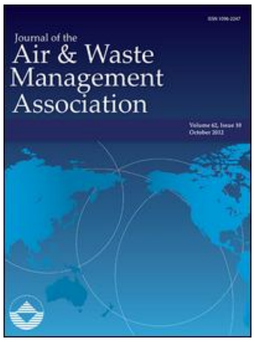

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A Cost-Effective Weighing Chamber for Particulate Matter Filters

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ABSTRACT

Particulate matter (PM) is a ubiquitous air pollutant that has been receiving increasing attention in recent years due in part to the association between PM and a number of adverse health outcomes, including mortality and increases in emergency room visits and respiratory symptoms, as well as exacerbation of asthma and decrements in lung function.[1-5] As a result, the ability to accurately sample ambient PM has become important, both to researchers and to regulatory agencies. The federal reference method for the determination of fine PM as $PM_{2.5}$ in the atmosphere recommends that particle-sampling filters be conditioned and weighed in an environment with constant temperature and relative humidity (RH).[6] It is also recommended that vibration, electrostatic charges, and contamination of the filters from laboratory air be minimized to reduce variability in filter weight measurements. These controls have typically been maintained in small, environmentally controlled "cleanrooms." As an alternative to constructing an elaborate cleanroom, we have designed, and presented in this paper, an inexpensive weighing chamber to maintain the necessary level of humidity control.

IMPLICATIONS

The association between PM and a number of adverse health effects has made it important for researchers and regulatory agencies to accurately quantify PM concentrations. Accurate gravimetric analysis of PM filters requires the filters to be stored and conditioned under stable environmental conditions. Such conditions have traditionally been maintained in cleanrooms. As an alternative to these facilities, we present in this paper a relatively inexpensive chamber that achieves the necessary humidity control. This chamber could be useful to regulatory or research agencies that wish to weigh PM filters but cannot afford a more elaborate weighing facility.

INTRODUCTION

The small masses collected on particulate matter (PM) sampling filters, especially from personal and indoor samples in many exposure studies, are typically on the order of micrograms, depending on sampling flow rate and pollution levels. Significant weighing errors can be caused by a number of environmental factors when handling filters with small weight gains. Filter contamination, vibration of the balance, electrostatic charges, and fluctuations in temperature and relative humidity (RH) in the filter-conditioning environment all contribute to uncertainties in filter handling and weighing and must be controlled to achieve reliable weight measurements. Typically, weighing facilities consist of a small room in which temperature, RH, and dust are controlled. The environmental controls in such facilities normally cost from USD $10,000 to $60,000, and maintenance of these facilities can range from several hundred to several thousand dollars per year. In addition to the difficulties in controlling the temperature and RH in the room, controlling dust is challenging due to the penetration of outside air when the balance operator enters and exits the room. The costs to build and maintain such a facility could be significant to many government agencies and research institutions.

This paper describes an inexpensive and reliable alternative to these facilities. The chamber described in the following section was constructed for use in the PM exposure assessment studies at the University of Washington in Seattle. The total cost for the chamber and its humidity control was approximately $5000 (not including the cost of the balance or its accompanying electronics).

DESCRIPTION

The chamber, shown in Figure 1, consists of two parts: an RH control chamber and a main chamber. The main chamber (part A, Figure 1), built from 1.27-cm acrylic, is 122 × 76.2 × 88.4 cm (W × D × H) and is divided into an upper and lower area. The upper portion contains three shelves

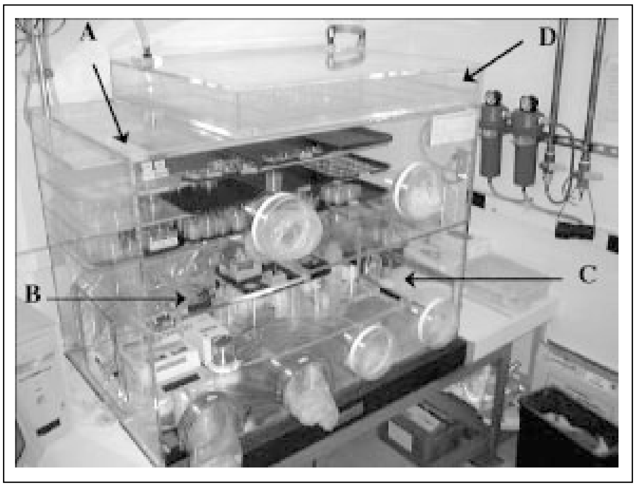

Figure 1. The environmental weighing and conditioning chamber. A: main chamber, B: sliding door, C: insertion/removal door, D: RH control chamber.

made from 1.27-cm acrylic and is entirely devoted to filter conditioning and storage. The maximum capacity of the storage area is 17 trays (40.6 × 27.9 cm), with 20 filters in petri dishes on each tray, for a total conditioning/storage capacity of 340 filters. The lower portion of the main chamber contains the filter handling area as well as the balance and its accompanying electronics. The two sections of the main chamber are separated by 1.27-cm acrylic, and a sliding door (part B, Figure 1) allows access to the storage area from the weighing area below. Filters or equipment can be inserted into or removed from the chamber via a hinged door located on the end of the main chamber (part C, Figure 1).

The RH control chamber (part D, Figure 1), also built from 1.27-cm acrylic, is 91.5 × 76.2 × 10.2 cm (W × D × H) and sits above the main chamber. The RH chamber consists of a series of five baffles, constructed of 0.32-cm acrylic. RH control is achieved by a saturated aqueous solution of $MgCl_2$. For this RH control system to be effective, the RH of the incoming air must be below the desired RH of the chamber. Air is supplied by an air compressor (1500 cfm at 100 psi), which also dries the air to ~10% RH, to two filters (Balston Filters; Whatman Inc.) connected in series, which remove 99.99% of particles 0.1 µm and larger. This filtered air flows through a rotameter and into the RH control chamber at ~11 L/min. The incoming air enters the RH control chamber and flows through the baffles before entering the main chamber. The baffles give an effective distance of ~455 cm, over which the incoming air must flow in contact with the $MgCl_2$ solution. Because of its ability to provide stable RH in the required range (34% RH at 23 °C), $MgCl_2$ was the chosen solution.[7]

Originally, 11.3 kg of $MgCl_2 \cdot 6H_2O$ were added to 6.8 L of water in the RH chamber. Our chamber operation procedure is the following: 200 mL water is added approximately every 3 days on dry days and every 5 days on rainy days. Based on the ideal gas law, air flowing into the chamber at 11 L/min and 12% RH would require the addition of ~70 mL of water per day to achieve a chamber RH of 34%

$$v = (P/1\ \text{atm}) \times Q \times (RH_f - RH_i) \times (1/V) \times M \times (1/\rho) \times 1440 \quad (1)$$

where v is the volume of water to be added (mL/day), P is the vapor pressure of water at 23 °C (0.02774 atm), Q is the air flow rate (11 L/min), RH_f is the desired chamber RH (34%), RH_i is the incoming air RH (12%), V is the molar volume of an ideal gas at 23 °C (24.2 L/mol), M is the molar mass of water (18 g/mol), ρ is the density of water (1 g/mL), and 1440 is the number of minutes in a day. After the water is added, the RH chamber must be shaken to ensure that the solution is well mixed. After the RH chamber, air flows into the storage area of the main chamber, then into the working area, and finally flows out of the main chamber at the end of the working area opposite the microbalance. The airflow not only controls RH, but also maintains a slight positive pressure in the chamber, thus minimizing penetration of room contaminants.

The operator, wearing nitrile gloves, works through plastic sleeves connected to ports in the front of the chamber. The sleeves and gloves allow for very little contact between the operator and the chamber environment. The six ports, each with an inside diameter of 16.5 cm, are made from 0.64-cm acrylic and extend out 4.5 cm from the front surface of the chamber. The sleeves attached to the ports are plastic veterinary examination gloves, from which the glove end has been removed (VET-R-SEM gloves; Jorgensen Laboratories). Since the users often operate the balance for several hours at a time, the two ports through which weighing is performed were placed in the most ergonomically appropriate position that would promote neutral body posture and minimize acute contact stress on the forearms. There is an optional airlock box (not shown), which fits next to the hinged door (part C, Figure 1) and is used for moving filters and equipment in and out of the chamber. Due to the positive pressure in the chamber, very little contamination occurs without the airlock box, and thus we have chosen not to use it.

The chamber rests on a 345-kg, 122 × 91.5 × 10.2 cm granite surface plate (Starrett; J&L Industrial Supply) that helps minimize vibration. The surface plate is supported by a steel surface plate stand (J&L). Chamber vibration is further reduced by six vibration absorbers, which sit between the granite plate and the stand. Ideally, the chamber would be better housed on the bottom floor of the building to minimize vibration. However, our chamber is located on the third level because of space constraints. In some cases, a specially designed vibration-absorbing table might further reduce vibration, although in our case, the vibration absorbers and surface plate have proven to be sufficient.

Electrostatic charges are minimized before weighing by passing the filters between two Po^{210} sources (500 microcuries each), and during weighing by two Po^{210} strips placed on top of the filter-weighing pan. Temperature control is maintained passively by housing the chamber in a small (2.8 × 2.5 × 3.3 m; W × D × H) internal room in a building that is heated in winter but not air-conditioned in summer. The balance used in our weighing chamber is a Mettler model UMT2 (Mettler-Toldedo). It is readable to 0.1 µg and repeatable within 0.25 µg. The electronics are housed separately to reduce temperature fluctuations inside the balance.

PERFORMANCE

The U.S. Environmental Protection Agency (EPA) requirements for the filter conditioning and weighing environment are a mean temperature of 20–23 ± 2 °C and a mean RH of 30–40 ± 5% over 24 hr.[6] In our first year of operation (February 2000–January 2001), the chamber has maintained a mean 24-hr RH of 34.8 ± 2.5%, with a daily coefficient of variation of 3.6 ± 2.8% (N = 201). Temperature was relatively constant where the chamber is located, with a 24-hr mean of 22.2 ± 1.8 °C and a daily coefficient of variation of 1.9 ± 1.0% (N = 201).

EPA requires that temperature and RH be measured continuously inside the chamber and that the measurement systems be calibrated monthly.[8] The recommended calibration procedure involves the use of the instant model Fisher brand Certified Traceable Digital Hygrometer/Thermometer as a laboratory reference standard.[9] In our chamber, temperature and RH are monitored by Hobo loggers (Onset Computer Corp.), which record 15-min average data and are accurate to ±0.7 °C and ±5% RH. A dual-purpose thermometer/hygrometer, with a digital display, allows the chamber operator to monitor the chamber environment before weighing. According to the Onset Computer Corporation, the Hobo loggers do not need to be calibrated, so periodic collocation tests are used to validate the performance of the loggers. While this method of monitoring has been sufficient to demonstrate the amount of temperature and RH variability in the chamber, the use of a laboratory reference standard, traceable to the National Institute of Standards and Technology, would be ideal to demonstrate compliance with EPA specifications when actual ambient filter samples are being weighed.

Despite the constant airflow, there are essentially no temperature gradients within the chamber. All areas of both the weighing and conditioning sections of the chamber (including the point at which the air supply enters the main chamber) are consistently within 1 °C of one another. In addition, there is negligible air movement near the balance, and airflow throughout the chamber is consistently below the limit of detection (~15 cm/sec) of the anemometer (Series 471 Thermo-Anemometer; Dwyer Instruments Inc.) used for this measurement.

Laboratory blanks weighed on consecutive days during our first year of operation indicate minimal filter contamination inside the chamber. The average absolute change in laboratory blank filter mass over 24 hr was 1.8 ± 1.7 µg (N = 97). EPA requires a maximum variation of 10 µg over 24 hr.[8]

We participated in two round-robin weighing tests, comparing filter weights of the same 20 blank Teflon filters (Pall/Gelman part #RP2J037) measured by nine U.S. laboratories (including six typical cleanroom facilities). In these tests, a series of 20 blank filters were measured and passed on by each laboratory. Measurements made inside our weighing chamber produced results that were comparable with those produced by the other laboratories. Figure 2 is a boxplot, summarizing the results of these tests. Measurements inside our chamber, represented by lab ID “E,” produced residuals (residual = mean value of all lab measurements minus value measured in our chamber) with a comparable mean (0.8 µg) to other facilities and less variation than many of the other facilities.[10] These round-robin tests demonstrate the ability to produce accurate blank filter weights inside our chamber; however, they do not allow for a comparison of weighing performance using filters loaded with actual ambient particles. Due to technical and transport issues, there are currently no round-robin programs using filters loaded with actual ambient particles. If such a

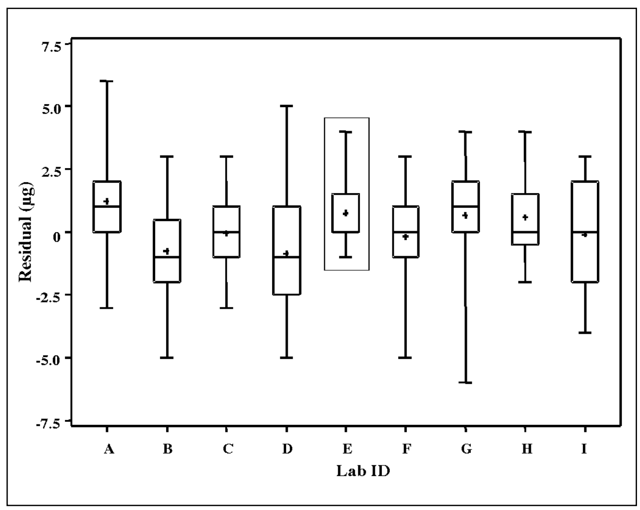

Figure 2. Summary of round-robin test results (source: EPA/Harvard Center for Ambient Particle Health Effects, 2000).

program did exist, it would be possible to better determine if the filter-conditioning atmosphere in this chamber is equivalent to those in other laboratories.

DISCUSSION

Our chamber is considerably easier and less expensive to construct, operate, and maintain than are most weighing facilities. Furthermore, we have placed our chamber in a location that has made temperature control unnecessary. Thus, it is important to note that this chamber only controls humidity, and an internal temperature control mechanism would be required should the chamber be placed at a location where temperature is not controlled. It is quite possible that our RH control methodology, in conjunction with relatively simple temperature control in a small room, would be adequate to achieve the EPA specifications for filter conditioning and weighing. As with other weighing facilities and cleanrooms, this chamber design requires occasional monitoring to maintain the necessary environmental conditions.

A laboratory interested in reproducing this chamber will need to spend time and effort in constructing the chamber and acquiring the necessary materials and equipment described previously. As an alternative to our chamber, environmentally controlled chambers are commercially available (PLAS-LABS). A chamber similar to ours, in size and environmental controls, currently costs about USD $10,000 (not including the balance), and some weighing laboratories have used such chambers with limited success.[11] A potential problem with these commercial chambers is that they are not designed for filter weighing and require significant modifications before they are capable of providing adequate environmental control and filter storage capability.

CONCLUSION

We have designed and built a weighing chamber for the gravimetric analysis of airborne PM filters. This chamber was considerably cheaper and easier to build than traditional cleanroom weighing facilities. In its first year of operation, the chamber maintained an RH that was within the guidelines put forth by EPA. Filter weight measurements made inside the chamber also agreed well with more elaborate, and more expensive, weighing facilities.

The main advantages of our chamber over traditional weighing facilities are the low cost and the ease with which the chamber is maintained. This chamber might be useful to air pollution control agencies or research institutions that cannot afford a more elaborate facility. The chamber has shown that the necessary humidity controls can be maintained, and reliable measurements can be made, at a reasonable cost.

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