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The effect of environmental conditions and electrical charge on the weighing accuracy of different filter materials

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Abstract

Different filter materials and electrical charge elimination methods were used to investigate the weighing accuracy of filter papers under different environmental conditions. The results show that the standard deviations (S.D.) of weight data for glass fiber and MCE filters were substantial without environmental control, whether or not the electrical charge eliminators were used. Values of 0.157 and 0.349 mg were determined for glass and MCE filters, respectively. The accuracy of weighing was substantially improved and the S.D. was reduced to 0.01 and 0.09 mg for glass fiber and MCE filters, respectively, after applying the environmental control conditions. For PVC and Teflon filters, the accuracy of weighing was good, even in the uncontrolled environmental conditions, whether or not the electrical charge eliminators were used. The S.D. values of weighing data of PVC and Teflon filters were 0.007 and 0.011 mg, respectively.

Keywords: Filters; Environmental conditions; Electrical charge; Weighing accuracy

1. Introduction

Accurate weighing of filters before and after sampling is important in order to obtain the true concentrations of aerosols existing in the atmosphere. Weighing results are influenced by the ambient relative humidity (RH), temperature and electrostatics on filters. Koistinen et al. (1999) indicated that a buoyancy effect should be taken into account during weighing, hence, the weight of a filter sample must be corrected by the following expression:

$$\Delta b = V_f \cdot (\rho_{a2} - \rho_{a1}) \cdot 10^9 \quad (1)$$

where Δb (μg) represents the buoyancy effect, V_f (m^3) is the volume of the filter, and ρ_{a1} and ρ_{a2} (kg/m^3) are the air densities at filter weighing before and after filter sampling, respectively. The air density is given by:

$$\rho_a = \frac{[3.848 \cdot P - (0.00252 \cdot T - 0.02058) \cdot \mathrm{RH}]}{(273.2 + T)} \quad (2)$$

where P (kPa) is the atmospheric pressure, T (°C)

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is the atmospheric temperature and RH (%) is the ambient relative humidity.

The electrostatic charge is gained through the actions of friction, contact or stripping between materials (Council of Labor Affairs, 1996). The Council of Labor Affairs (1997) declared that the variation of temperature and RH should be kept within ±2.0 °C and ±10.0%, respectively, during weighing, before and after sample collection. Electrostatic effects appear on the filter by touching tweezers or scales and causes a weight error. In order to prevent such errors, the use of an electrical charge neutralizer to eliminate the electrostatics from the filter is necessary.

The US EPA (1988) specification of standard operation process for PM_{10} filters stated that the average temperature of the environment should be kept between 15 and 30 °C, and the temperature variation should be maintained within ±3.0 °C over 24 h, whereas, the average RH of the environment should be kept between 20 and 45%, and the RH variation should be maintained within ±5.0 °C over 24 h, before and after weighing. Following the standard operation process for $PM_{2.5}$ filters, the average environmental temperature should be kept between 20 and 23 °C and the temperature variation should be maintained within ±2.0 °C over 24 h, whereas the average RH of environment should be kept between 30 and 40%, and the RH variation should be maintained within ±5.0 °C over 24 h before and after weighing.

Among the several different kinds of filter materials which are used, glass fiber filters can sustain higher temperatures and are less hygroscopic than a cellulose filter (US EPA, 1994; Hering, 1989). Li and Lundgren (1999) suggested that the standard deviation (S.D.) of weighing data of PVC filters under controlled environmental conditions (i.e. the variation range of the temperature is 21–33 °C, and the RH is 50–98%) is less than 0.006 mg in deviations within 14 runs of weighing tests. MCE filters are usually used for collecting the sample for further chemical analysis to determine the species concentration. Charell and Hawley (1981) tested MCE and PVC filters at different RHs, and showed that the weight of the filters increases with the increasing RH, and that a MCE filter is much more sensitive than a PVC filter with respect to this effect. Mark (1974) tested glass fiber, MCE and PVC filters at different RHs and found that MCE shows the largest hygroscopicity when compared with glass fiber and PVC filters.

Table 1
The weighing results of glass fiber filters with three different electrical charge eliminators

Glass fiber	Without controlled (*T*, RH)	Controlled (*T*, RH)
Without charge elimination	Ave. = 87.933 Std. = 0.0628 R.S.D. = 0.0714	Ave. = 87.844 Std. = 0.0118 R.S.D. = 0.0134
Using Po^{210} electrical charge neutralizer	Ave. = 91.314 Std. = 0.0653 R.S.D. = 0.0715	Ave. = 88.999 Std. = 0.0038 R.S.D. = 0.0043
Nilstat air ionizer	Ave. = 90.433 Std. = 0.0713 R.S.D. = 0.0788	Ave. = 89.497 Std. = 0.0057 R.S.D. = 0.0064
Domestic electrical charge neutralizer	Ave. = 87.455 Std. = 0.0724 R.S.D. = 0.0828	Ave. = 89.256 Std. = 0.0032 R.S.D. = 0.0036

Ave.: average weight, mg; Std.: standard deviation, mg; R.S.D.: relative deviation, %.

Teflon filters are widely used for sampling particles and gases (Willeke and Baron, 1993). Tsai et al. (1997) tested MCE and Teflon filters in a chamber over a temperature range of 15–22 °C and a RH 40±5%. The results show that the S.D. of MCE and Teflon filters was 0.0151 and 0.0039 mg, respectively, whereas, Teflon filters performed better in weighing accuracy than MCE filters.

In this study, four different filter materials and three different electrical charge eliminators were used under controlled and uncontrolled weighing environments to understand the influence of environmental conditions and electrostatics on the weighing accuracy of filters.

2. Methods and materials

The four types of filter materials used in this experiment were: glass fiber (Cat #1882866, Whatman Corp., dia. 37 mm); PVC (Cat #P-503700, Omega specialty instrument Co., dia. 37 mm); Teflon (Cat #LZ0204750, Omega specialty instrument Co., dia. 47 mm); and MCE (P/N 64678, Gelman Sciences Co., dia. 37 mm). Three types of electrical charge eliminators were used,

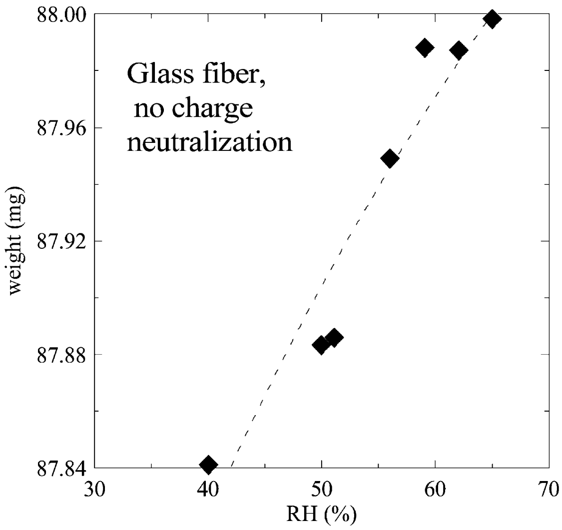

Fig. 1. Effect of ambient relative humidity on glass fiber filters under uncontrolled environmental conditions and in the absence of the electrical charge eliminators.

namely: Po^{210} electrical charge neutralizer; Nilstat air ionizer (Nilstat 2020, Ion Systems, Inc.); and domestic electrical charge neutralizer (Model: SN-2001, Taiwan). The Nilstat air ionizer has the dimensions of 10×7×5 cm and has four needles operating at 24 VAC. The power of the internal fan of the ionizer was disconnected and the four needles were centered at the exit of the fan to enhance the effect of electrostatic elimination. The domestic electrical charge neutralizer has dimensions of 13×11×9 cm with one discharge needle, operating at 5000 VAC in front of the 25-cm snake tube.

The experiment was conducted in a controlled chamber. Four different filters were weighed after 24 h of environmental conditioning (RH=40–45%). The weighing of filters with an electronic scale (Sartorius A200S) was performed at controlled (the temperature and RH ranges were 22–26 °C and 39.5–41%, respectively) and uncontrolled (the temperature and RH ranges were 24–28.5 °C and 40–65%, respectively) weighing environments.

3. Results and discussions

3.1. Glass fiber filter

The effect of RH on the weighing data of glass fiber filters under uncontrolled environmental conditions is shown Fig. 1, the weights of glass fiber filters are increased with the increasing RH. The high hygroscopic behavior of glass fiber filters may be one of the reasons for this. Table 1 shows the weighing results of the glass fiber filter under controlled and uncontrolled environmental conditions. The S.D. of the weighing data of filters indicate that the weighing results show better accuracy under controlled environmental conditions rather than under uncontrolled conditions. With the electrical charge eliminators, the experimental results show the same consequences of weighing accuracy. The results show that the weighing accuracy of glass fiber filters is significantly influenced by environmental conditions, such as temperature and ambient RH. The results also show that the weighing accuracy of filters is not improved by using electrical charge eliminators under uncontrolled environmental conditions before weighing (S.D.s calculated under this condition are all larger than 0.065 mg). In contrast, the weighing accuracy of filters is obviously improved under controlled environmental conditions and the weighing accuracy can be further improved by using electrical charge eliminators before weighing. The S.D. of weighing data can

Table 2
The weighing results (mg) of Teflon filters without using electrical charge eliminators

Day	1	2	3	4	5	6	7
Uncontrolled (*T*, RH)	244.367	244.363	244.370	244.378	244.374	244.375	244.373
Controlled (*T*, RH)	244.364	244.361	244.372	244.376	244.373	244.372	244.371

Table 3
The weighing results of Teflon filters with three different electrical charge eliminators

Teflon	Uncontrolled (*T*, RH)	Controlled (*T*, RH)
Without charge elimination	Ave. = 244.371 Std. = 0.0047 R.S.D. = 0.0019	Ave. = 244.370 Std. = 0.0049 R.S.D. = 0.0020
Using Po^{210} electrical charge neutralizer	Ave. = 272.801 Std. = 0.0040 R.S.D. = 0.0015	Ave. = 272.800 Std. = 0.0087 R.S.D. = 0.0032
Nilstat air ionizer	Ave. = 277.004 Std. = 0.0073 R.S.D. = 0.0026	Ave. = 277.003 Std. = 0.0096 R.S.D. = 0.0035
Domestic electrical charge neutralizer	Ave. = 254.636 Std. = 0.0029 R.S.D. = 0.0011	Ave. = 254.637 Std. = 0.0082 R.S.D. = 0.0032

Ave.: average weight, mg; Std.: standard deviation, mg; R.S.D.: relative deviation, %.

be decreased from 0.01 mg (without electrostatic elimination) to 0.003 mg (with electrostatic elimination), whereas the relative standard deviation (R.S.D.) can be decreased from 0.013% to 0.004%.

3.2. Teflon filter

The weighing results of Teflon filters without using electrical charge eliminators are shown in Table 2. The weighing data are very close for both controlled and uncontrolled environmental conditions (the largest S.D. of weighing data is less than 0.015 mg). The results given in Table 3 show that the weighing accuracy is good enough and not dependent upon the use of electrostatic eliminators before weighing. The S.D.s indicate that no effect of environmental conditions was observed on weighing accuracy (S.D. for both, controlled and uncontrolled conditions was 0.005 mg).

3.3. PVC filter

The PVC filter showed similar characteristics to those shown by the Teflon filter. Table 4 shows that the weighing results were very close to each other and did not depend on the environmental conditions. The largest variation in weighing data, when no electrical charge eliminator was applied was 0.007 mg with a R.S.D. of 0.017%.

Table 5 shows that the weighing accuracy of PVC filters is good even at uncontrolled environmental conditions (S.D. = 0.0021 mg, R.S.D. = 0.016%). The data show that the weighing accuracy of PVC filters could not be improved with electrical charge eliminators.

Table 5
The weighing results of PVC filters with three different electrical charge eliminators

PVC	Uncontrolled (*T*, RH)	Controlled (*T*, RH)
Without charge elimination	Ave. = 13.259 Std. = 0.0021 R.S.D. = 0.0160	Ave. = 13.257 Std. = 0.0023 R.S.D. = 0.0174
Using Po^{210} electrical charge neutralizer	Ave. = 13.056 Std. = 0.0029 R.S.D. = 0.0220	Ave. = 13.052 Std. = 0.0023 R.S.D. = 0.0176
Nilstat air ionizer	Ave. = 12.190 Std. = 0.0030 R.S.D. = 0.0244	Ave. = 12.187 Std. = 0.0033 R.S.D. = 0.0273
Domestic electrical charge neutralizer	Ave. = 10.758 Std. = 0.0019 R.S.D. = 0.0179	Ave. = 10.752 Std. = 0.0013 R.S.D. = 0.0122

Ave.: average weight, mg; Std.: standard deviation, mg; R.S.D.: relative deviation, %.

Table 4
The weighing results (mg) of PVC filters without using electrical charge eliminators

Day	1	2	3	4	5	6	7
Uncontrolled (*T*, RH)	13.260	13.258	13.262	13.260	13.259	13.261	13.255
Controlled (*T*, RH)	13.255	13.254	13.260	13.257	13.257	13.257	13.261

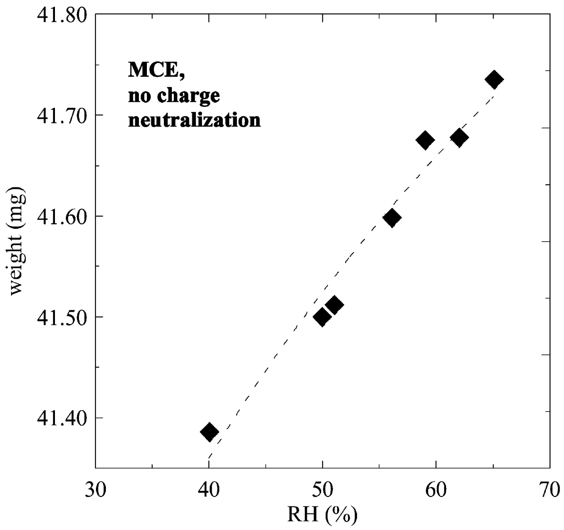

Fig. 2. Effect of ambient relative humidity on MCE filters under uncontrolled environmental conditions and in the absence of the electrical charge eliminators.

3.4. MCE filter

MCE (mixed cellullose ester) filters are economical and suitable for air monitoring applications. Fig. 2 shows that the weight of the MCE filters was increased with the increasing RH under uncontrolled environmental conditions and in the absence of electrostatic eliminators. This proves the strongly hygroscopic character of MCE filter materials. Due to this character, the weight of the MCE filters was increased by 0.349 mg, which was approximately three times higher than the increase in weight of 0.157 for glass fiber filters, when the ambient relative humidity was 40–60%.

The results given in Table 6 show that the weighing accuracy cannot be improved by using electrical charge eliminators instead of controlling the environmental conditions. The S.D.s were not reduced very much after using electrical charge eliminators under controlled environmental conditions (S.D.s before and after use were 0.043 and 0.038 mg, respectively).

3.5. Correction of buoyancy effect

The correction of the buoyancy effect is shown in Eqs. (1) and (2). Fig. 3 shows the weighing results of glass fiber filters under uncontrolled conditions without using the electrostatic eliminators. Comparing the original weight of glass fiber filters (87.933 ± 0.0582 mg) with the weight after taking into account the buoyancy effect

Table 6
The weighing results of MCE filters with three different electrical charge eliminators

MCE	Uncontrolled (T, RH)	Controlled (T, RH)
Without charge elimination	Ave. = 41.582 Std. = 0.1132 R.S.D. = 0.2722	Ave. = 41.435 Std. = 0.0431 R.S.D. = 0.104
Using Po^{210} electrical charge neutralizer	Ave. = 42.803 Std. = 0.1173 R.S.D. = 0.2740	Ave. = 42.606 Std. = 0.0354 R.S.D. = 0.0831
Nilstat air ionizer	Ave. = 42.968 Std. = 0.1101 R.S.D. = 0.2563	Ave. = 42.791 Std. = 0.0354 R.S.D. = 0.0828
Domestic electrical charge neutralizer	Ave. = 42.862 Std. = 0.1257 R.S.D. = 0.2933	Ave. = 42.664 Std. = 0.0377 R.S.D. = 0.0883

Ave.: average weight, mg; Std.: standard deviation, mg; R.S.D.: relative deviation, %.

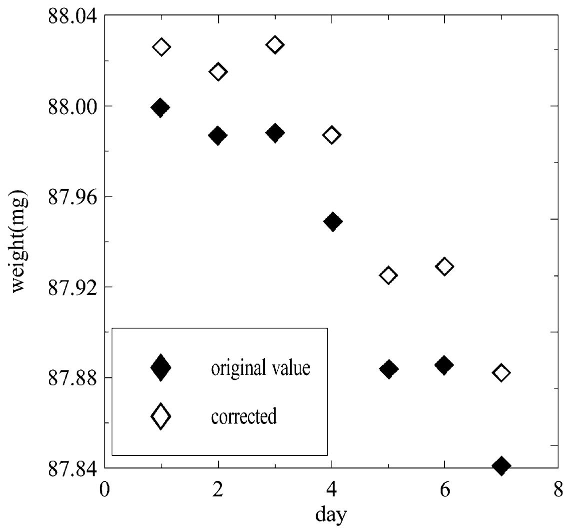

Fig. 3. The weighing results of glass fiber filters before and after buoyancy modification under uncontrolled environmental conditions and in the absence of the electrical charge eliminators.

(87.970 ± 0.0581 mg), no improvement in results was observed for accuracy, and the buoyancy effect was not obvious. Therefore, the weighing of filters should be conducted in well-controlled environmental conditions, and it is hard to obtain accurate results just by considering the buoyancy effect. The buoyancy effect is also shown not to improve the weighing accuracy of Teflon filters, MCE filters or PVC filters.

4. Conclusions

The present study documents the accuracy of weighing different filter materials. The weighing accuracy of glass fibers under controlled environmental conditions is good enough, and could be improved if the electrical charge eliminators are used simultaneously (R.S.D. is reduced to 0.006%). MCE filters show similar weighing characteristics with respect to environmental conditions and the use of electrical charge eliminators. The hygroscopicity of MCE filters is more serious than glass fiber filters, and the R.S.D. was found to be 0.088% under the controlled environmental conditions and after using the electrical charge eliminators. PVC filters and Teflon filters showed good weighing results, and weighing data were not influenced by the environmental conditions and electrical charge eliminators. The R.S.D.s calculated for PVC and Teflon filters were 0.016% and 0.002%, respectively, under uncontrolled environmental conditions and in the absence of the electrical charge eliminators. The weighing accuracy of PVC and Teflon filters could not be improved under controlled environmental conditions and after using the electrical charge eliminators.

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