Effects of Sampling Artifacts on Occupational Samples of Diesel Particulate Matter

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Total carbon (TC) is sometimes used to measure or characterize diesel particulate matter (DPM) in occupational settings such as underground mines. DPM samples are collected on quartz fiber filters. When using quartz fiber filters, adsorption of gas phase organic carbon (OC) has been reported, causing a positive bias in the particulate TC results (adsorption artifact). Most of the data on the sampling artifacts and corrections apply to environmental air sampling, where samples are collected at a much higher filter face velocity and the OC concentrations are generally much lower relative to occupational sampling. In this study, we investigated the effects of adsorption artifact on samples from occupational settings. Samples were collected with and without denuders to determine the amount of gas phase OC collected and the accuracy of certain corrections. In underground stone mines, the adsorption artifact was found to positively bias the particulate TC by greater than 20% for filter loadings below 25 $\mu g/cm^2$ TC (8-h time weighted average = 262 $\mu g/m^3$). The tandem filter correction reduced the effect of the artifact, as high as 60% of the TC value, to less than 11% for laboratory data. It also significantly reduced the effect of the artifact obtained for field samples.

Introduction

Long-term exposure to diesel exhaust is a public health concern because diesel particulate matter (DPM) has been reported as a potential (*1*) or probable (*2*) human carcinogen. While environmental exposure is a concern, occupational exposure is a greater one because workplace concentrations of DPM are generally much higher than environmental (*3–8*). Therefore, it is important to monitor and control workplace exposure to DPM, especially for underground miners, which can be the highest exposed workforce (*4–8*).

Measuring DPM mass is prone to interferences in many workplaces, and gravimetric methods are not sensitive enough for low-level determinations. Therefore, a surrogate is needed to determine exposure to DPM. In many occupational settings, elemental carbon (EC) is used as a surrogate because there are no other substantial sources of EC besides DPM (*5, 8, 9*). In some circumstances, when interferences to total carbon (TC) measurement are minimal, TC is used because it accounts for over 80% of the DPM (*10, 11*). The Mine Safety and Health Administration (MSHA) uses both EC and TC for compliance sampling of DPM in underground metal/nonmetal mines (*8*). TC is both measured directly and calculated based on EC results and a predetermined EC fraction. If both the calculated and measured TC are above the interim limit (350 $\mu g/m^3$ TC), the sample is out of compliance. TC is commonly determined by collecting air samples onto quartz filters and analyzing them for organic carbon (OC) and EC (TC = OC + EC) using NIOSH Method 5040 (*12*). Quartz filters are used because of their high collection efficiency for particulate matter and resistance to the heat generated during the analysis.

Researchers have reported two anomalies, commonly called sampling artifacts, when collecting particulate OC on quartz fiber filters. These artifacts do not affect the EC results (or the calculated TC from EC results used by MSHA to determine compliance measurements), but they cause a positive or negative bias in the measurement of particulate OC (and TC). Eatough et al. (*13, 14*) observed loss of semivolatile OC from particles during sampling, referred to as the "negative" or evaporation artifact. This artifact causes an artificially low result for particulate OC (and TC) because OC initially present in air as condensed matter is lost through evaporation from the filter during sampling. Several studies have also demonstrated an artifact that results in overestimation of the true airborne particulate OC due to filter adsorption of gas phase OC (*15–23*). This is considered the "positive" or adsorption artifact. OC in the vapor or gas phase is present in the air from multiple sources. The quartz fiber filter primarily collects airborne particulate matter and allows gases and vapors to pass through, but adsorption of some gas (vapor) phase OC does occur. Thus, this positive artifact causes an artificially high result for particulate OC (and TC) because both particulate and gaseous OC are quantified.

Some approaches that have been used to correct for the positive adsorption artifact are the use of tandem quartz filter samplers (incorporating two quartz filters in series) and the use of an additional sampler containing a quartz filter behind a Teflon filter (*15–23*). When sampling with tandem quartz filters, particulate matter is collected only by the first filter, while both the first and second filters are exposed to and adsorb gas phase OC. For the correction to be effective, both filters must be in equilibrium with the sampled airstream, adsorb the same amount of gas phase OC, and not have a significant amount of OC loss through evaporation. The OC on the second filter can then be subtracted from the OC on the first filter to account for the adsorbed gas OC. This correction has not always been reported as effective. Several studies have reported the tandem filter correction to underestimate the adsorption artifact (*15–18*). However, other studies have shown effective correction when using the tandem filter method under the right sampling conditions (*19–22*). The efficacy of the correction depended upon sampling conditions such as filter face velocity, sampling time, loading, and filter media in these studies (*19–22*).

If a sampler containing a Teflon and quartz filter is used for correction, the Teflon filter collects particulate matter but OC gas adsorption is negligible, so only the quartz filter beneath it adsorbs gas phase OC. For this correction to be effective, the Teflon filter cannot adsorb any gas phase OC

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and the Teflon filter cannot lose particulate OC. Several studies have shown the quartz beneath Teflon to have a greater OC value than the quartz beneath quartz (tandem filter corrections) (*15, 18*). Some researchers have attributed this to the quartz beneath quartz not reaching equilibrium with the sampling stream thereby underestimating the adsorption artifact (*15, 18*). Others have attributed this phenomenon to the evaporation artifact being more prevalent when using a Teflon filter instead of a quartz filter and reported the quartz behind Teflon to overestimate the adsorption artifact (*21*). Several studies have shown no difference when using either type of correction (*20, 22*). Use of two quartz filters is preferable to Teflon and quartz because both the collection and blank filters are in the same sampler.

Currently, there is very little information on sampling artifacts in occupational settings, and it is not well understood how these artifacts will affect the TC results for workplace DPM samples (e.g., from mines). Most of the existing data on sampling artifacts and their corrections apply to environmental air sampling. Results for occupational samples may differ from environmental samples because sampling conditions are much different, and the effects of artifacts and corrections are known to depend upon conditions such as face velocity, composition of the sampling air stream, sampling time, and filter media (*15–23*). Environmental air samples are usually collected at much higher face velocities (20−80 cm/s as opposed to 3−4 cm/s for occupational samples). In addition, the concentrations of carbon are much lower in environmental air than in most occupational settings (*3–8*), and the types of aerosols sampled are different (e.g., aged aerosol from multiple environmental sources, as opposed to aerosols close to source). Olson and Norris (*18*) reported limited data on sampling artifacts for indoor sampling at flow rates similar to occupational sampling (2 Lpm), but the collected aerosols and their concentrations were not similar to most occupational settings where DPM is monitored.

The effect of the positive sampling artifact on occupational samples of DPM was the focus of this study. Several studies have indicated that adsorption (rather than evaporation) is the dominant artifact, especially at lower face velocities (*15, 16, 23*). Therefore, given the much lower filter face velocities typical of occupational sampling, positive artifact was expected over evaporation. The objective of the study was to determine the contribution of the adsorption artifact to occupational DPM samples and the accuracy of the corrections for these types of samples. This was accomplished by comparing samples with and without a denuder and using both the tandem quartz filter and quartz behind Teflon corrections for DPM samples collected in the laboratory, underground mines, and a loading dock area.

Experimental Section

Laboratory Experiments. To determine the effects of the adsorption artifact and the accuracy of the tandem filter correction, samples of DPM were collected in an environmental chamber (*24*) at flow rates and loadings similar to those in underground mines. For sampling, two quartz fiber filters (QQ1 and QQ2) were placed in tandem in a 37 mm three-piece plastic cassette (SureSeal, 225-2LF) along with a stainless steel support screen. Prior to use, screens were washed and dried and filters were precleaned in an oven at 800 °C for at least one hour to remove possible OC contamination. To avoid potential variability due to lot-to-lot differences, filters from the same lot were used to collect a given sample set. Once loaded, the tandem filter cassettes were compression sealed.

Three tandem quartz filter samplers were used to collect DPM, hereafter referred to as "inlet samples". These samples were subject to OC adsorption artifact and possible loss of semivolatiles. Additionally, three carbon plate denuder (Sunset Laboratory, Tigard, OR; similar to the ones used by Eatough et al. *25, 26*) sampling trains were assembled. The denuders are designed to remove gas phase OC, but not particulate OC. Two sampling cassettes (each with two quartz filters in tandem) were placed downstream of each denuder. The second cassette was used to determine whether any semivolatiles evaporated from the first one.

Presuming that the denuders efficiently remove gas phase OC and loss of semivolatiles is minimal, the difference between the results for the inlet samples and the denuder samples provides an estimate of the amount of gas phase OC adsorbed by the quartz fiber filter since both were exposed to particulate matter but only the inlet samples were exposed to gas phase OC. The concentration determined using the denuder samples (QQ1) should represent the particulate OC only. The accuracy of the tandem filter correction could then be evaluated by comparing the corrected value (QQ1 − QQ2) for the inlet (no denuder) samples to the OC concentrations (particulate only) determined using QQ1 results for the denuder samples.

After assembly, the inlet samplers and denuder setups were placed in the environmental chamber. Exhaust from a Kubota genset diesel engine (V1200-B engine, 4 cylinders), operating under 80% load, was plumbed into the chamber. A tapered element oscillating microbalance (TEOM) (Thermo Electron Corp., East Greenbush, NY), designed to measure the ambient particulate mass in real time by using a vibrating microbalance to measure the mass of the particles collected on a filter, was used to monitor the mass concentration of diesel exhaust. Vacuum pumps and critical orifices were used to draw the exhaust through the samplers at 1.7 Lpm or 5.1 Lpm. (5.1 Lpm was used for some samples to determine whether this higher flow rate would affect the denuder characteristics. No difference was seen between the denuder results obtained at the two different flow rates.)

After sampling, the pumps and the engine were turned off and residual DPM was ventilated from the chamber. When all the DPM was exhausted, the cassettes were removed, sealed, and preserved for later carbon analysis. Samples (both top and bottom filters) were analyzed for elemental, organic, and total carbon with a Sunset Laboratory carbon analyzer (Sunset Laboratory, Tigard, OR) according to NIOSH Method 5040 (thermal-optical method). The NIOSH 5040 procedure is described in detail elsewhere (*12*). Eleven different experiments were performed by operating the engine at different loads (idle, 5%, 10%, 25%, and 80% loads). The purpose was to achieve a variety of OC/EC ratios, various DPM concentrations and filter loadings, and different gas phase OC concentrations.

Field Samples. In addition to laboratory tests, field samples were collected in underground mines and two outdoor locations to further investigate the potential impact of the adsorption artifact on actual occupational samples. As with laboratory sampling, two precleaned quartz fiber filters from the same lot were placed in a three-piece plastic cassette with a stainless steel support screen. As previously discussed, most of the aerosol carbon is collected by the top quartz filter (QQ1), while the bottom filter (QQ2) is primarily exposed to gas phase OC. Thus, the TC contributed by the adsorption artifact might be estimated by comparing the OC on QQ2 to the TC on QQ1.

In one of the mines (a stone mine), a denuder setup similar to that used for laboratory work was used, but an impactor was added upstream of the denuder to exclude larger dust particles. Again, tandem filter samplers without denuders were used to permit a direct comparison between adsorbed gas phase and particulate OC, and to determine how well the tandem filter correction might work under actual mining conditions.

TABLE 1. Comparison of TC With and Without a Denuder[a]

sampling time (min)	flow rate (Lpm)	engine load	sample	TWA (μg/m^3) TC (QQ1)	TC_{pb}	TC_{corr}	difference between TC(QQ1) and TC_{pb} deviation (%)[b]	TC(QQ1) after subtraction of TC(QQ2) vs TC_{pb} deviation (%)[c]	% deviation between with and without denuder EC
33	5.1	0%	laboratory 1	171.52	122.21	135.55	40	11	6
54	1.7	0%	laboratory 2	162.72	101.74	100.90	60	−1	1
71	1.7	0%	laboratory 3	265.93	189.02	179.70	41	−5	4
184	1.7	5%	laboratory 4	388.73	291.92	291.39	33	0	11
62	1.7	10%	laboratory 5	315.07	246.34	238.69	28	−3	5
80	1.7	10%	laboratory 6	269.07	213.44	200.13	26	−6	4
73	5.1	10%	laboratory 7	248.75	206.97	197.96	20	−4	4
100	1.7	10%	laboratory 8	465.01	329.43	334.25	41	1	3
53	5.1	25%	laboratory 9	167.23	143.16	139.15	17	−3	3
98	1.7	80%	laboratory 10	427.50	344.83	404.55	24	17	15
286	1.7		field 1	149.29	132.57	122.68	13	−7	−5
419	1.7		field 2	203.65	140.90	119.98	45	−15	17
411	1.7		field 3	168.00	118.47	140.60	42	19	12
403	1.7		field 4	179.48	141.27	150.38	27	6	15

[a] TWA (time weighted average): μg/(flow rate (Lpm) × 480 minutes) × 1000. TC_{pb} is total particulate carbon on QQ1 after denuder. TC(QQ1) is uncorrected TC on QQ1 without denuder. TC_{corr} is TC(QQ1) minus TC on QQ2 without denuder. % deviation EC = (EC[without denuder] − EC[with denuder])/(EC[without denuder]) × 100. [b] % deviation = (TC(QQ1) − TC_{pb})/TC_{pb} × 100. [c] % deviation = (TC_{corr} − TC_{pb})/TC_{pb} × 100.

Some researchers have reported underestimation of the adsorption artifact with tandem quartz filters relative to a quartz filter under a Teflon filter, while other investigations have reported no difference between the two types of corrections (*15–23*). To investigate the potential effects of this phenomenon on occupational samples, samplers loaded with Teflon and quartz filters (i.e., upper Teflon filter and two quartz filters beneath) as well as the tandem quartz filter setup were used to collect air samples in a loading dock area and a smokers' shelter nearby. Details regarding the sample collection methods and different sampling locations are provided in following sections.

Mine Surveys. Submicrometer particulate matter was collected using SKC DPM Cassettes (part 225-317; SKC, Inc., Eighty Four, PA) with an MSA Elf personal pump operated at 1.7 Lpm. Area and personal breathing zone samples were collected during actual production in two stone mines and one metal mine for 2.5–8 h. The DPM Cassettes contained an impactor with a 0.8 μm cutpoint at 1.7 Lpm and two quartz fiber filters in tandem. Each quartz filter was analyzed for OC, EC, and TC using NIOSH Method 5040. On some days, a denuder setup that included an impactor (SKC DPM Cassette) without filters was used in exhaust areas in one of the stone mines to exclude the mineral dust from the DPM sample.

Loading Dock/Smokers' Shelter Samples. Eight 37-mm cassettes were each loaded with two precleaned quartz-fiber filters. In four of the eight cassettes, a Teflon filter was placed on top of the two quartz filters. Filters in four additional cassettes served as passive field blanks, meaning no air was pulled through them. The bottom quartz filters in all eight cassettes, as well as the four directly under the Teflon filters, provided measures of adsorbed OC. The second (bottom) quartz filters in the cassettes with the Teflon filters were compared to the bottom quartz filters in the cassettes containing only a quartz pair to see if there was any difference in the two types of corrections.

After assembly, the samplers were positioned in a portable dust chamber (*27*) designed for dust sampling in mines. Twelve cassettes were mounted symmetrically inside the chamber, which allows for simultaneous collection of up to eighteen samples. A homogeneous dust distribution was presented to the samplers inside the chamber. Air sampling pumps connected to ports on the outside of the chamber were programmed to run at 2 Lpm over an 8 h period. In one case, the pump was stopped after 23 min.

Samples were collected on six different days: five days in the loading dock area and one day near a smokers' shelter in the same vicinity. A diesel truck was operating in the loading dock area, over different periods, on three of the five sampling days. On the other two days, a truck entered the area but was not left in idle.

Results and Discussion

Denuder Effectiveness. As previously discussed, carbon plate denuders (Sunset Laboratory) were used to prevent gas phase OC from collecting on the quartz filter. This denuder is designed to adsorb gas phase OC at the optimum flow rate of about 8 Lpm; however, in this study, we mostly used a flow rate of 1.7 Lpm, which is typical for samples collected in underground mines (5.1 Lpm was also used for some samples). To ensure that no particulate carbon loss occurs in the denuder at these lower flow rates, we compared EC results for samples collected with and without the denuder. As EC exists only in the particulate form, results for the two samples should be comparable if no particle loss occurs. If the deviation (%), calculated as

$$\% \text{ deviation} = \frac{(\text{EC without denuder} - \text{EC with denuder})}{(\text{EC without denuder})} \times 100 \quad (1)$$

was above 20%, we did not include the data point in our results as this would indicate a potential sample collection problem. As seen in Table 1, the deviations for the laboratory data were at or below 11% for all samples except one, which had a deviation of about 15%.

In the field test, the deviation for one of the samples was above 20%. The other results showed deviations below 18%. The deviations in the EC values obtained with and without the denuder were higher for the field data than the laboratory data. In the field, more EC may have been trapped by the denuder setup because the size-selective sampling device used upstream of the denuder may have disrupted the flow pattern in the denuder. The higher deviation in the field samples could also have occurred due to spatial variation, which has been reported to cause a deviation of as high as 20% in other field samples (*28, 29*).

When using denuders, other concerns are gas phase breakthrough and the loss of semivolatiles in the particulate phase through evaporation. The efficiency of the denuders used in this study has not been reported but these denuders are similar to the ones used by Eatough et al. (*25, 26*). The efficiency of the denuders used by Eatough et al. has been reported to be around 87% at 35−40 Lpm (*26*) and increases with decreasing flow rate (*30*). Therefore, we would expect an efficiency between 90 and 100% for the denuders at the flow rates used. However, it is still important to determine the significance of any breakthrough of gas phase OC under the specific conditions used especially since it has been reported that the efficiency of other denuders could have been affected by the composition of the sampling stream (*18*). It is also important to determine the effect of the evaporation artifact on the results when using a denuder especially since it has been shown that the evaporation artifact is more prevalent when using a denuder than without one (*21*). As with previous studies (*20*), a set of quartz filters behind the collection quartz filter was used to indicate whether breakthrough or evaporation occurred. If a significant contribution by breakthrough or evaporation was indicated, the sample was not included in the data set.

With a few of the laboratory samples, the bottom filter (QQ2) in the denuder sampler (i.e., first after the denuder) contained a significant amount of OC (e.g., more than 0.9 $\mu g/cm^2$, or over two times higher than typical media blanks), which would indicate that some gaseous/semivolatile OC passed through the denuder or there was a loss of semivolatiles from the particulate. These laboratory samples were not included in the data analysis because they would not provide reliable quantification of the results. However, most of the OC results for QQ2 and the other two filters in the second cassette after the denuder were between 0.3 and 0.9 $\mu g/cm^2$. Some sets of field data also indicated gaseous OC passage (or OC evaporation) and also were not included in the analysis, but most results for OC on QQ2 (after denuder) and the two quartz filters in the second sampler after the denuder were at or below 0.8 $\mu g/cm^2$.

Impact of the Adsorption Artifact on Occupational DPM Results. When collecting samples in an atmosphere of just diesel emissions at flow rates and loadings typical of a mining environment, the adsorption of gas phase OC sometimes caused a significant bias in TC results. Table 1 lists TC results for DPM samples collected in a laboratory environmental chamber at flow rates and loadings typical in underground mines. As mentioned earlier, one set of samplers (inlet samples) had no sampling inlet preselector, and one set used a denuder to scrub out the gas phase OC. The denuder samples collected only particulate carbon, and the inlet samples collected both particulate and gas phase carbon. As indicated by the percent deviation (Table 1, column six) between the inlet and denuder samples, the TC sampled in the presence of gas phase OC was over 30% higher than the TC for samples not exposed to gas phase OC for 50% of the samples. The TC sampled in the presence of gas phase OC was also always larger than the TC for samples not exposed to gas phase OC, indicating an OC adsorption on all samples, and that the adsorption artifact had a greater contribution than the evaporation artifact. Sampling times did not appear to affect the contribution of the adsorption artifact to these samples.

Table 1 also shows TC results for denuder samples collected in an underground stone mine (field samples). Again, samples with and without a denuder were collected. As shown in column six, the TC samples exposed to gas phase OC were over 40% higher for 50% of the samples and were always higher in TC concentration. Thus, the adsorption artifact also had a major contribution to the TC in actual mining samples. This was further seen when taking air samples using an impactor during production in several underground metal/nonmetal mines (Figure 1). As discussed, QQ2 is not exposed to particulate carbon, so the majority of TC on QQ2 is adsorbed gas phase OC. Some of the OC could be semivolatiles that evaporated from the first filter, but most is likely due to gas adsorption (*15, 16, 23*), given the much lower (relative to environmental sampling) face velocities used in our study. In our study, we found higher TC for samples exposed to gas phase OC and affected by sampling artifacts relative to denuder samplers unaffected by gas adsorption, demonstrating positive sampling artifact.

As shown in Figure 1a, in underground mines the adsorption artifact can contribute between 0.3 and 5.8 $\mu g/cm^2$ on the filter. The average gas phase OC adsorbed by the quartz filters (i.e., OC on QQ2) was 3 $\mu g/cm^2$, with a 95% confidence range of 0.3−5.8 $\mu g/cm^2$. This range is fairly independent of the DPM concentration; therefore, the gas phase OC would be a larger portion of the collected TC at the lower TC concentrations. As shown in Figure 1b, the ratio of gas phase OC to TC (TC[QQ2]/TC[QQ1]) for many of the samples was over 20% when the TC collected was <25 $\mu g/cm^2$. The effect of the gas phase diminished as the concentration of DPM increased. As with the denuder data, the sampling time did not appear to affect the contribution of the adsorption artifact for these samples.

The adsorbed gas phase OC (QQ2) also was a large portion of the OC collected on QQ1 for most of the loading dock area samples (Table 2). The gas phase OC to TC ratio (QQ2/QQ1) was over 30% for 4 of 6 samples. Results for adsorbed OC on passive (i.e., no air drawn through filter) filter blanks are usually substantially lower than those obtained for bottom filters after tandem filter sampling and will underestimate the correction.

Accuracy of the Tandem Filter Correction. As mentioned earlier, researchers have applied the tandem filter correction to correct for the adsorption of gas phase OC. This correction relies on the second filter adsorbing the same amount of gas phase OC as the primary filter, which is not always the case with environmental sampling (*15–23*). We therefore tested the accuracy of this correction when sampling DPM in occupational settings.

As shown in Table 1, the tandem filter correction worked well when applied to laboratory data that simulated the DPM sampling procedure in underground mines. TC on the first filter went from being over 30% higher than the particulate TC for 50% of the samples to being within 11% of the particulate TC when the tandem filter correction was applied for all but one sample. For one sample, the deviation (%) only decreased from 24 to 17%, but this sample also had a higher deviation between the EC values than the other samples (15% compared to under 11% as described earlier), which suggests that sample collection had a higher contribution to the deviation for this sample.

The tandem filter correction seemed to also work relatively well for correcting the adsorption artifact in the field samples. As shown in Table 1, for 75% of the field samples, the deviations between particle TC (measured with a denuder) and TC without a denuder were about twice the deviation expected due to loss of particles through the denuder and analytical errors. EC is only in particulate form and is not affected by sampling artifacts. Therefore, the difference between EC results for samples with and without a denuder would be due to particle loss in the denuder and analytical and sampling errors. When the tandem filter correction was applied, the deviations between particle TC (measured through denuder) and corrected TC (using the tandem filter correction) were close to those expected due to sampling errors (deviation in EC values). That is, little effect from the artifact was observed when the tandem filter correction was made.

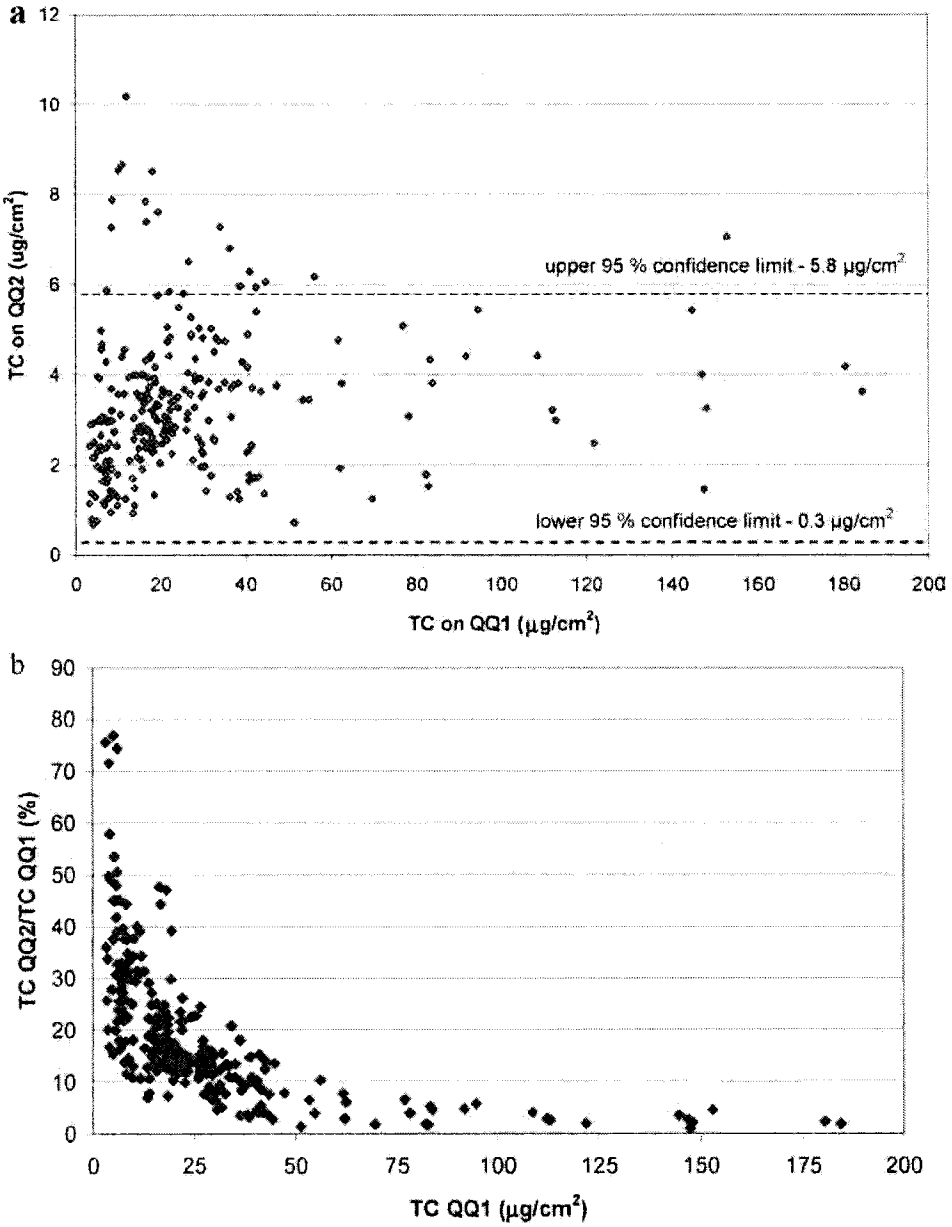

FIGURE 1. (a) TC(QQ2) for DPM samples in some underground mines. (b) Ratio of TC(QQ2) to TC(QQ1) showing the contribution of the adsorption artifact to mining samples.

TABLE 2. Total Carbon Results for Samples Collected in a Loading Dock Area and near a Smokers' Shelter

		mean TC, $\mu g/cm^2$ (RSD, %)		bottom quartz mean					
sample set[a]	location	QQ1	TQQ1	QQ2	TQQ2	pooled	RSD %	QQ2/QQ1 (%)	sampling time (min)
1	shelter	4.81 (9.77)	3.66 (11.75)	3.46	3.41	3.44	8.80	72	480
2	dock	3.52 (7.10)	2.82 (12.77)	2.48	2.33	2.43	9.57	70	480
3	dock	3.61 (1.39)	2.89 (1.38)	2.41	2.42	2.41	7.45	67	480
4	dock	4.59 (3.92)	1.79 (13.40)	1.41	1.36	1.38	6.46	31	23
5	dock	8.43 (3.91)	1.84 (19.02)	1.35	1.36	1.35	12.03	16	480
6	dock	22.78 (1.54)	3.62 (4.97)	3.10	3.18	3.14	4.09	14	480

[a] Sets of eight 37-mm cassettes: four containing two quartz filters (QQ1 upper and QQ2 lower) and four containing two quartz filters (TQQ1 upper and TQQ2 lower) plus a top Teflon filter. TQQ1, QQ2, and TQQ2 provided measures of adsorbed OC. See text for details.

In our studies with limited field samples, the tandem filter correction resulted in a good measure of the particulate TC. Our data show that the need to correct for the adsorption artifact, and the number of backup filters analyzed, depends on the sampling strategy and environment.

Teflon/Quartz Corrections. A quartz filter behind a Teflon filter has been shown to collect more OC than quartz behind quartz (*15, 18*). Some researchers have reported the quartz behind Teflon to be a better estimate of gas phase OC, while other researchers have reported no difference between the

two correction methods, or the quartz behind the Teflon overestimating the adsorption artifact (*15–23*). Therefore, as part of this study, we also investigated this phenomenon. As reported in Table 2 for samples collected in a loading dock area and near a smokers' shelter, we did not obtain a significant underestimation of adsorbed gas with the tandem quartz approach. Quartz filters placed immediately below Teflon filters (i.e., TQQ1) had only slightly higher OC loadings than did the bottom quartz filters of stacked quartz pairs (i.e., QQ2 and TQQ2). Since the tandem quartz correction gave results similar to those found with a quartz filter behind a Teflon filter, it is unlikely that there was a significant volatilization artifact. Sampling time (23 min compared to 480 min) did not appear to affect the results for this data set, though this is just one result and more data would be needed to fully understand the impact of sampling time on these types of samples. Our findings may differ from those reported in previous studies on environmental samples due to the lower face velocities used in our study and the air composition.

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