



## Development of a Reliable and Cost-Effective Weighing Chamber for Aerosol Sample Analyses

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### ABSTRACT

Reliable gravimetric analysis of particulate matter filters is of great importance in exposure and risk assessment in industrial hygiene and environmental health, especially for light weight fine particles like PM<sub>2.5</sub>. Weighing bias may be caused by a number of environmental and operational factors. Among them, the humidity effect is most often addressed. This study proposes a cost-effective weighing chamber with humidity control by using a saturated magnesium chloride solution to meet the USEPA requirements for filter weighing. To exclude the interference of electrostatic charges, filter samples are treated with a radioactive source, Am<sub>241</sub>, on a microbalance pan before weighing. The results of long term monitoring showed that the relative humidity inside the weighing chamber is between 31–35%, when the temperature is between 18–21°C. The air pressure inside the weighing chamber is kept slightly positive by adjusting the air supply of the humidity control unit at 15 L/min during filter conditioning and at 25 L/min during filter weighing to maintain a stable humidity condition and prevent aerosol contamination from outside. Moreover, the operator should wear gloves to prevent hand moisture evaporation. We suggest that filter samples to be stored and conditioned in a weighing chamber with the filter holder's lid open to expedite and enhance the filter conditioning. When a hygroscopic filter, such as an MCE, is used to collect about 0.5 mg of hygroscopic NaCl particles, a mass increase of 0.5 mg results occurs due to the filter. An additional 1.2 mg mass increase occurs due to collected NaCl particles, when the weighing is performed under RH 85% rather than in the environmentally-well-controlled weighing chamber. With the use of the weighing chamber and the recommended practices, this study demonstrates excellent weighing quality. The mass determination limits are below 3 µg for 37-mm particle-laden filter samples commonly encountered in practical situations.

**Keywords:** Weighing chamber; Humidity; Electrostatic charge; Filter samples.

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### INTRODUCTION

Particulate matter (PM) has long been a critical hazard in the fields of industrial hygiene and/or environmental health, because it has been linked to a range of serious respiratory and cardiovascular health illnesses (Delfino *et al.*, 2005; Künzli *et al.*, 2005; Grigg, 2009). Owing to findings related to the effects of fine particles on human health, regulations have shifted from monitoring particulate matter of less than 10 micrometer (PM<sub>10</sub>) to monitoring particulate matter of less

than 2.5 micrometer (PM<sub>2.5</sub>). PM regulations are mass-based and, therefore, direct gravimetric analysis is the most accurate way to measure the concentration of particulate matter. In general, ambient PM<sub>10</sub> mass concentrations vary from several tenths to hundreds of µg/m<sup>3</sup> and the corresponding PM<sub>2.5</sub> concentrations are even lower. For personal and indoor exposure samplings, the mass of aerosols collected on a filter are as low as several tenths µg due to the use of low sampling flow and small particle size. Therefore, the weighing accuracy of particle-laden filters is becoming increasingly important, especially for light weight filters.

Significant weighing bias may be caused by a number of factors such as temperature, humidity, vibration, draft and electrostatic charge on the filters. To assure the reliability of PM<sub>2.5</sub> weighing data, the U.S. Environmental Protection Administration (USEPA) reference method requires filter

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samples of PM<sub>2.5</sub> to be conditioned and weighed in an environment that maintains the average air temperature between 20 to 23°C. The temperature variation should be maintained within  $\pm 2^\circ\text{C}$  over 24 hours and the average relative humidity (RH) should be kept between 30 to 40% with a variation of not more than  $\pm 5\%$  RH over 24 hours. It is also recommended that electrostatic charges, vibration and contamination of the filters from laboratory air be minimized to reduce variability in filter weighing measurements (USEPA, 1998).

Among all the factors affecting weighing accuracy, the humidity effect has been most commonly addressed during filter weighing (Tierney and Conner, 1967; Charell and Hawley, 1981; Lawless and Rodes, 1999; Tsai *et al.*, 2002; Brown *et al.*, 2006). Charell and Hawley (1981) found that the weight of filters increases with increasing RH and that mixed cellulose esters (MCE) filters are much more sensitive than PVC filters with respect to the humidity effect. Tsai *et al.* (2002) evaluated the variation of weight data for GF, MCE, PVC and Teflon filters under controlled (around 40%) and uncontrolled (40–65%) RH conditions and found that the weighing precision of GF and MCE filters is subjected to substantial humidity fluctuation whereas PVC and Teflon filters are not.

During the filter conditioning and weighing process, moisture absorption may occur not only in filters but also in collected particles. In fact, the collected particles may absorb or desorb moisture in response to humidity change. In a practical situation, the composition of collected particles is difficult to experimentally characterize in this respect. As a worst-case scenario, Lawless and Rodes (1999) used ammonium sulfate, a highly water-soluble particle species, to evaluate the moisture uptake by collected particles. The mass of ammonium sulfate aerosols when thoroughly dried (or equilibrated at 23% RH) represents only 30% of the total mass at 90% RH. If equilibrated at 40% RH instead (as in the weighing laboratory), the mass is about 40% of the total mass at 90% RH.

Typically, a walk-in weighing room with controlled temperature and RH is constructed to isolate filters and balance(s) from forces and environmental conditions affecting microbalance measurement stability and variability. However, there are disadvantages to the use of a weighing room such as the difficulties in maintaining a steady temperature and RH required by reference methods and controlling dust that results from the penetration of outside air when personnel enter and exit the room. In addition, the cost of building a facility that meets all the requirements for filter conditioning and weighing can reach tens of thousands of US dollars or more and the maintenance fee can range from several hundred to several thousand dollars per year. As a cost-effective alternative, Allen *et al.* (2001) proposed the use of a weighing chamber and controlling RH by using a saturated aqueous solution of MgCl<sub>2</sub>. A weighing chamber with controlled humidity and no energy consumption is a great application in a hot climate because the humidity level is often higher than 60% in a traditional weighing room and difficult to maintain at a steady low humidity as required.

This study presents a systematic investigation of the

variability of weighing data resulting from assorted filters and particles with different hygroscopic properties under different weighing environment as in a “non-standard” weighing room (RH 75–85%) and a “standard” weighing chamber (RH 30–35%). The objectives of the present study are to develop a reliable weighing technique with the use of a cost-effective weighing chamber, and to demonstrate the efficacy of this chamber.

## METHODS

### *Weighing Chamber*

The weighing chamber is composed of two separable parts: a main chamber for filter conditioning and weighing, and a humidity control chamber for supplying air with constant humidity as shown in Fig. 1. The weighing chamber is housed in a “non-standard” weighing room (3 × 3 × 4 m; W × D × H) equipped with a regular air conditioning system. The temperature inside the weighing chamber is maintained at about the same as in the room, since it is enclosed in the weighing room.

The main chamber, also made of 1-cm acrylic, is 84 × 72 × 75 cm (W × D × H) and can be divided into an upper portion for filter conditioning and a lower portion for filter weighing. These two portions are separated by 1-cm acrylic and a sliding door (32 × 35 cm), which allows access to the conditioning area from the weighing area below. There are three 33-cm-depth shelves in the upper portion of the main chamber. Filters or equipment can be moved in or out of the main chamber via a hinged door (36 × 28 cm) located in the weighing area on the side wall of the main chamber. There are four round ports, each with an inner diameter of 17 cm, in the front of the main chamber that extend out 4.5 cm from the front surface of the chamber. Two ports are located in the weighing area and the other two are located in the conditioning area. A special design called “Iris” is applied to the opening of the ports which allows the operator to easily access the conditioning and weighing area. The “Iris” is opened and closed by turning the outer ring counterclockwise and clockwise, respectively. The air pressure inside the weighing chamber is kept slightly positive to maintain stable RH. The air can only flow outward through the ports, to prevent filter from contamination with airborne particles from the room air during the weighing process.

The RH control chamber is 84 × 72 × 10 cm (W × D × H) and rests on the top of the main chamber, as shown in Fig. 1. The stand-alone RH chamber is composed of a series of five baffles which are designed to create good mixing. Saturated aqueous solution of MgCl<sub>2</sub> is added to the RH chamber. Filtered air with RH less than 10% is supplied to the RH chamber and is controlled by a mass flow controller at the desired flow rate. The incoming air enters the RH chamber and flows through the baffles with effective distance of about 468 cm before entering the main chamber. The air flows in contact with the MgCl<sub>2</sub> solution and provides stable RH in the required range of about 30 - 40% RH. The air flow rate is adjusted from 5 to 50 L/min at 5 L/min intervals to evaluate the performance of the RH chamber at meeting humidity condition requirements for filter weighing.

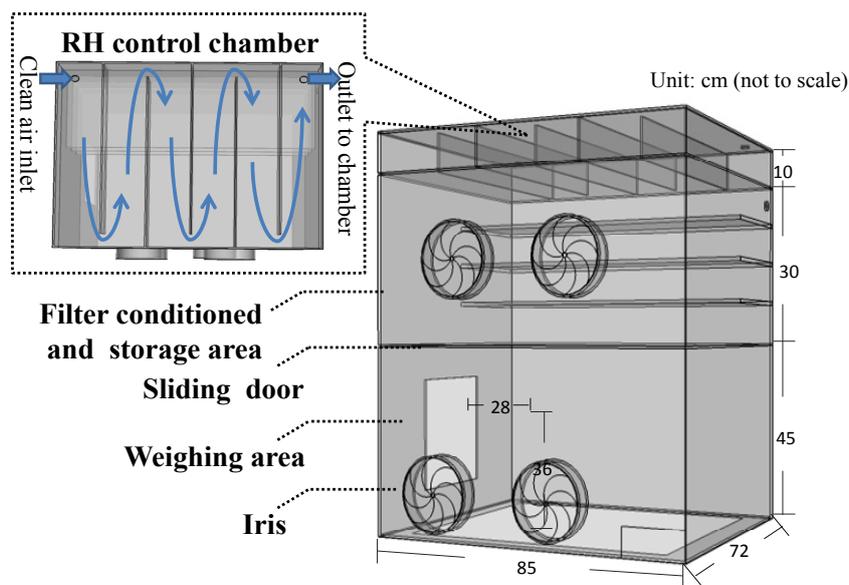


Fig. 1. The top view and 3D view of the weighing chamber.

The operating conditions of the weighing chamber are summarized in Table 1, and will be elaborated below.

#### Microbalance

A microbalance (Mettler Model UMX2, Toledo, USA) with readability of 0.1  $\mu\text{g}$  and repeatability within 0.25  $\mu\text{g}$  is employed in the present study. It features fully automatic adjustment (calibration and linearization) using internal weight. In addition, an external 100-mg OIML Class E2 mass standard provided by the balance manufacturer is used daily in the beginning and at the end of each weighing session to re-calibrate the internal weight. The uncertainty stated by the manufacturer is 2.6  $\mu\text{g}$ . To help minimize vibration, the balance is placed on a  $90 \times 71 \times 79$  cm (W  $\times$  D  $\times$  H) marble stone surface plate which is supported by a heavy concrete stand. The vibration is reduced by four vibration absorbers, each of which sits between a marble plate and a concrete stand.

#### Electrostatic Charge Neutralization and Measurement

An electrical charge neutralizer (Model M2012-00628, Fortelice International Co., Taiwan) and an  $\text{Am}^{241}$  (5  $\mu\text{Ci}$ ) strip are used to eliminate the electrostatic charge. The voltage produced by the electrostatic charge on filters is measured using a non-contacting electrostatic voltmeter (Surface voltmeter, Model SVM2, AlphaLab, Inc., Salt Lake City, UT). For non-conductive filters used in this work, the meter reading in volts is proportional to the filter's surface charge density in coulombs per  $\text{cm}^2$ . The filter's charge per area "Q/A" can be estimated by the following equation:

$$Q/A = V \times 3.6 \times 10^{-14} \times f(f-1) \quad (1)$$

where Q is the quantity of charge in coulombs, A is the area of the filter in  $\text{cm}^2$ , V is the meter reading in volts, f is the square root of  $[1 + D^2/4L^2]$ , D is the diameter of the filter and L is the sensor-to-filter distance which is 2.5 cm in this case.

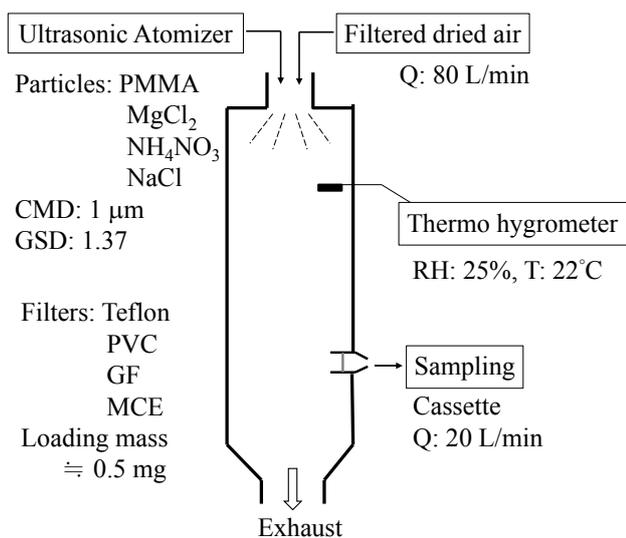
#### Test Filters and Aerosols

Seven different types of filters widely used for aerosol sampling are chosen to perform the gravimetric analysis of the blank filter, in order to investigate the characteristics of moisture uptake by the filter material itself. The test filters are 37-mm MCE (mixed cellulose esters filter, pore size 5  $\mu\text{m}$ , SKC Inc., Eighty Four, PA), GF (glass fiber filter, pore size 1  $\mu\text{m}$ , SKC Inc.), PVC (polyvinyl chloride filter, pore size 5  $\mu\text{m}$ , SKC Inc.), Zefluor (pore size 2  $\mu\text{m}$ , Pall Co., Port Washington, NY), Teflon (pore size 2  $\mu\text{m}$ , PALL Co.), QZ (quartz filter, pore size 1.2  $\mu\text{m}$ , SKC Inc.) and AF (aluminum foil filter, MSP Co., MN). The specifications of the test filters are summarized in Table 1. Filters are conditioned in the weighing chamber for 24 hrs before weighing. Five blank filters of the same lot for each type of filter are used to conduct the ten consecutive mass measurements in the weighing room and weighing chamber, separately. In the beginning of each weighing session, the air temperature, RH and air pressure in the weighing room and weighing chamber are registered.

To evaluate the moisture absorption in collected particles, 1- $\mu\text{m}$  Polymeric methyl methacrylate (PMMA), Magnesium chloride hexahydrate ( $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ ), Ammonium nitrate ( $\text{NH}_4\text{NO}_3$ ) and Sodium chloride (NaCl) representing different hygroscopic properties are used to load the four selected types of filters, including Teflon, PVC, GF and MCE. PMMA is non-deliquescent and the deliquescent RHs for magnesium chloride, ammonium nitrate and sodium chloride at 25°C are about 40, 60 and 75%, respectively. The experimental system for aerosol generation and loading is shown in Fig. 2. Aerosols with a count median diameter (CMD) of 1  $\mu\text{m}$  are generated by using an ultrasonic atomizer (model 8700-120, Sonotek Inc., Highland, NY). Then a 37-mm filter cassette with the test filter is used to load the aerosols with a mass level around 0.5 mg, at a flow rate of 20 L/min. The temperature and RH inside the mixing chamber are maintained at 22°C and 25%, respectively, and monitored by

**Table 1.** Summary of operating conditions and the parameters.

Parameter	Code	Operating
Saturated solution	Sat. soln	MgCl <sub>2</sub> ·6H <sub>2</sub> O
Temperature	T	20–23±2°C
Relative humidity	RH	30–40 ± 5%
Flow rate	Q	5–50 L/min
Filter		Pore size (mm)      Weight (mg)      Thickness (mm)
	Teflon	2                      93                      46
	Zefluor	2                      188                     152
	PVC	5                      13                      152
	MCE	5                      36                      160
	GF	1                      70                      330
	QZ	1.2                    90                      432
	AF	none                 45                      200
Particle		Non-deliquescent
	PMMA	
	MgCl <sub>2</sub>	39% DRH
	NH <sub>4</sub> NO <sub>3</sub>	60% DRH
	NaCl	75% DRH
Particle size	Dp	1 mm
Loading mass	M	0.5 mg

**Fig. 2.** The schematic diagram of the system for aerosol generation and sampling.

a thermo-hygrometer (Rotronic, HygroLog NT2-DP). Blank filters and dust-laden filters are conditioned in the weighing chamber for 24 hrs before weighing. For each combination of test filter and aerosol, five aerosol filter samples are collected and used to conduct the ten consecutive mass measurements.

## RESULTS AND DISCUSSION

### Operation and Performance of the Weighing Chamber

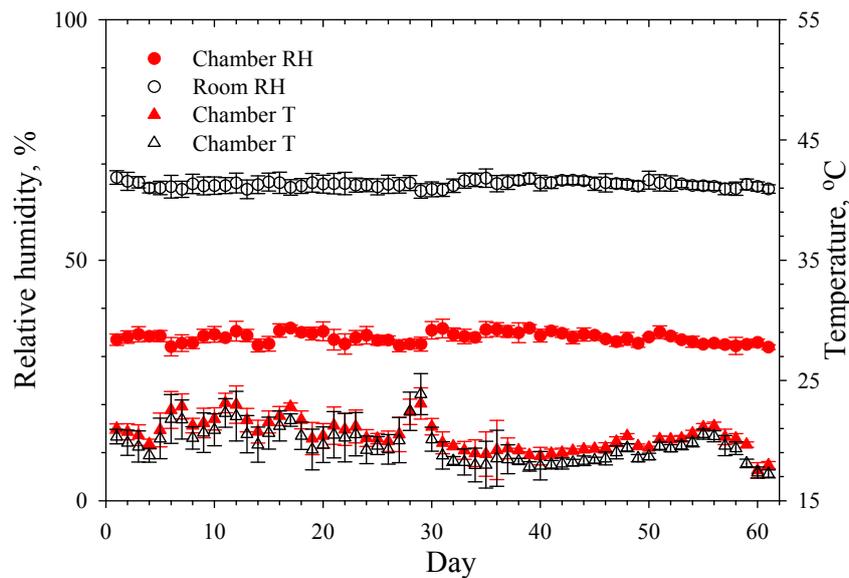
In the present study, saturated MgCl<sub>2</sub> solution is used for humidity control inside the weighing chamber to meet the environmental requirements for filter weighing. A previous study has shown that saturated MgCl<sub>2</sub> solution can produce humidity of 33% RH at 20°C in a closed system

(Winston and Bates, 1960). In this work, the performance of the RH chamber is evaluated by varying the flow rate of the filtered air (RH around 9%) from 5 to 50 L/min at 5 L/min increments. The air volume above the surface of the MgCl<sub>2</sub> solution is 0.04 m<sup>3</sup>. The contact time for 5 L/min air flowing through the RH chamber is 8 minutes while that for 50 L/min is 48 seconds, if airflow were laminar and the MgCl<sub>2</sub> solution had no boundary layer. The results show that the RH inside the weighing chamber varies from about 32 to 30% when the supply air flow rate changes from 5 to 50 L/min. The variation of RH inside the weighing chamber is insignificant (less than 2% RH). To secure a stable desired RH condition inside weighing chamber, the flow rate of the supply air for the RH control unit is set at 15 L/min for the filter conditioning and 25 L/min during filter weighing.

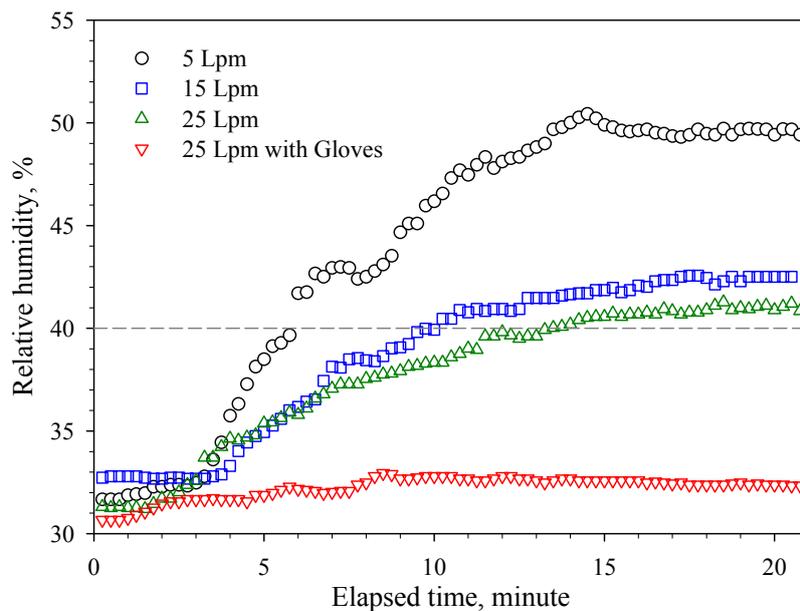
The daily average temperature and RH in the weighing chamber under an air flow rate of 15 L/min and in the weighing room are shown in Fig. 3. The temperature and RH in the weighing chamber are in the range of 18–23°C and 30–35%, respectively, over 60 consecutive days, while those in the weighing room fall in the range of 18–23°C and 63–69%, respectively. The temperature in the weighing chamber is affected mostly by the weighing room's air conditioning system. The RH in the weighing chamber is well controlled by the supply air flowing through the liquid surface of the aqueous MgCl<sub>2</sub> solution. As a result, the weighing chamber is able to maintain stable RH in the required range.

### Weighing Bias Resulted from Hand Moisture

Generally, it is suggested that gloves be worn during the filter weighing process. The impact of hand moisture on the RH in the weighing chamber is evaluated under different operating air flow rates ranging from 5 to 25 L/min, as shown in Fig. 4. The RH increases soon after bare hands intrude the weighing chamber. The elapsed times as the RH exceeds the USEPA standard's upper limit of 40% RH



**Fig. 3.** The daily average temperature and relative humidity in weighing chamber (well controlled) and in weighing room (less well controlled).



**Fig. 4.** Impact of Hand moisture evaporation on the relative humidity inside the weighing chamber.

for filter weighing are about 6, 10 and 14 minutes for the corresponding air flow rates of 5, 15 and 25 L/min, respectively. The influence of hand moisture evaporation on the RH cannot be totally compensated for by increasing the air flow (from 15 to 25 L/min). Therefore, the use of gloves in the weighing chamber should be mandatory and included in the standard operating procedure.

#### **Weighing Bias Resulted from Electrostatic Charges**

The buildup of electrostatic charges on filters during handling can contribute to weighing bias. It has been found that the charges on a filter do not only lead to an increase (positive bias) in weighing mass but also affect weighing

precision (Lawless and Rodes, 1999; Tackett and Saldana, 2013). Tsai *et al.* (2002) found that the weighing accuracy of an MCE filter is affected most by electrostatic charges when compare to GF, Teflon and PVC filters. Therefore, the MCE filter is chosen to investigate the mass change before and after charge neutralization.

In this work, an electrical charge neutralizer (M2012-00628, Model Fortelice International Co., Taiwan) and a radioactive neutralizer-Am<sup>241</sup> (5  $\mu$ Ci) are used to eliminate the electrostatic charge. Firstly, the MCE filters are not treated by any neutralizers. Secondly, the MCE filters are treated using an electrical charge neutralizer for a few seconds. Thirdly, the filters are treated using an Am<sup>241</sup>

source for a few seconds before placed on the balance for weighing. The fourth way is to expose the filter to an  $\text{Am}^{241}$  source not only before but also after placing it on the balance pan for weighing. The negative charges carried by a MCE filter are  $1.1 \times 10^{-11}$  coulombs without any charge-neutralizing treatment,  $4.8 \times 10^{-12}$  coulombs when treated with an electrical charge neutralizer before weighing,  $9.9 \times 10^{-13}$  coulombs when treated with an  $\text{Am}^{241}$  source before weighing, and  $2.6 \times 10^{-13}$  coulombs when treated with an  $\text{Am}^{241}$  source both before and after being placed on the balance pan for weighing. The electrostatic charges on the filter are found to be the lowest by sweeping a radioactive source on the balance pan. This implies that handling a filter with tweezers over a radioactive source may not totally eliminate filter charges, especially for the non-conductive filters, like MCE.

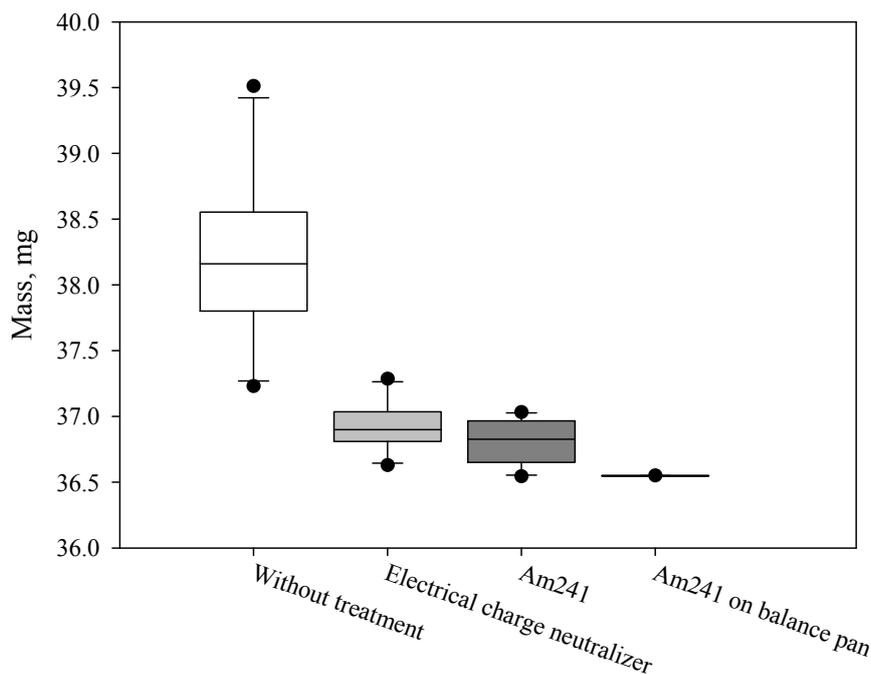
After treated with different charge neutralization methods, the MCE filters are weighed ten times under supply air of 25 L/min from the RH control unit at 32% RH and 20°C. As shown in Fig. 5, the average weights and standard deviations (SDs) are  $38.178 \pm 0.623$  mg with a relative standard deviation (RSD) of 1.63% under no treatment,  $36.918 \pm 0.178$  mg with a RSD of 0.48% when using an electrical charge neutralizer,  $36.805 \pm 0.163$  mg with a RSD of 0.44% when using a  $\text{Am}^{241}$  before weighing and  $36.549 \pm 0.001$  mg with a RSD of 0.004% when using a  $\text{Am}^{241}$  before and after being placed on the balance pan for weighing. There is a good agreement between the electrostatic charges carried by the filter and the filter weighing accuracy. The results show that the use of an  $\text{Am}^{241}$  before and after placing filter on the balance pan produces the most accurate and precise weighing results, because most of the electrostatic charges are eliminated. Therefore, a radioactive neutralizer is recommended to eliminate filter charges before

and after placing filter on the balance pan during filter weighing to improve the filter weighing data quality.

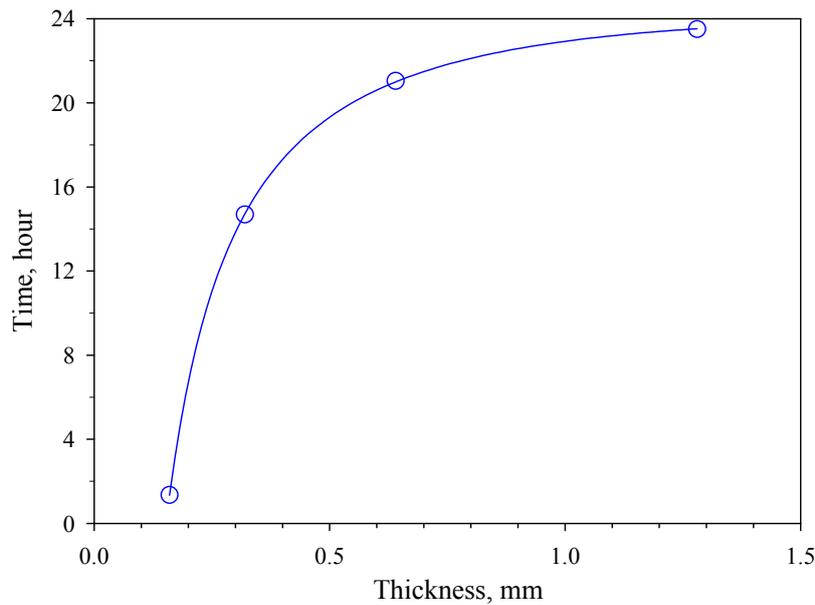
#### **The Required Time for Filter Conditioning**

As the moisture in the air can be absorbed by certain filter materials, especially for hygroscopic ones like MCE filters, the time required for a filter to reach equilibrium during filter conditioning is of great importance to weighing data quality. The effect of filter thickness (or the amount of collected particle mass) in terms of filter layers on the conditioning time is evaluated by using MCE filters. The air supply of the RH control unit is set at 15 L/min and the temperature and RH are 19°C and 33%, respectively, in the filter conditioning area inside the weighing chamber. A piece of MCE filter is about 160  $\mu\text{m}$  thick and eight MCE filters are stacked together to achieve a test thickness of 1280  $\mu\text{m}$ . Fig. 6 shows the times required to reach 99% equilibrium (or constant weight) are 1.3, 15, 21 and 24 hours for the corresponding 1, 2, 4 and 8 layers of filters, respectively. The required condition time increases abruptly with increasing filter thickness at first and then slowly reaches a plateau.

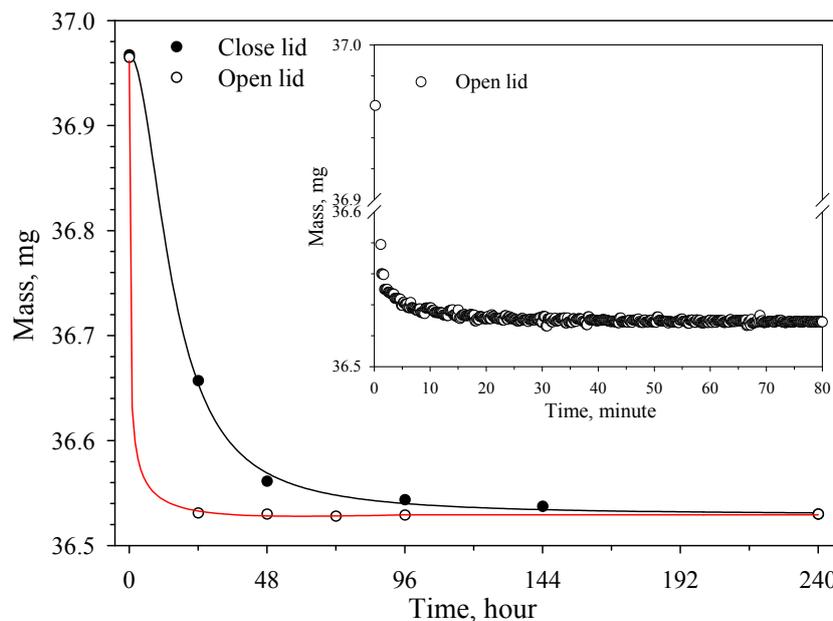
In general, filter samples are kept in a filter container like polycarbonate Petri dishes (e.g., Gelman Analyslide) to hold filters for conditioning. The temporal variations of filter weighing mass with the filter holder's lid opened or closed during conditioning in the weighing chamber are investigated. The supply air for the RH control unit is set at 15 L/min. The air temperature was 20°C and the RH in the weighing chamber is 34%. As shown in Fig. 7, the time needed for a MCE filter to reach equilibrium with the air of the conditioning chamber is much longer than 24 hours (as generally recommended) when the filter holder's lid is left closed during filter conditioning. In fact, the filter



**Fig. 5.** The weighing precision of the MCE filter under different charge neutralization treatments.



**Fig. 6.** The time required to reach 99% equilibrium for MCE filters of different thickness.



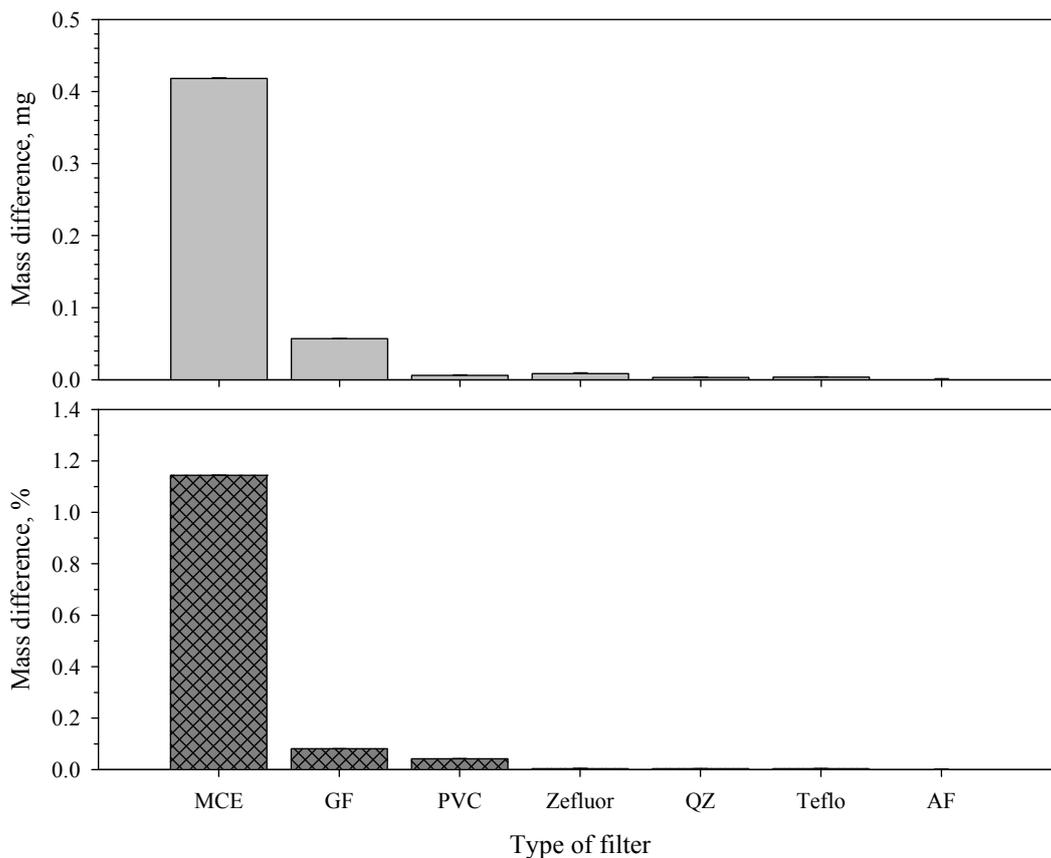
**Fig. 7.** The temporal variation of filter weighing mass with the filter holder's lid opened and closed.

conditioning can be completed in less than two hours (about 81 minutes) in our weighing chamber if the filter holder's lid is open. Therefore, it is important to leave the lid of the filter container open during filter conditioning.

#### ***Effect of Hygroscopicity of Filters and Aerosols on Weighing Data Quality***

To evaluate the influence of the hygroscopicity of filters on the weighing accuracy, seven types of filters commonly used in industrial hygiene and environmental health applications are chosen to conduct the experiments. With reference to the weighing mass at a 35% RH environment (as in the weighing chamber), the average mass change and

percentage of mass change in mg and%, respectively, as weighed at 77% RH environment (as in the weighing room, which is not environmentally-well -controlled), are showed in the upper and lower plot of Fig. 8. The temperature is 19°C and the air flow passing through the RH chamber is 25 L/min. The mass changes for MCE, GF, PVC, Zefluor, QZ, Teflon and AF filters are  $0.418 \pm 0.0008$ ,  $0.057 \pm 0.0003$ ,  $0.006 \pm 0.0007$ ,  $0.009 \pm 0.0009$ ,  $0.003 \pm 0.0005$ ,  $0.004 \pm 0.0005$  and  $0.001 \pm 0.0004$  mg, respectively. The corresponding mass changes in percentage are 1.1, 0.08, 0.04, 0.004, 0.004, 0.004 and 0.002% for MCE, GF, PVC, Zefluor, QZ, Teflon and AF filters, respectively. The results show that the MCE filter is the most hygroscopic one among



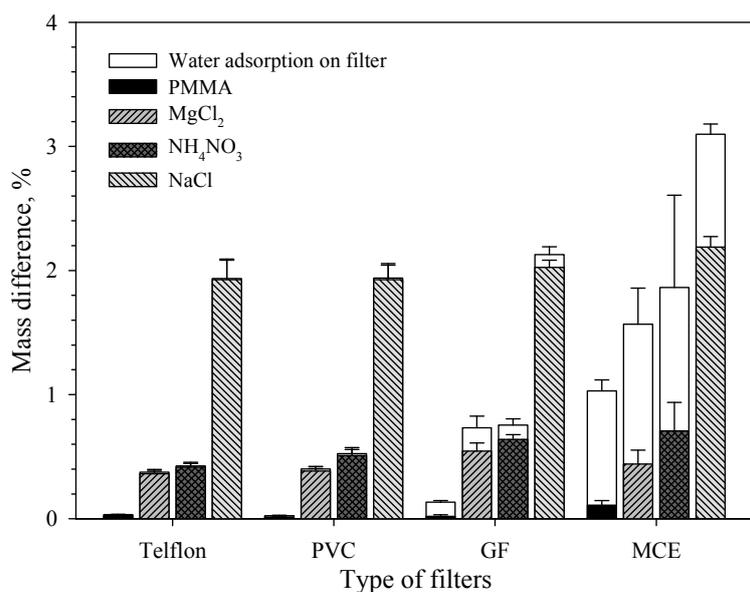
**Fig. 8.** The weighing mass change (upper plot) and percentage of mass change (lower plot) in response to different humidity for seven types of filters.

the tested filters, followed by GF, PVC, Zefluor, Teflon, QZ and AF. The mass change of a 37-mm MCE filter can be as much as 0.418 mg. Except for MCE and GF filters, the average mass changes of test filters under low (35% RH) and high (77% RH) humidity environments are below 10  $\mu\text{g}$ . This implies that MCE and GF filters are not suitable for gravimetric analysis of aerosol samples, unless the relative humidity of the conditioning environment is well controlled.

In a real situation of aerosol sampling, both the filter material and the collected aerosols may present different hygroscopic properties. To evaluate the moisture absorption in filter materials and collected particles, PMMA,  $\text{MgCl}_2$ ,  $\text{NH}_4\text{NO}_3$  and NaCl representing different hygroscopic properties are used to separately load the four selected types of filters, including Teflon, PVC, GF and MCE filters, in the mass range of 0.4–0.6 mg. With the reference to the weighing mass at a 35% RH environment (as in the weighing chamber), the mass change is calculated when the particle-laden filter samples are weighed in the (not-environmentally-well controlled) weighing room at 85% RH. The results shown in Fig. 9 indicates that the average mass increases attributed to water vapor absorption by PMMA,  $\text{MgCl}_2$ ,  $\text{NH}_4\text{NO}_3$  and NaCl particles are 0.02, 0.2, 0.3 and 1.2 mg, respectively. This implies that the weighing data quality can be devastated if the humidity is not well controlled during sample conditioning and weighing. Not surprisingly,

the highly hygroscopic aerosols like  $\text{NH}_4\text{NO}_3$  and NaCl absorb more moisture than the other two less-hygroscopic ones. Overall, the hygroscopicity of both the filters and collected particles can lead to inaccurate and imprecise gravimetric measurements when particle-laden filter samples are weighed in a high RH environment. In the worst-case scenario, when a hygroscopic filter, such as MCE, is used to collect 0.5 mg hygroscopic NaCl particles, a mass increase of 0.5 mg is due to the filter and an additional 1.2 mg of mass is due to collected NaCl particles, when the weighing is performed under RH 85% rather than RH 35% in the weighing chamber.

To assure a reliable and accurate weighing data in filter weighing, filter samples should be conditioned for at least two hours with the filter holder's lid open, treated with a radioactive source during the weighing process and weighed with hands wearing gloves in an environmentally well controlled weighing chamber. To further evaluate the performance of this weighing chamber, five randomly selected filters are weighed 10 times to determine the mass determination limit (MDL) for each type of filter. The MDLs, defined as three times the standard deviation, in the descending order are 3, 2, 2, 2, 1, 1 and 1  $\mu\text{g}$  for Zefluor, MCE, PVC, QZ, Teflon, GF and AF filter, respectively. As for particle-laden filter samples tested in the present study, the MDLs are 2  $\mu\text{g}$  under all the combinations of aerosols and filters. With the use of a weighing chamber and the



**Fig. 9.** Impact of air humidity on the weighing accuracy of the aerosol-laden filters.

recommended weighing procedures, this work demonstrates excellent weighing quality for light weight fine aerosol sampling (e.g., PM<sub>2.5</sub> personal sampling).

## CONCLUSIONS

In this work, a reliable weighing technique using a cost-effective weighing chamber is successfully developed. The cost-effective weighing chamber is built and its performance in providing the required environmental conditions has been demonstrated. The flow rate of the supply air for the RH control unit is set at 15 L/min for filter conditioning and 25 L/min during filter weighing to secure a stable desired RH condition inside the weighing chamber. Aerosol filter samples should be conditioned in the weighing chamber for at least two hours, depending on the mass of the filtered particles. The condition process should be with the lid of the filter holder open. In addition, wearing gloves during weighing and using a radioactive source like Am<sup>241</sup> for electrostatic charge elimination before and after placing filter samples on the balance pan are also recommended. This study demonstrates excellent weighing accuracy for light weight aerosol samples with the use of the weighing chamber. The mass determination limits are below 3 µg for 37-mm particle-laden filter samples commonly encountered in practical situations.

In addition to gravimetric data, however, some PM filters are typically analyzed for elemental composition. With the most sensitive XRF analysis, detection levels for Mg and Cl can be less than a nano-gram/filter. Therefore, the issue of potential contamination needs to be considered; particularly if there is any chemical buildup within the unit over time.

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