts, otherwise we cannot publish your paper. Please keep a second copy of your manuscript in your office. When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. Should authors use tables or figures from other Publications, they must ask the corresponding publishers to grant them the right to publish this material in their paper.

1. Introduction
Air pollution in developing countries has recently become a serious environmental problem, which needs more active air quality monitoring and analyses [1]. Fine particulate matter (PM) is considered to be the most significant ambient air pollutant in terms of potential health impacts. Since epidemiological studies have shown that exposure to PM with aerodynamic diameters of <10μm (PM$_{10}$) and especially <2.5 μm (PM$_{2.5}$) induces an increase of lung cancer, morbidity, and cardiopulmonary mortality [2-5]. Therefore, it is important that regulators are able to accurately assess the exposure of PM$_{10}$ and PM$_{2.5}$. The increasing portability of analytical instruments which can measure PM$_{10}$ and PM$_{2.5}$ has appeared, however, there are also a number of technical problems exist, specifically related to calibration.

In this study, a new device for calibrating the PM$_{10}$ and PM$_{2.5}$ mass concentration monitor was designed, however, it is unknown whether the device could be used to calibrate the PM$_{10}$ and PM$_{2.5}$ mass concentration monitor, so the uniformity and repeatability of the device were evaluated.

2. Materials and methods
In this study, some apparatus were used in the process of calibrating the PM$_{10}$ and PM$_{2.5}$ mass concentration monitor, such as dust generator (RBG-1000, PALAS, USA), electrostatic neutralizer (EAN-581, Topas, Germany), PM$_{10}$ cutter (2616, 16.7 L/min, BGI, USA), PM$_{2.5}$ cutter (URG-2000-30ENS, 16.7L/min, URG, USA), vacuum pump (GA-164X, Shanghai guilai industrial co., Ltd), uniform mixing box (AMMC-120, Beijing bundant technology development co., Ltd), integrated work
station (AMCP-100, Beijing bundant technology development co., Ltd), electronic scales (Dandong Baxter instrument co., Ltd), Microdust pro (880nm, CASELLA) and test dust (ISO 12103-1, A2, USA).

The test process of the calibration device is showed in Fig.1, and it include air pump (1), the controller (2~4,13~14), dust generator (5), electrostatic neutralizer (6), three-way valve(7), PM\textsubscript{10} cutter (8), PM\textsubscript{2.5} cutter (9), uniform mixing box (10), membrane bracket (11~12), vacuum pump (15) and equipment being calibrated (16~17).

In order to calibrate the PM\textsubscript{10} and PM\textsubscript{2.5} mass concentration monitor, the test dust (drying to constant weight) was placed into the dust generator, and was released stably and uniformly by a certain rise speed and brush speed, then the test dust was neutralized by electrostatic neutralizer, and was diluted by clean air at a certain flow, then went through the PM\textsubscript{10} cutter and PM\textsubscript{2.5} cutter in turn, and entered into the uniform mixing box, and the four thief hatch of the uniform mixing box were connected to the membrane bracket and equipment being calibrated, then the mass concentration of the test dust was acquired by comparing the weight difference of the filter paper (drying to constant weight before tested). In this study, equipment being calibrated were instead by the membrane bracket, and the thief hatch which connected to 11, 12, 16 and 17 in Fig.1, were signed by a, b, c, d respectively.

In this study, the calibration device was positioned on the horizontal floor of the selected place. To investigate the uniformity of the device, the feed rate of the test dust was setted at 60-80 mm/h, the speed of the brush was setted at 900 rpm, and sampling time of 30 min was set for each cycle using a constant flow of 16.7 L/min, which both the electrostatic neutralizer branch and the dust diffuser branch were 8.35 L/min, and dilution air flow of 20 L/min, then PM was collected by polycarbonate Track-Etch membrane of 50.0 mm diameter. Most important of all, the device must be placed at specific environment more than 2 hours, which the temperature is (15~30) °C, the relative humidity is no more than 75%.

To investigate the repeatability of the device, the thief hatch of the calibration device connected to the microdust pro. The device and the microdust pro started at the same time, record data once a minute after the calibration device run steadily. Each thief hatch had three replicates.

3. Results and discussion
Jin et al. [6] measured the concentration of PM\textsubscript{2.5} in the ambient air by Determination of atmospheric articles PM\textsubscript{10} and PM\textsubscript{2.5} in ambient air by gravimetric method (HJ 618—2011), analyzed the influence factors, and found that the sampler, filter membrane and the accuracy of the balance had important effect on the measure result, especially, the uncertainty of the sampler mainly contained the deviation of cutter capture efficiency and sampling flow meters. Moreover, some researchers found that the cutting efficiency of the cutter may change the measure result of the instrument [7]. In order to reduce the error, the properties of PM2.5 cutter and PM10 cutter were evaluated before starting the test. The result could be seen in Fig.2 and Fig.3, it showed that when the cyclone flow rate was greater than 15 L/min, the cutpoint diameter of PM\textsubscript{10} cutter and PM\textsubscript{2.5} cutter were less than 10 μm and 2.5 μm respectively. During the test, the cyclone flow rate was setted at 16.7 L/min, it indicated that PM\textsubscript{10} cutter and PM\textsubscript{2.5} cutter could meet the demand of the test.
According to the test process of the calibration device, the test was carried out and the uniformity (U) was calculated by

\[ U = \frac{1}{1.13} \times \frac{\rho_j - \rho_i}{\bar{\rho}} \times 100\% \]  

(1)

Where \( \rho_i \) and \( \rho_j \) showed the measure result of \( i \) and \( j \) thief hatch respectively, \( \bar{\rho} \) showed the arithmetic mean of \( \rho_i \) and \( \rho_j \). The data was shown in Fig.4, although the uniformity of the thief hatch \( a \) and \( b \), \( a \) and \( c \), \( a \) and \( d \), \( b \) and \( c \), \( b \) and \( d \), \( c \) and \( d \) were different, but all the uniformity was no more than 8%, it indicated indirectly that the uniform mixing box of the calibration device was in good working status.

Moreover, the obtained repeatability data was shown in Fig.5~Fig.8, and the repeatability (R) was calculated by

\[ R = \frac{1}{\bar{\rho}} \sqrt{\frac{\sum_{i=1}^{n} (\rho_i - \bar{\rho})^2}{n-1}} \times 100\% \]  

(2)

Where \( \rho_i \) showed the measure result of \( i \) thief hatch, \( \bar{\rho} \) showed the arithmetic mean of \( \rho_i \) when \( i \) started from 1 to \( n \), \( n \) showed the total test number. The calculated data of the four thief hatch was 0.42%, 0.49%, 0.51%, 0.59%, 0.55%, 0.97%, 0.75%, 0.80 %, 0.55%, 0.45%, 0.43% and 0.66%,
respectively. It was observed that the repeatability of the thief hatch was no more than 5%, and showed that the calibration device had good repeatability.

In this study, the test dust was dried before the experiment, so that it decrease the error which caused by high humidity, it was consistented with previous research [8]. They found that there was a significant discrepancy between the concentration measured for heated and non-heated inlet in high humidity conditions. Without the heated inlet, it was likely that water droplet was contributing a significant proportion of the overall particle count.

In the process of evaluating the repeatability of the standard measurement equipment [9], some researchers found that when the repeatability of the measured objects was as small as possible, the repeatability obtained by experimental standard deviation would be more close to the repeatability of the standard measurement equipment, the data would be more accurate and reliable.

**Figure 5.** The repeatability of The thief hatch a.

**Figure 6.** The repeatability of The thief hatch b.

In this study, the uncertainty of PM concentration was from the standard device and the equipment being calibrated. The uncertainty of the standard device was introduced by the sampling flow rate of the standard membrane, time, scales and aerosol blending device. The uncertainty of the equipment being calibrated was mainly depended on its own repeatability.

**Figure 7.** The repeatability of The thief hatch c.

**Figure 8.** The repeatability of The thief hatch d.

It is known to all, the most common air sampling devices are those that collecting PM which passing through the sampling inlet on the filters. In this filter-based method, error would produce in the filter-handling process because filters must be weighed before and after sampling. When sampling and weighing, it would also lead to the loss of some semi-volatile species including organic
compounds and ammonium nitrate. Furthermore, no information was gained about the error of time during sampling [10].

In this study, due to the feed rate was set at 60-80 mm/h and the brush rate set at 900 rpm, so the obtained concentration of PM$_{2.5}$ was 4 to 10 mg/m$^3$, if the feed rate could be decreased furtherly, and the effect of other factors on the experimental result could be controlled better, the obtained concentration of PM$_{2.5}$ would be lower than previous obtained, even could reach the required concentration range of GB 3095-2012 in china. The calibration device could calibrate the PM$_{10}$ mass concentration monitor when PM$_{2.5}$ cutter was removed. Furthermore, the calibration device could real-time measure the concentration of PM$_{2.5}$, PM$_{10}$ and total suspended particulate matter in the air by switching the three-way valve.

4. Conclusion
This work proved that the calibration device had good properties, such as cutting efficiency, uniformity and repeatability, and could be used to calibrate the PM$_{10}$ and PM$_{2.5}$ mass concentration monitor, and would have a good application prospect in real-time measure the PM concentration of the air.

Acknowledgments
This work was financially supported by the Science and Technology Research Project of Henan Province (Nos. 172102210313) fund.

References
[1] R. Alireza, C. Rautenbach, G. Patrik, G. Dimitris, G. Pawan, Temporal changes of particulate concentration in the ambient air over the city of Zahedan, Air Qual. Atmos. Hlth. 6 (2013) 123–135.
[2] K. Bhaskaran, P. Wilkinson, L. Smeeth, Cardiovascular consequences of air pollution: what are the mechanisms, Heart. 97 (2011) 519–520.
[3] R. Brook, B. Urch, J. Dvonch, R. Bard, M. Speck, G. Keeler, M. Morishita, F. Marsik, A. Kamal, N. Kaciroti, J. Harkema, P. Corey, F. Silverman, D. Gold, G. Wellenius, M. Mittleman, S. Rajagopalan, J. Brooky, Insights into the mechanisms and mediators of the effects of air pollution exposure on blood pressure and vascular function in healthy humans, Hypertension. 54 (2009) 659–667.
[4] G. Sivagangabalan, D. Spears, S. Masse, B. Urch, R. Brook, F. Silverman, D. Gold, K. Lukic, M. Speck, M. Kushla, T. Farid, K. Poku, E. Shi, J. Floras, K. Nanthakumar, Mechanisms of increased arrhythmic risk associated with exposure to urban air pollution, Circulation. 122 (2010) A17901.
[5] M. Stafoggia, E. Samoli, E. Alessandrini, Short-term associations between fine and coarse particulate matter and hospitalizations in Southern Europe: results from the med-particles project, Environ. Health. Persp. 121 (2013) 1026–33.
[6] H. Jin, Q. Fu, X. Wu, Y. Yao, The Uncertainty of Determination of PM2.5 in the Ambient Air by Gravimetric Method, Environ. Monit. in China. 30 (2014) 32-35.
[7] Y. Cai, Y. Zhang, F. Sha, L. Shen, H. Hu, Determination of PM2.5 Concentration by Manual Sampling and Auto Monitoring, Environ. Sci. Mana. 37 (2012) 110-113.
[8] E. Michael, J. Samantha, K. Amy, M. Adam, S. Thomas, Practicalities of mapping PM10 and PM2.5 concentrations on city-wide scales using a portable particulate monitor, Air Qual. Atmos. Hlth. 2016.
[9] Y. Zhang and C. Zhou, The influences on the results of repeatability of measurement standard using different DUT, Metrol. Test. Technol. 40 (2013) 51-52.
[10] Y. Lee, H. Kim, K. Lee, Development of monitoring technology for airborne particulate matter, Environ. Monit. Assess. 70 (2001) 3-20.