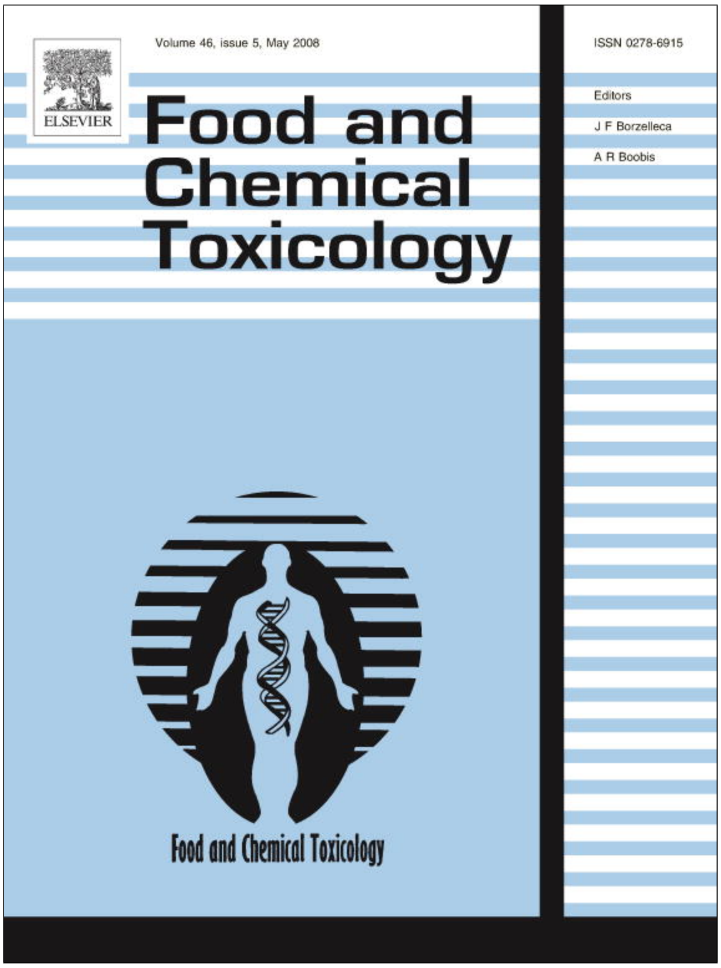
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Elevated toxicant yields with narghile waterpipes smoked using a plastic hose

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Abstract

The effect of hose permeability on toxicant yields for the narghile waterpipe is investigated, with special reference to the recent adoption of plastic as a hose construction material. Measurements of air infiltration rates for 23 leather and plastic hoses representing 11 types commonly available in Beirut, Lebanon were made, revealing that while leather hoses allowed significant outside air infiltration during a puff constituting up to 31% of the puff volume, plastic hoses were found to be air-tight, indicating that the smoke reaching the waterpipe user can be considerably more concentrated when delivered via a plastic hose. Total particulate matter (TPM), nicotine and carbon monoxide (CO) yields were compared when a waterpipe was machine smoked using a highly permeable leather and an air-tight plastic hose. It was found that the plastic hose resulted in similar yields of nicotine, but more than double the CO yielded with the highly permeable leather hose. Thus, even if narghile smokers titrate for nicotine intake, the use of a plastic hose will likely greatly increase the exposure to CO, a major causative agent in cardiovascular disease.

Keywords: Argileh; Arguileh; Narguile; Nargileh; Shisha; Hooka; Hubble–bubble; Water-pipe; Tobacco smoke; Carbon monoxide; Nicotine

1. Introduction

With the ongoing global resurgence of the narghile waterpipe as a tobacco smoking device (American Lung Association, 2007; Smith-Simone et al., 2007; Chaaya et al., 2004; Maziak et al., 2004; Shediac-Rizkallah et al., 2002), entrepreneurs have brought a number of modern innovations to market which may have unforeseen consequences for toxicant intake. One such innovation is the use of plastic instead of leather to construct the hose through which the user draws smoke (Fig. 1). In recent visits to waterpipe cafés and supply shops in Beirut, Lebanon, we have noted several cafés that served waterpipes exclusively with plastic hoses, and several tobacco supply outlets, including a major supermarket chain, which only sold plastic hoses, though most sold both. While the plastic hose is promoted as a more durable and easy-to-clean alternative, the air-tight character of plastic, as opposed to the conventional porous leather, gives rise to the concern that the smoke reaching the mouthpiece will be less dilute, potentially resulting in greater toxicant exposure. Cigarette paper permeability has for some time been understood as a key determinant of toxicant uptake by smokers (e.g. Owen and Reynolds, 1967). During a puff, the negative pressure in the cigarette rod gives rise to the infiltration of fresh air which can dilute the smoke. In addition, the permeable flow boundary can allow mobile gas molecules such as CO and CO_2 to escape by diffusion to the ambient surroundings. For example, measurements by Durocher et al. (1978) showed that 26–32% of the CO generated in the cigarette during a puff escapes by diffusion through the paper before reaching the smoker.

In addition, the greater the flow rate of infiltrating air ($\dot{V}_{\text{infil}}$) the lower the flow rate through the burning tobacco of the waterpipe head or cigarette tip ($\dot{V}_{\text{tobacco}}$) for a given draw velocity ($\dot{V}_{\text{mouth}}$) at the mouthpiece ($\dot{V}_{\text{mouth}} = \dot{V}_{\text{tobacco}} + \dot{V}_{\text{infil}}$). Replacing a porous waterpipe hose with

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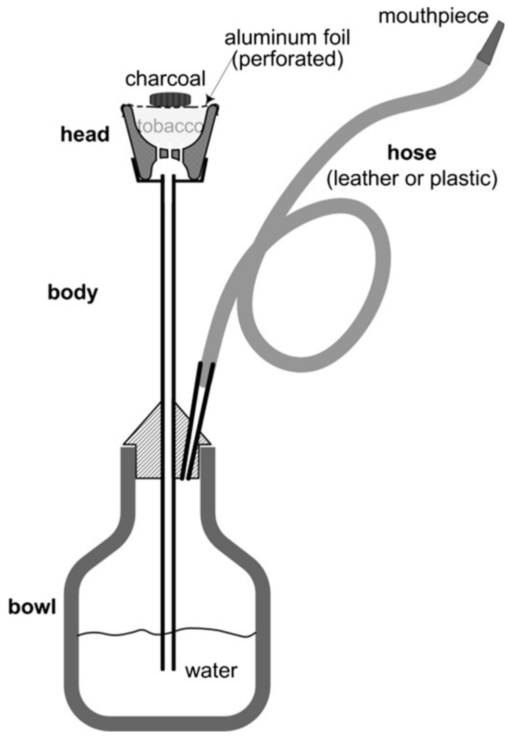

Fig. 1. Schematic of a narghile waterpipe. The head (fired clay), body (metal or wood), water bowl (metal or glass), and corrugated hose (leather or nylon stretched over a wound flexible wire coil support) are the primary elements from which a narghile is assembled. Tobacco is loaded into the head, where several large holes in the base allow the smoke to pass into the central conduit of the body that leads to the water bowl. When a smoker inhales through the hose, a vacuum is created in the space above the waterline, causing smoke to bubble into the water bowl from the body. The negative pressure in the system during a puff favors air infiltration through porous or leaky components, including the hose. With the *ma'assel* configuration shown here, a relatively deep (approximately 3 cm) head is filled with 10–20 g of a flavored tobacco mixture and covered with an aluminum foil sheet that is perforated for air passage. Burning coals are placed on top of the aluminum foil. *Note:* plastic hoses are usually covered in a fabric that gives the appearance of leather or some other "natural" material.

a sealed one will result in a net increase in air volume drawn through the tobacco in the head that could affect the smoke aerosol production temperatures and chemistry. In summary, at least three phenomena are affected which can alter toxicant yields when a porous leather hose is replaced by a non-porous plastic one: (1) escape of mobile species through the hose walls, (2) simple dilution, and (3) varying combustion/pyrolysis/distillation chemistry.

Despite its long history and recent global resurgence few studies (Shihadeh and Saleh, 2005; Shihadeh, 2003; Sajid et al., 1993; Hoffmann et al., 1963; Rakower and Fatal, 1962) have been conducted to measure the toxicant content of the narghile waterpipe (see Table 1 for previously measured toxicant yields), and no consideration has been made for the potential role of hose permeability as a determinant of toxicant delivery. This study was conducted to examine whether the conventional leather hose used with the waterpipe exhibits significant permeability

Table 1
Previously reported toxicant yields for a single narghile waterpipe smoking session

	Shihadeh and Saleh (2005)	Shihadeh (2003)	Single cigarette
"Tar", mg	802	242	1–27[a]
Nicotine, mg	2.96	2.25	0.1–2[a]
CO, mg	145		1–22[a]
PAH			
Phenanthrene, ng	748		200–400[a]
Fluoranthene, ng	221		9–99[b]
Chrysene, ng	112		4–41[b]
Metals			
Arsenic, ng		165	40–120[c]
Beryllium, ng		65	300[c]
Nickel, ng		990	0–600[c]
Cobalt, ng		70	0.13–0.2[c]
Chromium, ng		1340	4–70[c]
Lead, ng		6870	34–85[c]

Data for a single cigarette are shown for comparison. Waterpipe data were generated using a smoking machine programmed to provide the puffing parameters shown. Waterpipes were loaded with 10 g of "two-apples" flavor (Nakhla brand) *ma'assel* tobacco, and one or one-and-a-half three Kings brand quick-light charcoal disks. Puffing parameters of Shihadeh and Saleh (2005) were based on detailed smoking topography measurements in Beirut area cafés, whereas of Shihadeh (2003) were based on visual observation and estimated puff volume.
[a] Reported ranges for commercial cigarettes, Jenkins et al. (2000).
[b] LGC (2002).
[c] Hoffmann and Hoffmann, (1988).

under typical use conditions, and to compare TPM, nicotine, and CO yields measured with a leather hose to those measured with a non-porous "washable" plastic hose. Apart from their importance as key toxicants, CO and nicotine were selected for study because they, respectively, represent a highly diffusive gas phase component, and a low vapor pressure particle phase smoke component and thereby span the range of behaviors expected of various smoke components in a flow bounded by permeable walls.

2. Methods

2.1. Smoke generation and sampling

The smoke generation and sampling procedures were identical to those presented in Shihadeh and Saleh (2005). In brief, a digital waterpipe smoking machine (described in Shihadeh and Azar, 2006) was programmed to produce a smoking regimen consisting of 171 puffs of 530 ml and 2.6 s duration, spaced 17 s apart. These puffing parameters were derived from a field study in which topographies of 52 smokers in a café in Beirut were recorded, and represent an "average" waterpipe smoking session (Shihadeh et al., 2004). Ten grams of "two apples" flavor (Nakhla brand, Egypt) tobacco mixture was loaded in the waterpipe head during each smoking session, and covered with a 9 × 9 cm sheet of aluminum foil, perforated with an 18 hole pattern. A single quick-light charcoal disk (three Kings, Holland) was lit and placed atop the perforated foil at the beginning of the smoking session, and a second ½ disk was added after the 105th puff.

The smoke exiting the waterpipe mouthpiece was split into two parallel streams and each stream drawn through a 47 mm glass fiber filter pad (Gelman type A/E) to collect the particulate phase. Multiple filter changes were required during each smoking session to avoid filter overload (defined as collection of greater than 150 mg TPM per 47 mm filter, per ISO 4387:1991). For the leather hose, six pairs of filters were used for each smoking session, with filters swapped at 40, 60, 80, 105, 140 puffs. For the plastic hose, a total of nine pairs of filters were swapped at 25, 35, 45, 55, 70, 90, 110, 130, and 150 puffs. The more intensive filter swapping regimen required of the plastic hose reflected the greater particulate loading of this experimental condition. Each filter pad was held in a transparent polycarbonate holder equipped with quick-release fittings to allow rapid filter assembly changes between puffs.

For CO determination, a fraction (circa 9 vol%) of the smoke was sampled from the main flow path through a critical orifice by a miniature sealed diaphragm pump that exhausted into a 10 L Tedlar grab sample bag. The pump was activated during each puff by the smoking machine via a digital solid state relay. The flow rate of the sampling pump was taken into account in programming the smoking machine, and thus did not affect the overall flow rate through the waterpipe. Further, because the extraction point was downstream of the particulate filters, the TPM and nicotine yields were not affected by this measurement.

To test whether CO yield was sensitive to variations in $\dot{V}_{\text{tobacco}}$ over the ranges observed in this study, additional experiments were conducted in which CO yield with the plastic hose was compared for $\dot{V}_{\text{tobacco}}$ of 12.2 and 8.4 standard liters per minute (SLPM), corresponding to the maximum and minimum values observed in this study. For both of these conditions, procedures were simplified by smoking the waterpipe without tobacco in the head (i.e. a charcoal-only condition); therefore TPM and nicotine were not determined for this part of the study. We believe that this simplification is valid for the purpose of comparing CO yields, since greater than 90% of the CO yield of the waterpipe is produced by the combustion of the charcoal (Monzer, 2005).

2.2. Gravimetric and chemical analyses

TPM, CO, and nicotine were determined for three replicate smoking sessions with each hose type. In accordance with ISO 4387:1991, TPM was determined as the aggregate weight gain of the filter assemblies (filter pad plus holder) used during each smoking session. In addition, the waterpipe head with the tobacco loaded was weighed before and after each smoking session to determine the amount of tobacco mixture consumed.

Each filter pad was separately analyzed for nicotine by GC-MS in accordance with the method presented by Siegmund et al. (1999) except for the modifications to the extraction and clean up steps as follows: each filter pad was placed in a separate test tube and extracted on a shaker overnight (12 h) in a mixture of 6 ml of 1 M NaOH and 6 ml of hexane. The organic layer was transferred by glass pipette to another test tube, and 6 ml of 1N HCl was added to it. The resulting mixture was shaken on a vortex for 1 min to obtain phase separation. The organic layer was then removed by pipette and discarded, 2 ml of 5N NaOH and 2 ml of hexane were added, and the tube was shaken on a vortex for 1 min. 0.2 ml of the resulting organic layer was then taken and added to 0.8 ml of hexane to obtain a 1:5 diluted sample. An aliquot of this sample was then introduced into the GC column for quantification.

Carbon monoxide was quantified for each smoking session using a calibrated electrochemical CO analyzer that was connected to the Tedlar sample bag after the smoking session was terminated. Measured volume concentrations of CO were reported in units of mass by multiplying by the total drawn smoke volume and the density of the CO at ambient temperature and pressure. The initial dead volume between the sampling point and grab bag was negligible to the accuracy of the CO instrument, and was therefore excluded from analysis.

2.3. Waterpipe hoses

Thirteen leather and 10 plastic hoses representing a range of commonly used types (length and diameter, materials of construction, manufacturer) were purchased at tobacco supply shops in Beirut, Lebanon. Dimensions are given in Table 2.

Table 2
Measured infiltration rates for 23 hoses spanning 11 common types, subjected to a mouthpiece flow rate of 12 SLPM

Test	Hose	Material	Length (cm)	Outer dia. (cm)	Infiltration rate (SLPM)
1	A1	Leather	158	1.5	3.3
2	A2	Leather	162	1.5	3.8
3	B1	Leather	142	1.5	1.5
4	B2	Leather	142	1.5	1.4
5	B3	Leather	144	1.5	2.1
6	B4	Leather	143	1.5	3.3
7	B5	Leather	145	1.5	1.2
8	C1	Leather	131	1.2	1.3
9	C2	Leather	134	1.2	2.5
10	D1	Leather	129	1.3	0.9
11	D2	Leather	130	1.3	1.2
12	E1	Leather	116	1.3	2.7
13	E2	Leather	113	1.3	2.4
14	F	Plastic	130	1.4	0
15	G	Plastic	190	1.2	0
16	H1	Plastic	134	1.1	0
17	H2	Plastic	134	1.1	0
18	I1	Plastic	175	1.2	0.8
19	I2	Plastic	177	1.2	1.1
20	J1	Plastic	182	1.3	0
21	J2	Plastic	181	1.2	0
22	K1	Plastic	191	1.5	0
23	K2	Plastic	191	1.5	0

2.4. Infiltration measurements

A schematic of the experimental setup for infiltration measurements is shown in Fig. 2. A soap-bubble flow meter (Gilian, Gilibrator 2) was inserted between the waterpipe and the hose to measure air flow into the hose, while a controlled flow rate was imposed by the smoking machine at the mouthpiece. Hose infiltration rate was measured as the difference between the flow readings of the smoking machine and soap-bubble flow meter. Because the soap-bubble flow meter imposes negligible pressure drop in the system, this experimental configuration insured that the vacuum pressure in the hose, and therefore infiltration rate, was representative of that under normal use conditions. The mouthpiece flow rate in this study was maintained at 12 SLPM, based on the average flow rate previously found in the aforementioned 52 smoker-puffs topography study. For infiltration measurements, the narghile was prepared for smoking as per the procedures described above but was not lit. To check repeatability, five hoses were randomly selected for repeated measurement, and self-consistent results (to within 0.05 SLPM) were obtained in all cases.

2.5. Data analysis

For the two hose types, differences in means for all outcome measures (infiltration rate, CO, nicotine, and TPM yields) were analyzed for significance using a two-sided t-test assuming equal variances. For any given measure, probability values below 0.05 ($p < 0.05$) were taken to indicate a statistically significant difference.

In some cases it was useful to calculate a "dilution-adjusted yield" to check whether the differences in toxicant yields for cases with different infiltration rates could be attributed to simple dilution, all else being equal, including chemical formation rates. Based on the principle of mass conservation, it can be shown that for a measured yield, Y_0, the dilution-adjusted yield, $\dot{V}_{\text{dil}}$, for a dilution flow rate of $\dot{V}_{\text{infil}}$ is $\dot{V}_{\text{dil}} = Y_0\left(\frac{\dot{V}_{\text{mouth}} - \dot{V}_{\text{infil}}}{\dot{V}_{\text{mouth}}}\right)$.

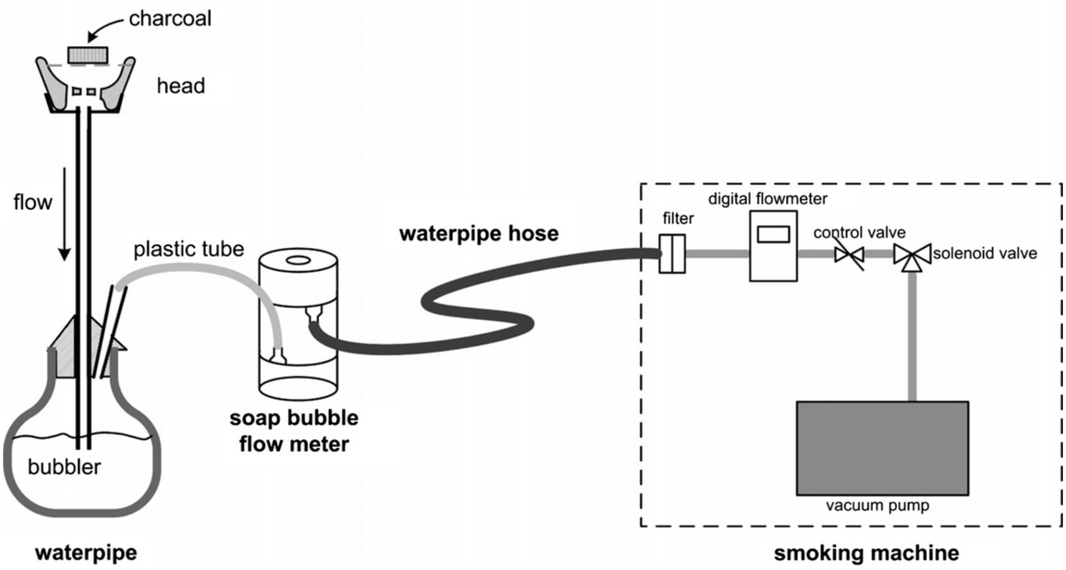

Fig. 2. Schematic of the experimental setup used in this study. The difference between the soap-bubble flow meter reading and that of the digital smoking machine flow meter is due to infiltration through the hose. The smoking machine flow rate was set at 12 SLPM. Thus, a typical infiltration rate of two SLPM through the hose means that only 10 SLPM flows through the waterpipe head.

3. Results

3.1. Infiltration rate

Infiltration rates for the 23 hoses are given in Table 2. Difference in infiltration rate by hose construction material was highly significant ($p < 0.001$). For the leather hoses, infiltration was found to be large (up to ~25% of the mouthpiece flow) and varied both within and across type. In contrast, except for type "I", plastic hoses did not exhibit any measurable infiltration. Hoses A2 (leather) and F (plastic) were chosen for the subsequent toxicant analyses with a lighted waterpipe since they represented the maximum and minimum infiltration rate cases.

3.2. Tobacco consumed

Tobacco consumed was 3.6 ± 0.1 g/session (mean ± standard deviation) and 5.1 ± 0.1 g/session for leather A2 and plastic F hoses, respectively ($p < 0.001$).

3.3. TPM

The average TPM with leather hose A2 was 1180 ± 60 mg/session, while for the plastic hose F it was 2860 ± 340 mg/session ($p < 0.005$).

3.4. Carbon monoxide

Determinations of carbon monoxide using leather hose A2 yielded an average of 99 ± 9 mg/session, while for plastic hose F the mean was 241 ± 21 mg/session ($p < 0.003$).

To check whether the difference in CO yield was inherent to the hose material, six leather and six plastic hoses were randomly selected and the CO yield was determined for a single experiment with each hose using the charcoal-only smoking regimen described in Section 2. The mean CO yield for the plastic hoses was found to be 49% greater than that of the leather hoses ($p < 0.016$).

There was no significant effect on CO yield when $\dot{V}_{tobacco}$ was varied between 8.4 and 12.2 SLPM using plastic hose F; the mean CO yield for the 12.2 SLPM condition was 5% greater than that of the 8.4 SLPM condition, however this difference was not statistically significant ($p > 0.69$). Eight repeated trials were conducted for each $\dot{V}_{tobacco}$.

3.5. Nicotine

The nicotine determinations using leather hose A2 yielded an average of 6.06 ± 0.14 mg/session, while for plastic hose F the average was 5.23 ± 0.7 mg/session. The difference between the two hoses was not significant ($p > 0.1$). Representative moving-average production rates of nicotine and TPM during the smoking sessions are shown in Fig. 3a and b for the leather (A2) and plastic (F) hose conditions, respectively.

4. Discussion

This study was undertaken to address the dearth of information regarding the importance of hose type on toxicant delivery to narghile users. Measurements of air infiltration rates in leather and plastic hoses under typical use conditions showed that the leather hoses are highly permeable, allowing up to 31% of the volume of gases reaching the mouthpiece during a puff to be made up of fresh air infiltrating through the hose. In contrast, the plastic hoses were air-tight. The importance of differing permeability was investigated by comparing TPM, CO, and nicotine yields for leather and plastic hoses using idealized 171

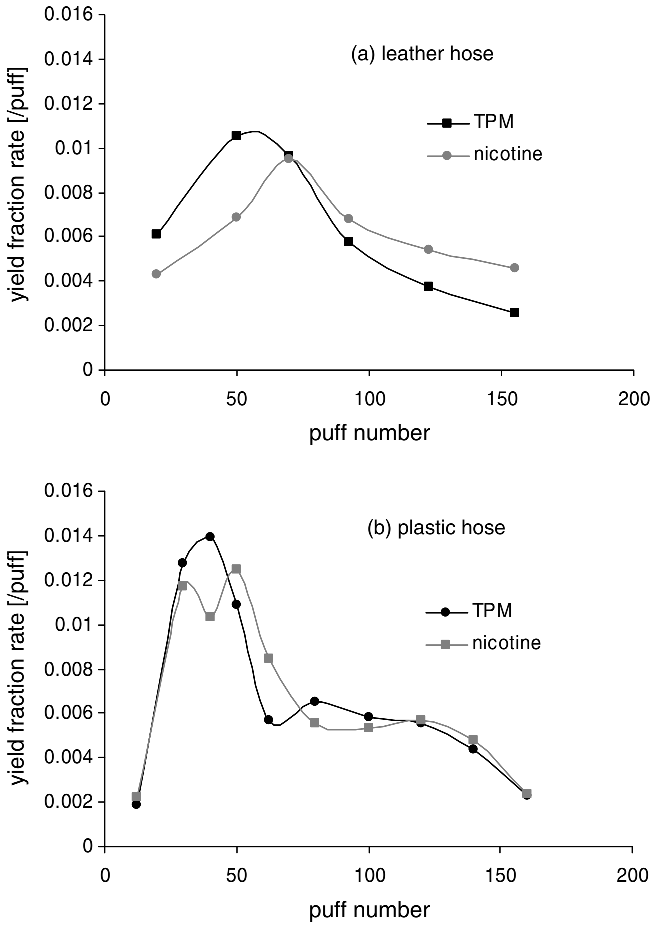

Fig. 3. Typical moving average TPM and nicotine yield fraction rates for (a) leather hose and (b) plastic hose conditions. Yield fraction rate is a density function calculated as the ratio of TPM or nicotine mass yielded on a given filter to the number of puffs drawn through that filter, normalized by the total yield of TPM or nicotine for a given smoking session.

puff-smoking regimens derived from the previous puff topography measurements of narghile smokers. Limitations of the study include the potential that a smoker may puff differently when using a plastic rather than leather hose; it may turn out, for example, that a user of a plastic hose unconsciously reduces the puff volume to such an extent that CO intake is actually less than when using a porous leather hose.

The results are summarized in Table 3, where it is readily apparent that the use of a plastic hose significantly increased the particulate matter and carbon monoxide delivery, but paradoxically had no significant effect on nicotine yield. Previously measured yields of tobacco burned, CO, nicotine, and TPM with a leather hoses of uncharacterized infiltration rate generally fell between those of the leather and plastic hose of the current study, except for nicotine, which was found to be considerably greater for both, conditions of this study.

The large difference in CO yields between the leather and plastic hoses is greater than that can be explained by dilution from air infiltrating through the leather hose. That is,

Table 3
Summary of results

	Current study			Shihadeh and Saleh (2005) Leather
	Leather	Plastic	Yield ratio	
Infiltration rate, SLPM	3.8	0	–	Not reported
Tobacco consumed, g	3.6	5.1	1.2	4.7
TPM, mg/session	1180	2860	2.4	1380
CO, mg/session	99	242	2.4	143
Nicotine, mg/session	6.06	5.23	0.9	2.96
CO:nicotine	16.3	46.3	2.8	48.3

10 g of tobacco mixture, 1.5 quick light charcoal disks, 171 puffs of 530 ml volume, 2.6 s duration, and 17 s interpuff interval. Data from Shihadeh and Saleh (2005) generated under similar conditions with a leather hose of unknown permeability are shown for comparison.

replacing 3.8 SLPM of the original 12.2 SLPM of smoke by fresh air would result in a dilution-adjusted yield of 166 mg of CO, rather than the observed 99 mg of CO. Because the CO production in the narghile head is not affected by the increased $\dot{V}_{tobacco}$ encountered when the plastic hose is installed (as shown in Section 3), the missing 67 mg of CO must have escaped the leather hose by diffusion through its porous walls, in a process analogous to CO transport through porous cigarette paper.

As with the CO yield, the difference in TPM yield for the two hose types significantly exceeds that predicted by simple dilution. Given the plastic hose yield of 2860 mg, the dilution-adjusted yield of 1970 mg is much greater than the observed 1180 mg with the leather hose. Thus the leather hose loses 790 mg of TPM more than it should by dilution alone. A previous study at our lab (Haddad, 2003) has shown that for conditions similar to those of this study, the TPM is approximately 55% water by mass just, upstream of the leather hose, and that by the time it traverses the hose length, the water fraction has dropped to approximately 12% as a result of the drying effect of infiltrating air as well as evaporation from the particle phase due to the hygroscopic boundary imposed by the leather. The hygroscopic boundary absorbs water vapor from the smoke, causing liquid water in the particulate matter of the smoke to evaporate to restore equilibrium between the vapor and liquid phases, resulting in a net decrease in TPM yield. Assuming the same change in water fraction for the current study as previously found by Haddad (2003), the dilution-adjusted TPM yield calculated from the plastic hose yield drops to 1020 mg, a value close to that found experimentally for the leather hose (1180 mg). Thus while the plastic hose does increase the TPM yield by eliminating dilution, an equally important determinant of the difference in TPM between the leather and plastic hose is the water loss due to the leather hose's hygroscopicity. Dry particulate matter, or "tar" yield ratios would likely be closer to the dilution ratio since these would exclude water from the yield.

In sharp contrast to the CO and TPM yields, nicotine yield was not significantly affected by the hose type. Fig. 3a and b indicate that nicotine and TPM production rates track one another closely in both experimental conditions. However, the plastic hose condition exhibits high peak production rates early in the smoking session, followed by a precipitous decline that is not reversed even after a charge of fresh charcoal is added to the head at the 105th puff. With the leather hose condition, the nicotine and TPM production build later in the smoking session to a lower peak rate, and decline gradually as it proceeds.

Given that the nicotine production rate declines well before the charcoal temperature begins to drop due the consumption of the fuel (Monzer, 2005), we believe that the most compelling explanation for the trends shown in Fig. 3a and b is that the transfer of nicotine from the tobacco to the smoke is limited by the mass of nicotine in the heat-affected zone of the tobacco. With the plastic hose, the higher air flow rates in the head lead to a more rapid depletion of the available nicotine than with the leather hose early in the smoking session, though conditions with either hose are sufficient to transfer the available nicotine by the end of the smoking session.

5. Conclusions

Taken together, the data reveal a complex role of hose permeability on waterpipe toxicant generation and transport by overlapping the effects of dilution, diffusion, and mass transfer, and point to at least two important practical implications. First, for a fixed smoking behavior, non-permeable plastic waterpipe hoses lead to greater absolute and nicotine-normalized yields of CO and TPM than leather hoses. Second, because leather hoses exhibited widely varying permeability within and across type under normal smoking conditions, future smoking machine studies of waterpipe toxicant yields must control for permeability.

Conflict of Interest statement

We have no conflict of interest in connection with the research reported in this manuscript.

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References

American Lung Association, 2007. An emerging deadly trend: Waterpipe tobacco use. Tobacco Policy Trend Alert, February 2007. http://slati.lungusa.org/alerts/Trend%20Alert_Waterpipes.pdf, (accessed 24.03.07).

Chaaya, M., El Roueiheb, Z., Chemaitelly, H., El Azar, G., Nasr, J., Al-Sahab, B., 2004. Argileh smoking among university students: A new tobacco epidemic. Nicotine and Tobacco Research 6, 457–463.

Durocher, D., Mattina, C., Selke, W., 1978. Diffusion of gaseous components through the wrapper of a cigarette. Beitrage zur Tabakforschung International 9, 201–207.

Haddad, A., 2003. Experimental investigation of aerosol dynamics in the argileh water pipe. Masters thesis, American University of Beirut, Beirut, Lebanon.

Hoffmann, D., Hoffmann, I., 1988. Letters to the Editor, Tobacco Smoke Components. Beitrage zur Tabakforschung International 18, 49–52.

Hoffmann, D., Rathkamp, G., Wynder, E., 1963. Comparison of the yields of several selected components in the smoke from different tobacco products. Journal of the National Cancer Institute 31, 627–635.

Jenkins, R., Guerin, M., Tomkins, B., 2000. The Chemistry of Environmental Tobacco Smoke. Lewis Publishers, Boca Raton.

LGC, 2002. Comparison of mainstream smoke yields of tar, nicotine, carbon monoxide and polycyclic aromatic hydrocarbons from cigarettes and small cigars. LGC Report GC15/M09/02. <http://www.advisorybodies.doh.gov.uk/scoth/pdfs/cigarcigarettepah.pdf>, (accessed 14.09.04).

Maziak, W., Ward, K., Afifi Soweid, R., Eissenberg, T., 2004. Tobacco smoking using a waterpipe: A re-emerging strain in a global epidemic. Tobacco Control 13, 327–333.

Monzer, B., 2005. Experimental investigation of the relative contributions of charcoal and tobacco to carbon monoxide and polycyclic aromatic hydrocarbon yields in the mainstream smoke of the narghile waterpipe. Masters thesis, American University of Beirut, Beirut, Lebanon.

Owen, W., Reynolds, M., 1967. The diffusion of gases through cigarette paper during smoking. Tobacco Science 11, 14–20.

Rakower, J., Fatal, B., 1962. Study of narghile smoking in relation to cancer of the lung. British Journal of Cancer 16, 1–6.

Sajid, K., Akhter, M., Malik, G., 1993. Carbon monoxide fractions in cigarette and hookah (hubble bubble) smoke. Journal of Pakistan Medical Association 43, 179–182.

Shediac-Rizkallah, M., Afifi-Soweid, R., Farhat, T., Yeretzian, J., 2002. Adolescent health-related behaviors in postwar Lebanon: Findings among students at the American University of Beirut. International Quarterly of Community Health Education 20, 115–131.

Shihadeh, A., 2003. Investigation of mainstream smoke aerosol of the Argileh water pipe. Food and Chemical Toxicology 41, 143–152.

Shihadeh, A., Saleh, R., 2005. Polycyclic aromatic hydrocarbons, carbon monoxide, "tar", and nicotine in the mainstream smoke aerosol of the narghile water pipe. Food and Chemical Toxicology 43, 655–661.

Shihadeh, A., Azar, S., Antonius, C., Haddad, A., 2004. Towards a topographical model of narghile water-pipe café smoking. Biochemistry, Pharmacology, and Behavior 79, 75–82.

Shihadeh, A., Azar, S., 2006. A closed-loop control playback smoking machine for generating mainstream tobacco smoke. Journal of Aerosol Medicine 19 (2), 137–147.

Siegmund, B., Leitner, E., Pfannhauser, W., 1999. Development of a simple sample preparation technique for gas chromatographicmass spectrometric determination of nicotine in edible nightshades. Journal of Chromatography A 840, 249–260.

Smith-Simone, S., Maziak, M., Ward, K., Eissenberg, T., 2007. Waterpipe use on US college campuses. Poster presented at the 13th Annual Meeting of the Society for Research on Nicotine and Tobacco, February, Austin, TX.