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Waterpipe cafés are hazardous to your health: Determination of a waterpipe specific calibration factor

Mark J. Travers[a,*], **Jessica A. Kulak**[a,b], **Lisa Vogl**[a]

[a]Department of Health Behavior and Air Pollution Exposure Research Laboratory, Roswell Park Cancer Institute, Buffalo, NY, USA

[b]Primary Care Research Institute, Department of Family Medicine, University at Buffalo, The State University of New York, Buffalo, NY, USA

Abstract

Introduction: The use of a waterpipe to smoke tobacco has emerged as a popular trend in the United States. Waterpipe smoking establishments have had an increasing presence in the U.S., despite smoke-free air legislation. Dangers of waterpipe smoking have been documented, but less data has been gathered about the waterpipe café itself. This project sought to determine a waterpipe-specific calibration factor (CF) for measuring waterpipe aerosol, and field-test this CF by conducting surveillance on the existing waterpipe cafés of western and central New York.

Methods: Nine laboratory-controlled experiments were conducted to determine a waterpipe-specific CF. In the lab, two TSI SidePak AM510 Personal Aerosol Monitors and two sampling trains for gravimetric $PM_{2.5}$ sampling were present during waterpipe smoking sessions (lasting 1–3 hours). Indoor air quality was assessed in 7 waterpipe cafés in three counties of New York, and real-time measurements of particulate matter ($PM_{2.5}$) and carbon monoxide (CO) were obtained.

Results: Results from the 9 controlled waterpipe experiments determined a calibration factor of 0.38 (SD 0.08), which should be used to convert SidePak measurements to true $PM_{2.5}$ measurements. When applying the CF to the measurements taken in the 7 public waterpipe venues, the mean $PM_{2.5}$ concentration was 515 micrograms per cubic meter (SD=338.8) while the mean ambient CO was 20.5 parts per million (SD=18.3). The mean active smoking density was 2.41 waterpipes per 100 cubic meters of air. The $PM_{2.5}$ levels increased with increasing active smoking density (rho=0.68, p=0.09).

Conclusions: Applying the waterpipe-specific CF for the SidePak, 0.38, allowed for field assessments to be conducted in locations with waterpipe smoke to determine accurate particle exposure concentrations. The concentrations of both particulate matter and carbon monoxide were above established air quality standards and therefore increase the health risks of both patrons and workers of these establishments.

*Corresponding author: Department of Health Behavior, Roswell Park Cancer Institute, Elm and Carlton Streets, Buffalo, NY 14263, USA. Mark.Travers@roswellpark.org (M.J. Travers).

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Keywords

waterpipe; particulate matter; $PM_{2.5}$; calibration factor; indoor air quality

1. Introduction

Burning tobacco products are major emitters of respirable suspended particles that are less than 2.5 microns in diameter ($PM_{2.5}$). These particulates are easily inhaled deep into the lungs and are known to cause numerous adverse cardiovascular and respiratory health effects (Akl et al., 2010; Montazeri et al., 2016; Waziry et al., 2016). In laboratory tests, waterpipe, or hookah, use results in emissions of a wide range of known toxic and carcinogenic compounds including ultrafine to fine particulate matter (Fiala et al., 2012; Zhou et al., 2017), aldehydes (Al Rashidi et al., 2008; Shihadeh et al., 2012), carcinogenic polyaromatic hydrocarbons (Jacob et al., 2011, 2013; Shihadeh and Saleh, 2005), and carbon monoxide (Shihadeh and Saleh, 2005; Shihadeh et al., 2012). When comparing the emissions of cigarettes to waterpipes, the emissions from a single waterpipe use session exceed the emissions from a person smoking two cigarettes within the same time period (Daher et al., 2010). Waterpipes produce four times the acetaldehyde, 27 times the formaldehyde (Al Rashidi et al., 2008), and 38 times the yield of benzo[a]pyrene (Sepetdjian et al., 2008). Carbon monoxide (CO) is emitted at high rates as well, with CO from a single waterpipe session matching the CO of ten cigarette smokers (Daher et al., 2010).

Dangers of waterpipe use are being increasingly documented and include significant associations with lung cancer, respiratory disease, low-birth weight babies, and periodontal disease (Akl et al., 2010; Montazeri et al., 2017; Waziry et al., 2017). Reports of carbon monoxide poisoning associated with waterpipe smoking are also being increasingly documented in the literature (Hojer and Enghag, 2011; Lim et al., 2009; Turkmen et al., 2011). Despite these health hazards associated with hookah use, the number of waterpipe cafés has increased in the United States (Noonan, 2010). Several studies have sought to characterize the levels of particulate matter in these hookah café environments (Cobb et al., 2013; Fiala et al., 2012; Torrey et al., 2015), with mean $PM_{2.5}$ levels ranging from 374μg/m^3 in Virginia cafés (Cobb et al., 2012) to 1419μg/m^3 in cafés in Toronto, Canada (Zhang et al., 2015).

The TSI SidePak AM510 Personal Aerosol Monitor (TSI, Inc., Shoreview, MN, USA) is a light-scattering instrument or laser photometer that has proven useful in measuring exposure to cigarette smoke to inform debates over smoke-free air policies and to evaluate the effectiveness of these policies (Connolly et al., 2009; Hyland et al., 2008; Jones et al., 2006; Klepeis et al., 2007; Lee et al., 2008; Lee et al., 2009; Liu et al., 2011; Liu et al., 2010; Maziak et al., 2008; Schneider et al., 2008; Schoj et al., 2010). A protocol for using the SidePak to measure secondhand smoke has been developed and used in over 65 countries around the world (Hyland et al., 2008; Travers, 2006). The SidePak is a portable, battery-operated device using a built-in sampling pump that continuously measures $PM_{2.5}$. The sampling pump draws air inside and the particulate matter in the air scatters the light from an internal laser. The amount of light scattered is measured and converted into the mass concentration of fine particles ($PM_{2.5}$). The conversion from light scattered to mass concentration is dependent on the type of particles in the air (e.g. their size and density). Therefore, the SidePak needs to be calibrated for the specific type of aerosol measured. A custom calibration factor of 0.29–0.32 has been determined for the SidePak when measuring cigarette-specific second hand smoke (SHS) to ensure accurate measurements (Jiang et al., 2011; Lee et al., 2007; Travers, 2008b).

Currently, there is no validated TSI SidePak calibration factor for waterpipe smoke, and therefore, one major limitation of previous studies assessing waterpipe aerosol is the inconsistent application of a calibration factor specific to waterpipe smoke. For example, in the five previously published studies we are aware of reporting on waterpipe café aerosol, two of them (Cobb et al., 2012; Zhang et al., 2015) apply the cigarette-specific calibration factor (0.32) to their data, one uses a calibration factor of 0.6 (Torrey et al., 2015), and two do not use a calibration factor at all (calibration factor of 1.0) (Fiala et al., 2012; Zhou et al., 2015). There is then a 3-fold potential difference in the accuracy of reported particulate matter concentrations in these studies. This confusion regarding the application of an aerosol-specific calibration factor when using light-scattering instruments can result in very misleading results. For example, one paper in the literature underestimated true cigarette secondhand smoke $PM_{2.5}$ levels by 88% by not applying an appropriate calibration factor (Goodman et al., 2007; Travers and Lee, 2008). The lack of a consistent application of a waterpipe-specific calibration factor limits the validity and generalizability of findings. Therefore, the aims of this study were to determine a waterpipe-specific calibration factor for the TSI SidePak by comparing it to reference methods, and apply it to real-time data collected in waterpipe cafés in western and central New York State.

2. Materials and methods

2.1 Calibration factor experiments

The study carried out 9 controlled experiments where participants smoked a single waterpipe (hookah) in a manner of their choosing (*ad libidum*) in an enclosed room (40 m^3) for 1–3 hour sessions. Quick light charcoal was used and the bowl was packed with approximately 12 grams of shisha. Two TSI SidePak AM510 Personal Aerosol Monitors and two pumps with filters for gravimetric $PM_{2.5}$ sampling were present during smoking.

SidePaks were equipped with 2.5 micron impactors to measure $PM_{2.5}$. SidePak flow rates were calibrated to 1.7 L/min as required for the 2.5 micron impactor. The device calibration factor was set at 1.0. SidePaks were zero calibrated with a HEPA filter prior to each session. In the 6 experiments with two SidePaks running side-by-side, the mean difference in unadjusted $PM_{2.5}$ levels was 6.4%. In these experiments the mean of the two SidePaks was used for analysis. The other three experiments used data from a single SidePak due to equipment failure.

Gravimetric $PM_{2.5}$ was determined using two Leland Legacy Sampling pumps running at 10 L/min and connected to SKC Personal Environmental Monitors (PEM) consisting of a single-stage impactor loaded with pre-weighed 37mm PTFE filters. Large aerosol particles (>2.5 microns) tend to be filtered by the single-stage impactor and collected on the greased ring, while the remaining smaller particles ($PM_{2.5}$) are collected on the pre-weighed filter paper. Flow rates were calibrated before and after each experiment and were always within 5% of 10 L/min. After sampling was complete, the filter papers were manually removed and sent back to the certified laboratory (Galson Laboratories, Syracuse, NY) to be post-weighed. Duplicate gravimetric samples were obtained for all experiments and the mean of the two was used for all analyses. The mean difference between duplicates was 9.3%. Blanks were included with 25% of samples and all were negative for significant mass changes. Gravimetric $PM_{2.5}$ concentrations were calculated by dividing the weight of particulate matter collected by the volume of air sampled.

A Kanomax Piezobalance Dust Monitor was also used as a secondary reference instrument in one experiment. The piezobalance is not as portable, rugged, or sensitive as the TSI SidePak. It also has less time resolution and requires near constant user attention. However, the piezobalance can more directly measure the mass of airborne particles and is therefore not subject to the limitations of having to calibrate it for the aerosol in question, as with the light-scattering SidePak. The piezobalance was fitted with a 2.5 micron impactor. Particles enter the piezobalance, become electrically charged and deposit on the piezo-crystal. The total mass of the deposited particulates alters the piezo-crystal's frequency. Since the change in frequency is proportional to the mass of the particulates, the actual weight of the particulates is obtained.

In addition to the nine waterpipe experiments, nine positive control experiments were conducted with burning cigarettes (Marlboro Reds). Cigarettes were smoked by hand, using a 60cc syringe roughly following ISO standard smoking regimen 3308. All sampling methods were run identically to that of the waterpipe experiments.

2.2 Air quality monitoring in field:

Indoor air quality was assessed in seven hookah bars in three cities (from the different counties) in central and western New York State. These seven venues represented all the hookah establishments that allow indoor smoking in the 3 cities sampled. One venue was excluded from the sample as it only allowed smoking out-of-doors, and there was no smoking taking place (even outdoors) at this establishment due to the season of the study.

The TSI SidePak AM510 Personal Aerosol Monitor was used to sample and record the levels of respirable suspended particles that are less than 2.5 microns in diameter. The SidePak was calibrated to a flow rate of 1.7 liters per minute and was zero-calibrated prior to each use by attaching a HEPA filter according to instructions established by the Air Pollution Exposure Research Laboratory at Roswell Park Cancer Institute (Travers, 2008a). The SidePak uses a built-in sampling pump to continuously draw in air and was set to a thirty-second log interval, which averages the previous 30 one-second measurements. The calibration factor of 0.38 was applied to the raw data retrieved from the SidePak to account for the properties of waterpipe smoke. The calibration factor was determined from the experiments in first part of this study. The data points were then averaged to provide a mean $PM_{2.5}$ concentration for each establishment.

Sampling was discreet in order to not disturb the patrons' typical behavior. The SidePak was placed in a handbag with the sampling tube sticking out to conceal the device and minimize its sound. A minimum of 30 minutes was spent in each venue. The number of waterpipes burning, the number of people per waterpipe, and use of other tobacco products were recorded every 15 minutes during sampling. Room dimensions were also measured using a Laser Distance Meter (Leica Geosystems DISTO E7300).

Measurements of indoor carbon monoxide levels were taken using a Q-TRAK Indoor Air Quality Monitor (TSI, Inc., Shoreview, MN, USA). The Q-TRAK measures carbon monoxide (CO), carbon dioxide (CO2), temperature, and humidity. The equipment was set to a thirty-second log interval, and sampling procedures were the same as those described for the SidePak.

Field notes were used to document the presence of the use of other tobacco products, the products sold in the venue (tobacco products, food products, etc.), the type of waterpipe used (single hose versus multiple hose; vented versus non-vented), the type of charcoal used, and the behaviors of patrons in the café.

3. Results

3.1 Calibration factor experiments

Results from the 9 controlled waterpipe experiments yielded a mean calibration factor of 0.38 (SD 0.08, range 0.23 to 0.50) to convert SidePak measurements to true $PM_{2.5}$ measurements. Good linear correlation (R^2 = 0.91) between the SidePak and gravimetric method can be seen across a wide range of concentrations (72 – 1365 μg/m^3) in Figure 1. Positive control cigarette experiments yielded a mean cigarette-specific calibration factor for the SidePak of 0.29, the same as previously demonstrated by multiple research groups (Jiang et al., 2011; Lee et al., 2007; Travers, 2008b). In the cigarette experiments, the number of cigarettes smoked by hand was varied to increase the range of expected $PM_{2.5}$ concentrations. The waterpipe experiments were limited by having a single person smoke the waterpipe *ad libidum,* and therefore have a smaller $PM_{2.5}$ range. Across all controlled experiments the temperature ranged from 23.9°C to 26.0°C and the relative humidity ranged from 36% to 58.6%. No adjustments for relative humidity were made as we do not expect humidity below 60% to have a significant impact on the results (Wu, et al., 2005). Applying the 0.38 calibration factor to the SidePak data, seen in Figure 2, showed excellent quantitative and qualitative agreement between the adjusted SidePak data and piezobalance.

3.2 Air quality monitoring in field

An average of 49.75 minutes was spent on data collection at each venue, with a range of 37 to 64 minutes. Table 1 displays the mean characteristics of each venue. Mean $PM_{2.5}$ concentration ranged from 18 μg/m^3 to 1137 μg/m^3 and the overall mean for these venues was 515.0 μg/m^3 (SD=338.8 μg/m^3). All $PM_{2.5}$ levels are adjusted using the 0.38 waterpipe-specific calibration factor. Ambient carbon monoxide ranged from 1.5 ppm to 53.4 ppm with a mean of 20.5 ppm (SD=18.3 ppm). Real-time data for $PM_{2.5}$ and carbon monoxide concentrations in each venue sampled can be viewed in Figure 3.

Field notes were collected on a variety of behaviors and are also summarized in Table 1. On average, a waterpipe is shared among 3 persons. Almost half (four out of seven) of the cafés offer patrons their own hose while most (six out of seven) provide participants with their own mouthpiece. All of the venues except for one used quick-light charcoal; the one that did not reported using a “natural” charcoal made of coconut shells that was kept lit on electric coils in the back room. Just over half (57.1%) of the venues provided a waterpipe that was vented, meaning the waterpipe had a purge valve, which allows users to clear smoke from the base.

Of the seven establishments, three identified as a hookah lounge and smoke shop, two identified as a hookah lounge and restaurant (prepared food on premises) and two identified as primarily a hookah lounge. All venues had at least a minimal quantity of shisha available for take-home sale. Patrons smoking a tobacco product (cigarette or little cigar) other than hookah were observed in four of the seven establishments and the smell of marijuana was noted in one venue. All venues provided a menu to select a brand and flavor of shisha; none of these menus provided warnings about the consequences of tobacco smoke.

4. Conclusions

Using the SidePak with the factory calibration setting of 1.00 overestimated gravimetrically-determined $PM_{2.5}$ levels from waterpipe smoke. Applying the waterpipe-specific calibration factor for the SidePak, 0.38, allowed for field assessments to be conducted in locations with waterpipe smoke to determine accurate particle exposure concentrations. Light-scattering has several advantages over older, traditional methods of particle assessment: it measures and provides real-time data, is cost-effective, battery-operated and portable, and allows for discreet data collection, without affecting the patrons in the environment.

Limitations to this work include the relatively small convenience sample of publicly available hookah venues, though at the time of data collection, this sample accounted for all hookah cafés allowing indoor hookah smoking across three counties.

Another potential limitation and challenge is patrons’ concurrent use of other tobacco products. While bars have historically allowed the use of cigarettes, it was not common to have to take into account the use of other smoked products (tobacco or otherwise) when conducting cigarette air monitoring or other surveillance activities. In this sample of waterpipe cafés, the use of other combustible products was common (4 out of 7), and protocols will have to be developed to properly take this into account. While we suspect the bulk of the PM measured resulted from waterpipe usage, the fact remains that in many of the locations sampled there was likely additional particulate contributions from other burning tobacco products. Further studies should do surveillance to identify exactly what products are being used in waterpipe cafés and examine the impact of mixtures of particulate sources on the device calibration factor.

Waterpipe establishments have had an increasing presence in the United States, and accurate $PM_{2.5}$ levels determined with the SidePak in public waterpipe venues were high and pose a serious health risk as they exceed existing public health and worker exposure limits.

The mean $PM_{2.5}$ (μg/m^3) was well above the cutoff for hazardous air according to the United States EPA's Air Quality Index. When outdoor air quality reaches levels above 250 μg/m^3 ("hazardous"), people are advised to restrict outdoor physical activity while people with heart/lung disease, older adults, and children are advised to remain indoors and keep physical activity levels low (U.S. Environmental Protection Agency, 2013). Additionally, the mean $PM_{2.5}$ of the waterpipe cafés in this sample is higher than those observed in bars that allowed cigarette smoking. Measurements taken before Clean Indoor Air Laws went into effect suggest an average of 412 μg/m^3 in bars or restaurants where smoking was allowed (Center for Disease Control and Prevention, 2004).

With the appropriate calibration factor, the SidePak can now be used by researchers and public health practitioners to gather accurate data on levels of particulate air pollution exposure resulting from waterpipe smoking. Accurate exposure data is a powerful tool to inform debates over smoke-free air policies and to evaluate these policies.

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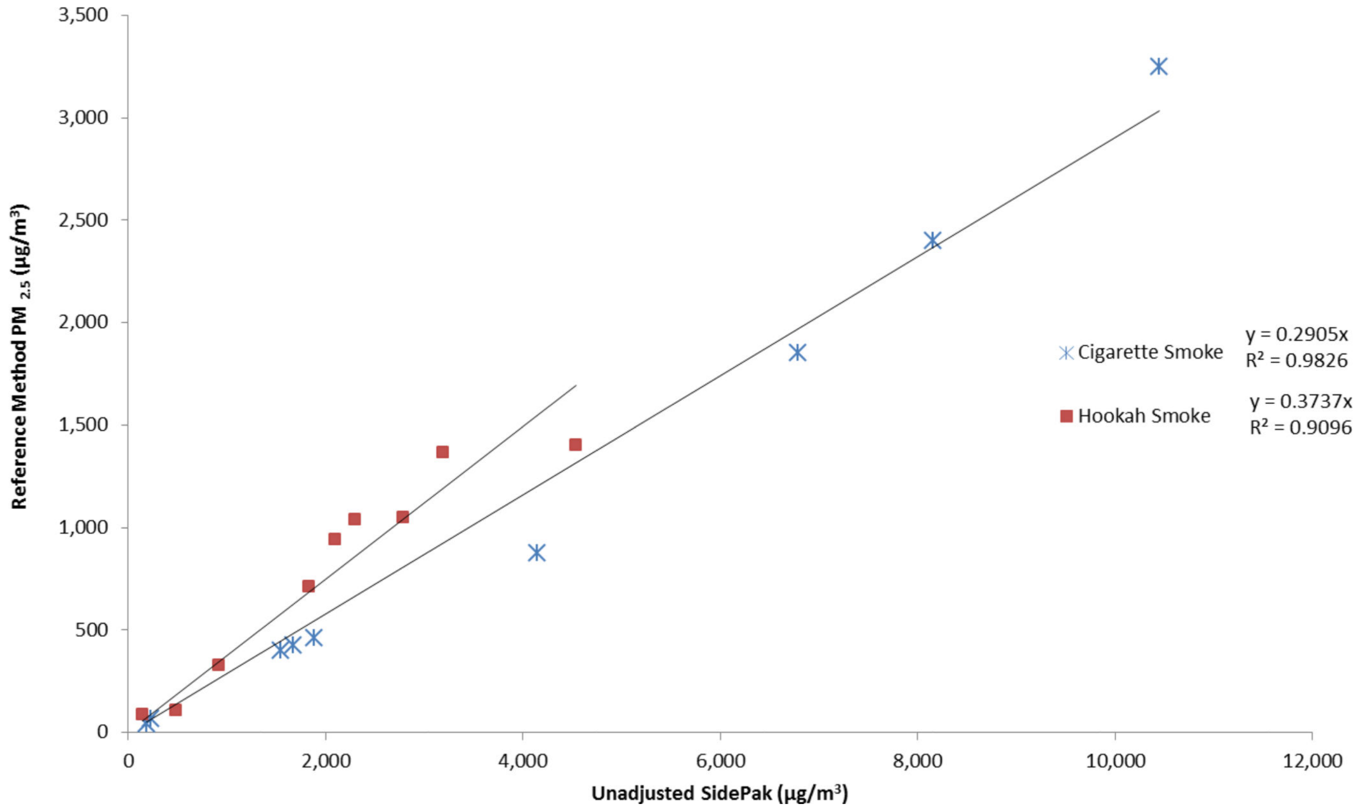

FIGURE 1.

Association between SidePak Aerosol Monitor and Gravimetric $PM_{2.5}$ in Controlled Lab Experiments with Cigarette Smoke & Hookah Smoke

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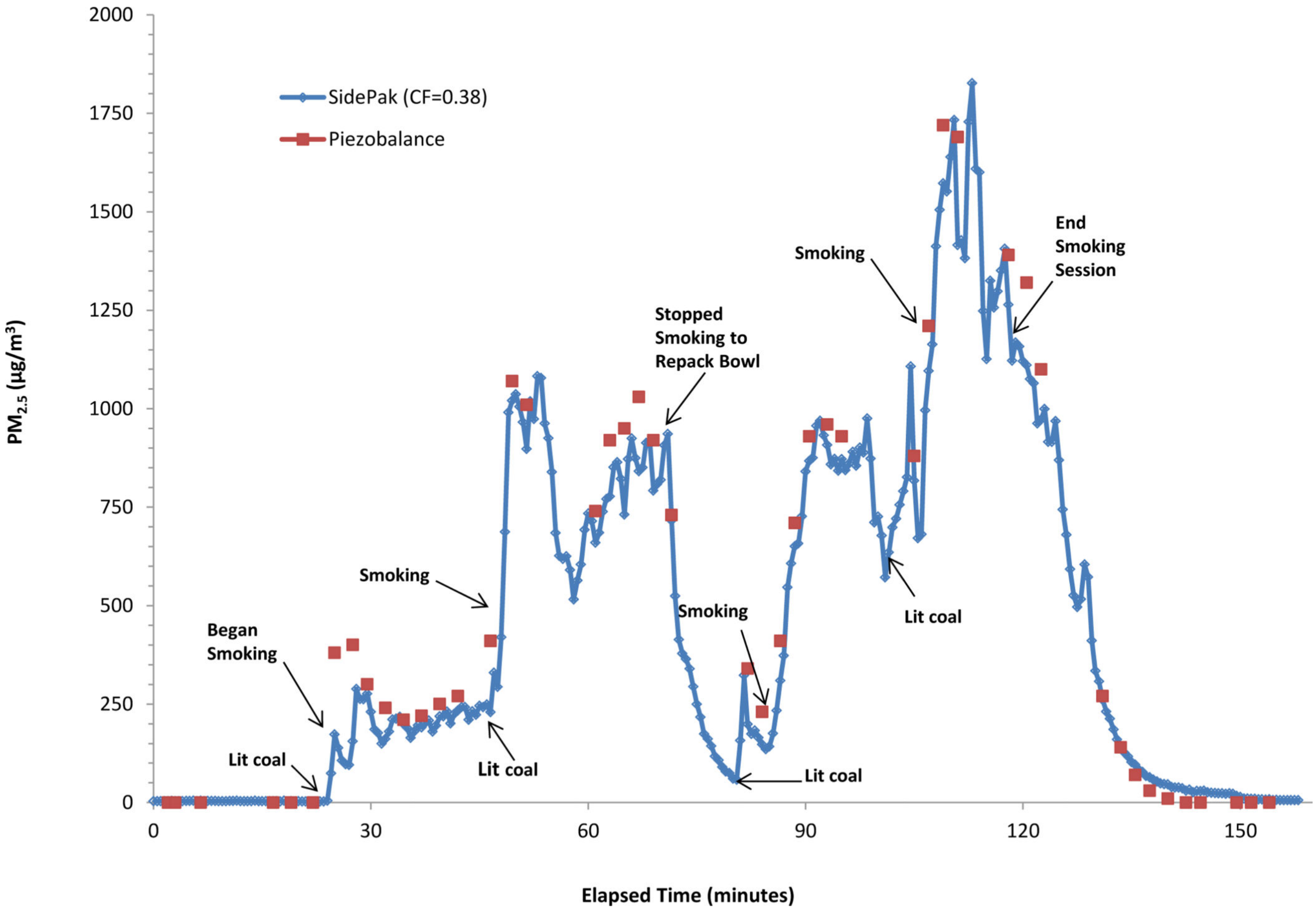

FIGURE 2.
SidePak AM510 versus Piezobalance (SidePak data multiplied by 0.38 calibration factor)

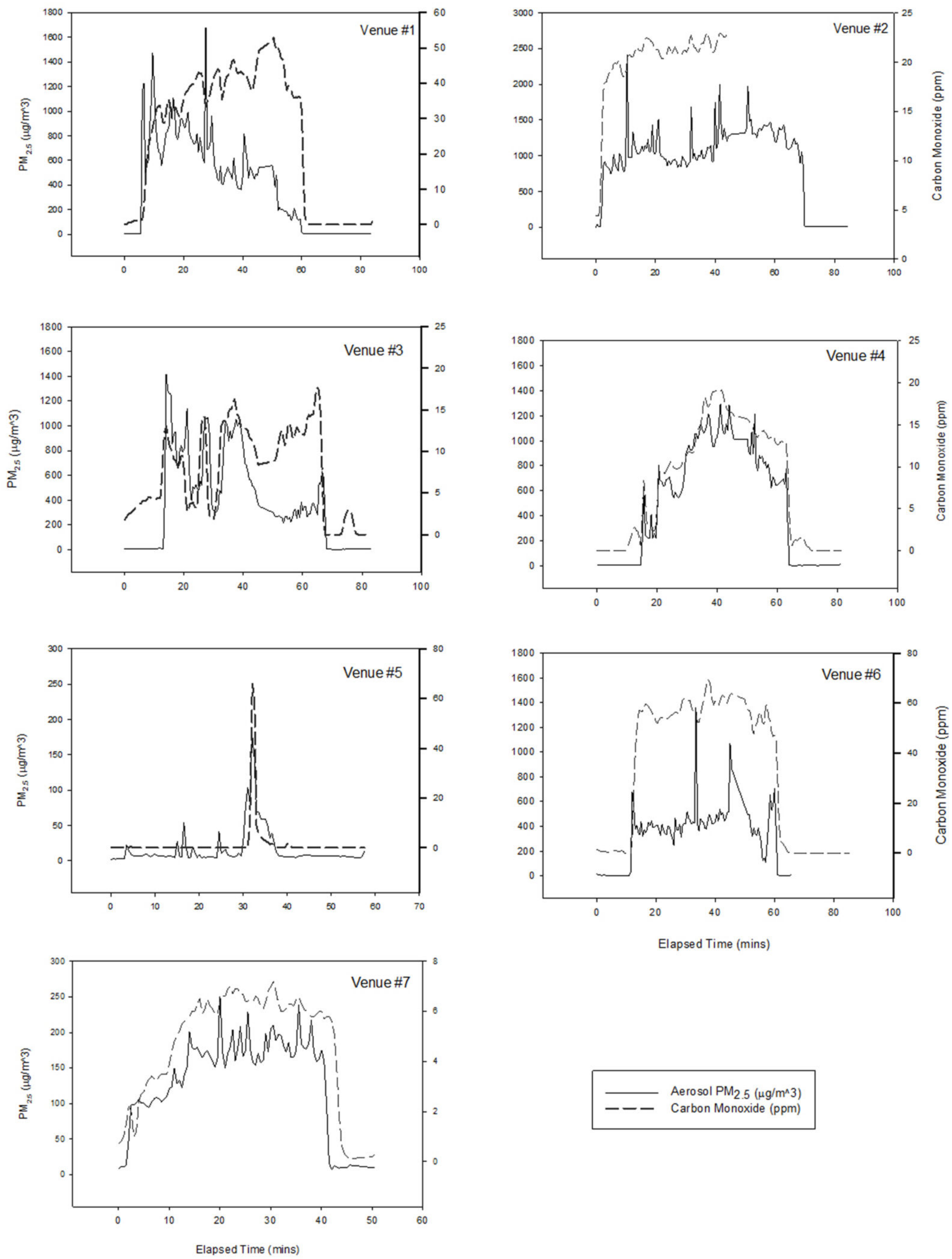

Figure 3:

Real-Time Plots of $PM_{2.5}$ (calibration factor = 0.38) and Carbon Monoxide in 7 Hookah Cafes Sampled.

Table 1.

Smoking conditions, particulate matter, and carbon monoxide air pollution in hookah bars in three counties in New York State

Venue Number	Vented WP	Quick-light charcoal used	Shared hose (Total number hoses)	Shared mouthpiece	Volume (m^3)	Mean number of people in venue	Mean number of WPs burning	Mean number of people per WP	Mean number of OTPs burning	WP + OTP Smoker Density*	Mean $PM_{2.5}$ level ($\mu g/m^3$)	Mean CO level (ppm)
1	Yes	Yes	Yes (1)	Yes	204	35.0	10.0	3.3	0.0	4.90	617.0	37.4
2†	Yes	Yes	No (2)	No	500	32.2	11.0	3.0	1.9	2.58	851.0	20.9
3	Yes	Yes	No (2)	No	143	21.0	4.3	4.8	2.0	4.39	593.0	10.7
4	No	Yes	No (2)	No	306	18.3	4.7	2.8	3.0	2.52	934.0	15.0
5	No	Yes	Yes (1)	No	357	6.0	1.5	2.0	0.0	0.42	18.0	1.5
6	No	No	Yes (1)	No	476	20.0	6.0	3.3	0.7	1.40	436.0	52.4
7	Yes	Yes	No (2)	No	229	4.0	1.5	3.0	0.0	0.66	158.0	5.5
Overall mean:	57.1%	85.7%	42.9%	14.3%	316	19.5	5.6	3.2	1.1	2.41	515.0	20.5

† data averaged across three observations

* WP + OTP Smoker Density = Mean number of waterpipes plus other tobacco products per 100 m^3 of venue volume.

Note: WP = waterpipe; OTP = other tobacco product; Calibration factor of 0.38 applied to all $PM_{2.5}$ data