Study on the Performance of the Fluidic Calibration Device of PM2.5 Mass Concentration Monitor

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Abstract. A fluidic calibration device of PM2.5 mass concentration monitor was developed successfully, its components were introduced and its properties were evaluated. The result showed that the designed concentration was highly consistent with the actual dust concentration, and the repeatability of the calibration device was less than 5%, and the uniformity of the calibration device was less than 7%, it indicated that the calibration device had a huge advantage in calibrating the PM2.5 monitor at low concentration of (25-75) μg/m3.

1. Introduction

With the rapid development of the economy, urbanization and transportation, almost all types of air pollution problems, which were experienced for nearly a century in developed countries, exploded in China within last two decades. Recent studies indicated that the status of air pollution in China was far more complicated than ever before [1, 2]. Complex air pollution, characterized by regional photochemical smog and haze, exhibited an increasing trend in recent years in rapidly developing regions such as the North China Plain, the Yangtze River Delta and the Pearl River Delta. It is known to all, particulate matter (aerodynamic diameter ≤ 2.5 μm, PM2.5) can go into the lungs. These fine particles further go to the deepest portion of the lungs, passing to the blood, and carried out through the whole body, and changed the body’s defense system against foreign materials, damaged lung tissues, aggregated existing respiratory and cardiovascular diseases, and might lead to cancer.

In order to prevent the further deterioration of air quality and to protect human health and the ecosystem, the Chinese government has implemented a series of national control policies to reduce the emissions of air pollutants since 2005 [2], such as 《The quality standards of ambient air》 (GB 3095-2012).

Therefore, monitoring PM2.5 has also become a main objective on the agenda of governments. The principle of PM2.5 mass concentration monitor is consists of micro oscillating balance method (TEOM), beta-ray method, light scattering method and weighing method, but weighing method is the foundation of PM2.5 measurement. The measure discrepancy of every kind of monitor even the same kind of monitor is very big, so it is necessary to calibrate the PM2.5 mass concentration monitor.

At present, the calibration device of PM2.5 mass concentration monitor is few, especially which can calibrate lower concentration of (25-75) μg/m3. In this study, a fluidic calibration device for...
calibrating the PM2.5 mass concentration monitor was developed, and its performance such as uniformity and repeatability were evaluated.

2. Device configuration and experimental design

The calibration device is made up of dust room, sampling room, control room and instrument room. There are three dust generator in the dust room, which can sent $$(25-75) \mu g/m^3, (75-250) \mu g/m^3, (250-600) \mu g/m^3$$ of the dust. Each dust generator is equipped with one feeding mouth and two trachea mouth. The solution of ISO12103-1 A1 test dust and water was stirred evenly through the air which go through one trachea mouth, and the other trachea mouth was connected to the aerosol generator, the solution was dried and settled in the cone-shaped stainless steel cylinder after being fluidiced and atomizated by the aerosol generator. At the same time, the air was passed into the cone-shaped stainless steel cylinder and diluted the dust. The sampling room was below the cone-shaped stainless steel cylinder, and was connected to the export of the cone-shaped stainless steel cylinder. There were three PM2.5 cutter of 16.7L/min which connected to the monitor or the membrane bracket. The control room was made up of the touch-screen computer, which can set up and display real-time the running parameters and the measure result of the calibration device. The standard monitor and being calibrated monitor were placed into the instrument room, which was at the bottom of the calibration device.

Some apparatus of the calibration device were very important in the process of calibrating the PM2.5 mass concentration monitor, such as dust generator (Langyi Electromechanical Equipment Co. Ltd.), PM2.5 cutter (URG-2000-30ENS, 16.7L/min, USA), cone-shaped stainless steel cylinder (Langyi Electromechanical Equipment Co. Ltd.), beta-ray PM2.5 monitor (Thermo Scientific, MP101M, USA), dust concentration monitor (LPM1000, Langyi Electromechanical Equipment Co. Ltd.)

To evaluate the performance of the calibration device, whether the designed concentration is consistent with the actual dust concentration by weighing was investigated. The designed concentration is 50 $\mu g/m^3$, 200 $\mu g/m^3$, 500 $\mu g/m^3$ respectively, which represented low concentration of $$(25-75) \mu g/m^3$$, moderate concentration of $$(75-250) \mu g/m^3$$, high concentration of $$(250-600) \mu g/m^3$$.

To investigate the uniformity and repeatability of the calibration device, the beta-ray PM2.5 monitor used as the standard instrument was installed permanently in the middle of the instrument room, and the dust concentration monitor of LPM1000 used as the being calibrated instrument was installed at a distance of 15cm around the standard instrument.

3. Results and discussion

Some researchers 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 [3, 4]. In order to reduce the error, the properties of PM2.5 cutter were evaluated before starting the experiment. The result could be seen in Fig.1, it showed that when the cyclone flow rate was 16 L/min, the cutpoint diameter of PM2.5 cutter was 2.50 $\mu m$ (signed by a in Fig.1), 2.40 $\mu m$ (signed by b in Fig.1) and 2.45 $\mu m$ (signed by c in Fig.1) respectively. Therefore, when the cyclone flow rate was 16.7L/min, the cutpoint diameter of PM2.5 cutter were less than 2.5 $\mu m$ respectively, it indicated that PM2.5 cutter could meet the measure demand.

Because of weighing method is the foundation of PM2.5 measurement, the PM2.5 monitor were instead by the membrane bracket to validate the reliability of the designed concentration [5]. The concentration of 50 $\mu g/m^3$, 200 $\mu g/m^3$, 500 $\mu g/m^3$ respectively used as a representative of the designed low concentration of $$(25-75) \mu g/m^3$$, moderate concentration of $$(75-250) \mu g/m^3$$, high concentration of $$(250-600) \mu g/m^3$$. First of all, When the designed concentration was 50 $\mu g/m^3$ (200 $\mu g/m^3$, 500 $\mu g/m^3$), the sampling time was set at 60min (5min, 5min), and each cycle using a constant flow of 16.7L/min, and dilution air flow of 20 L/min, then test dust was collected over polycarbonate Track-Etch membrane of 0.2 $\mu m$ and 50.0 mm diameter, and the mass concentration was acquired by comparing the weight difference of the filter paper (drying to constant weight before tested).
The result could be seen from Fig. 2 to Fig. 4, when the designed concentration was 50\(\mu\)g/m\(^3\), 200\(\mu\)g/m\(^3\), 500\(\mu\)g/m\(^3\), the measured concentration by weighing was (48.03-48.65) \(\mu\)g/m\(^3\), (195.52-196.31) \(\mu\)g/m\(^3\), (495.75-498.14) \(\mu\)g/m\(^3\), and the measurement deviation was 2.69%-3.94%, 1.84%-2.24% and 0.37%-0.85% respectively, it indicated the designed concentration is highly consistent with the actual dust concentration.

In this study, the repeatability (R) was calculated by

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

(1)

Where \(\rho_i\) showed the measure result of i thief hatch, \(\overline{\rho}\) showed the arithmetic mean of \(\rho_i\) when i started from 1 to n, n showed the total test number. The obtained repeatability data was shown in Fig. 5-Fig. 7, it showed that when the designed concentration was 50\(\mu\)g/m\(^3\), the obtained result of the standard instrument and the being calibrated instrument were (44.96-49.53)\(\mu\)g/m\(^3\) and (46.94-52.95)\(\mu\)g/m\(^3\), and the calculated repeatability of the standard instrument and the being calibrated instrument were 2.90% and 4.31%. When the designed concentration was 200 \(\mu\)g/m\(^3\), the obtained result of the standard instrument and the being calibrated instrument were (192.46-205.8) \(\mu\)g/m\(^3\) and (185.98-203.88) \(\mu\)g/m\(^3\), and the calculated repeatability of the standard instrument and the being calibrated instrument were 2.35% and 3.18%. When the designed concentration was 500 \(\mu\)g/m\(^3\), the obtained result of the standard instrument and the being calibrated instrument were (481.81-506.18) \(\mu\)g/m\(^3\) and (484.87-509.75) \(\mu\)g/m\(^3\), and the calculated repeatability of the standard instrument and the being calibrated instrument were 1.90% and 1.82%. It was observed that the repeatability of the calibration device was no more than 5%. Compared to the other calibration device [6], it had better repeatability especially at the concentration of 50 \(\mu\)g/m\(^3\).
In this study, the uniformity \((U)\) was calculated by

\[
U = \frac{1}{1.13} \times \frac{\rho_i - \rho_j}{\bar{\rho}} \times 100\% \tag{2}
\]

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. 8, it showed the uniformity of the standard instrument and the being calibrated instrument at four different site was \((3.30\%-6.53\%)\) at the concentration of 50\(\mu\)g/m\(^3\) (signed by M-L in Fig. 8), \((2.74\%-3.92\%)\) at the concentration of 200\(\mu\)g/m\(^3\) (signed by M-M in Fig. 8), \((0.79\%-1.37\%)\) at the concentration of 500\(\mu\)g/m\(^3\) (signed by M-H in Fig. 8). The result showed that when the being calibrated instrument was at a distance of 15cm around the standard instrument, the uniformity of the calibration device was less than 7\%, it indicated indirectly that the uniformity of the calibration device was very good.
4. Conclusion

In a word, the calibration device verified the reliability of the dust concentration by weighing, and use the beta PM2.5 monitor as the standard instrument, and use light scattering PM2.5 monitor as the being calibrated instrument, the result are proved that the calibration device has excellent repeatability and uniformity. Compared with other calibration devices, it has huge advantage in calibrating the PM2.5 monitor at low concentration of (25-75) μg/m3.

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