Study on the Uncertainty of the Calibration Device of PM$_{2.5}$ Mass Concentration Monitor

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Abstract. The fine particles (PM$_{2.5}$) has become a major air pollution problem in China, and PM$_{2.5}$ mass concentration monitor was used to measure the concentration of PM$_{2.5}$, and whether it is accurate or not determines the quality of the atmosphere. In this study, the uncertainty of the calibration device of PM$_{2.5}$ mass concentration monitor was estimated. By analyzing the source of the uncertainty of calibration device, the analytical method of the uncertainty was determined. It was proved that when the aerosol concentration were 50μg/m$^3$, 200μg/m$^3$ and 500μg/m$^3$, the expanded uncertainty of the calibration device were 0.90%, 0.90% and 10.02% respectively, and it showed that the major influence factor of the uncertainty of the calibration device was the mass concentration indication error.

1. Introduction

With the continuous growth of economy and accelerated city modernization, PM pollutionn, especially the fine particles(PM$_{2.5}$), has become a major air pollution problem in China, with a serious impact on global and regional climate changes, reduced visibility, and human health effects, especially associated with cardiovascular disease and wheezing[1]. In order to prevent the further deterioration of air quality and to protect human health and the ecosystem, a series of regional or national air pollutant emission inventories has been established in China in recent years [2-3]. It is well known that PM$_{2.5}$ mass concentration monitor was used to measure the concentration of PM$_{2.5}$, and whether it is accurate or not determines the quality of the atmosphere, so a series of national control policies for PM$_{2.5}$ mass concentration monitor has been implemented, such as Calibration Specification for PM$_{2.5}$ Mass Concentration Measurement Instruments (JJF 1659-2017).

In this study, a new device was used to calibrate the PM$_{2.5}$ mass concentration monitor. The working principle of the calibration device was that the three-channel jet aerosol generator sent out aerosol, which was diluted by the clean gas, and then mixed, diffused and settled, and the calibration process was completed by comparing the concentration indication error of the standard monitor and the measured monitor. According to the previous experiment and relevant test certificate, it was proved that the repeatability and uniformity of the calibration device were less than 5% and 5% respectively[4], which meet the requirement of the calibration specification of JJF 1659-2017, therefore it could be used to
calibrate the PM$_{2.5}$ mass concentration monitor. In order to further study the accuracy of calibration results, the uncertainty of the calibration device was estimated in this study.

2. The experiment design
In this study, the standard monitor was β-ray PM$_{2.5}$ monitor (Thermo Scientific, MP101M, USA), which was located in the center of the equipment room, and the measured monitor (LPM1000, zhangjiagang langyi electromechanical equipment co., LTD.) was located in the equipment room, which was 15cm away from the standard monitor. Because of the calibrated aerosol concentration of the device was divided into (25-75)μg/m$^3$, (75-250)μg/m$^3$ and (250-600)μg/m$^3$, so the aerosol concentration of 500μg/m$^3$, 200μg/m$^3$ and 50μg/m$^3$ which came from 2g/L, 1g/L and 0.5g/L of the mixture of ISO12103-1 A2 powder and pure water respectively, were selected to investigate the uncertainty of the calibration device. To achieve the purpose, when the aerosol generator sent out 500μg/m$^3$, 200μg/m$^3$ and 50μg/m$^3$ of the aerosol, record the data of the standard monitor and the measured monitor respectively, and every concentration of the aerosol was repeatedly sent out and measured 10 times.

3. Results and discussion
The measured result of the aerosol concentration of 500μg/m$^3$, 200μg/m$^3$ and 50μg/m$^3$ are shown in Fig.1-Fig.3. Because of PM$_{2.5}$ mass concentration standard monitor and the calibrated monitor were both connected to the PM$_{2.5}$ aerosol generating-mixing device, and their sampling-time and sampling-flow were the same. In addition, the PM$_{2.5}$ mass concentration instrument was devoted to measure the mass concentration of PM$_{2.5}$, therefore, the uncertainty of the calibration device was mainly influenced by the uncertainty of mass concentration indication error[5]. In this study, the calculate model of mass concentration indication error was as follows[6-7]:

$$\Delta C = \frac{(C_m - C_s)}{C_s} \times 100\%$$

Where $C_s$ is the standard mass concentration value of PM$_{2.5}$, $C_m$ is the being calibrated mass concentration value of PM$_{2.5}$, and $\Delta C$ is the mass concentration indication error.

According to the calculate model of mass concentration indication error (seen in formula 1), the uncertainty of mass concentration indication error was mainly composed of the uncertainty component introduced by the measured value of the being calibrated monitor and the uncertainty component introduced by the standard mass value of the standard monitor. However, according to the analysis, the repeatability made a major contribution to the uncertainty component introduced by the measured value of the being calibrated instrument, and the uncertainty component introduced by PM$_{2.5}$ mass concentration monitor and the nonuniformity of the PM$_{2.5}$ aerosol generating-mixing device were resulted in the uncertainty component introduced by the standard mass value of the standard device.

According to the experimental data, when the aerosol concentration were 50μg/m$^3$, 200μg/m$^3$ and 500μg/m$^3$, the repeatability of the being calibrated monitor were 0.62%、0.64% and 1.27%, and the measured uncertainty($u_1(C_m)$) were 0.44%、0.45% and 0.90% respectively. However, at the instance of Calibration Specification for PM$_{2.5}$ Mass Concentration Measurement Instruments(JJF 1659-2017), the uncertainty of the standard monitor for PM$_{2.5}$ mass concentration was no more than 8% (k=2), then its relative standard uncertainty($u_1(C_s)$) was 4%. In this study, the nonuniformity of the calibration device was less than 5%, and the being calibrated thief hatch and the standard thief hatch were assumed to be equally distributed, then the standard uncertainty ($u_2(C_s)$) was 2.89%, which introduced by the PM$_{2.5}$ aerosol generating-mixing device.
Fig.1 The measured result of the aerosol concentration of 50μg/m³.
(M: the being calibrated mass concentration value; S: the standard mass concentration value)

Fig.2 The measured result of the aerosol concentration of 200μg/m³.

Fig.3 The measured result of the aerosol concentration of 500μg/m³.
To sum up, the uncertainty component \( u_s(c_i) \), which introduced by the standard mass value of the PM\(_{2.5}\) standard measuring device, could be calculated as follows:

\[
\begin{align*}
    u_s(c_i) &= \sqrt{u_r^2(c_i) + u_s^2(c_i)} \\
    u_r(\Delta c) &= \sqrt{[u_r(c_m)]^2 + [u_r(c_i)]^2}
\end{align*}
\]

Hence, the final result of \( u_s(c_i) \) was 4.93% (according to formula 2), and the related combined standard uncertainty \( u_r(\Delta c) \) could be calculated according to formula 3. When the aerosol concentration were 50μg/m\(^3\), 200μg/m\(^3\) and 500μg/m\(^3\), the related combined standard uncertainty \( u_r(\Delta c) \) were 0.45%, 0.45% and 5.01%. Therefore, when the \( k \) was 2, the expanded uncertainty were 0.90%, 0.90% and 10.02% respectively.

4. Conclusion

In this study, on the basis of the calibrated aerosol concentration of the device, the aerosol concentration of 500μg/m\(^3\), 200μg/m\(^3\) and 50μg/m\(^3\) were choosed to evaluate the uncertainty of the calibration device. The results showed that when the aerosol concentration were 50μg/m\(^3\), 200μg/m\(^3\) and 500μg/m\(^3\), the expanded uncertainty of the calibration device were 0.90%, 0.90% and 10.02% respectively, indicated that the mass concentration indication error was the major influence factor of the uncertainty of the calibration device.

References

[1] Dunea, D., Iordache, S, Liu, H.Y., et al. Quantifying the impact of PM2.5 and associated heavy metals on respiratory health of children near metallurgical facilities[J]. Environ. Sci. Pollut. Res. 2016(23): 15395–15406.

[2] He, J., Wu, L., Mao, H., et al. Development of a vehicle emission inventory with high temporal-spatial resolution based on NRT traffic data and its impact on air pollution in Beijing-part 2: impact of vehicle emission on urban air quality[J]. Atmos. Chem. Phys. 2016(16): 3171–3184.

[3] Jing, B., Wu, L., Mao, H., et al. Development of a vehicle emission inventory with high temporal-spatial resolution based on NRT traffic data and its impact on air pollution in Beijing-part 1: development and evaluation of vehicle emission inventory[J]. Atmos. Chem. Phys. 2016(16):3161–3170.

[4] Zou,J.C., Zou, X.H., Fan,W., et al. Study on the performance of the fluidic calibration device of PM2.5 mass concentration monitor[C]. IOP Conf. Series: Materials Science and Engineering. (2018) 394: 052073 doi:10.1088/1757-899X/394/5/052073.

[5] Fan,W., Zou,J.C., Cui, Y.H., et al. Study on the calibration method and calibration device of particle Monitor [J]. Measurement Technique.2017:651-654.

[6] General Administration of Quality Supervision, Inspection and Quarantine of the people's Republic of China. Evaluation and Expression of Uncertainty in Measurement, JJF 1059.1-2012[S]. 2012.

[7] General Administration of Quality Supervision, Inspection and Quarantine of the people's Republic of China. Calibration Specification for PM2.5 Mass Concentration Measurement Instruments, JJF 1659-2017[S]. 2017.