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Effects of shisha smoking on carbon monoxide and $PM_{2.5}$ concentrations in the indoor and outdoor microenvironment of shisha premises

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ABSTRACT

There has been significant rise in shisha premises in the United Kingdom with an unsubstantiated belief that shisha smoking is harmless and relatively safe. This study aimed to assess the public health situation by evaluating the extent of shisha environmental tobacco smoke (ETS) exposure among those that work in, and are customers of shisha businesses. Concentrations of several ETS pollutants such as carbon monoxide (CO) and particulate matter with a diameter of less than 2.5 microns ($PM_{2.5}$) in shisha premises were measured using real-time sensors inside and outside twelve shisha premises and at 5 pubs/restaurants where smoking is prohibited. Mean concentration of CO (7.3±2.4 mg/m^3) and $PM_{2.5}$ (287±233 μg/m^3) inside active shisha premises were higher than concentrations measured within the vicinity of the shisha premises (CO: 0.9±0.7 mg/m^3 and $PM_{2.5}$: 34±14 μg/m^3) and strongly correlated ($PM_{2.5}$ R=0.957). Concentrations were higher than indoor concentrations in pubs and restaurants where smoking is not permitted under UK law. The number of shisha pipes was a strong predictor of the $PM_{2.5}$ concentrations. The study also assessed the risk perception within patrons and managers, with only 25% being aware of the risks associated to shisha smoking. The study identifies owners, employees and consumers within active shisha premises being exposed to concentrations of CO and $PM_{2.5}$ at levels considered hazardous to human health. The results and outcome of this research serve as a basis to influence a discussion around the need of developing specific policies to protect consumers and employees of such premises.

1. INTRODUCTION

Shisha tobacco consumption is a cultural and customary behaviour in the Middle East, North Africa and Southeast Asia regions of the world (Knishkowy and Amitai, 2005), where it is known with different names in different countries (Khater et al., 2008) as shown in Table S1 (SI). In recent years, it has spread to other regions of the world, such as North America (known as “water pipe and hubble-bubble”) and Europe (Maziak et al., 2014). The spread and growth of shisha smoking is associated with a perception of harm-reduced risk as compared to cigarette smoking (Maziak, 2011; Maziak, 2013; Maziak et al., 2015). Therefore, shisha smoking has become a more socially and culturally accepted activity than cigarette smoking by the younger generation(Asfar et al., 2005), becoming a global phenomenon among the youth, specially young, male, high socioeconomic and urban groups (Maziak et al., 2014). As a result, shisha smoking has been increasing among the youth and people of the United Kingdom, Middle East and other western countries. This leads to shisha smoking recently becoming an increasing threat to the health of the public (Fromme et al., 2009).

People have a misconception that shisha smoking is less toxic, addictive and harmful than cigarette smoking, and, as a result users consider smoking shisha less harmful as compared to smoking cigarettes (Asfar et al., 2005; Smith-Simone et al., 2008). A recent survey amongst college students in Britain illustrates that students consider shisha as an affordable and relaxing way to enjoy friend and family gatherings (Roskin and Aveyard, 2009). Perception of adverse effects associated with shisha smoke was also varied between employees as a study in New Zealand identified that only 61% of employees knew about the second-hand smoke and believed that there may be links associated between the adverse health risks and second-hand smoke (Jones et al., 2001). Students and younger people also think that shisha smoke is not harmful, as nicotine and other contaminants from the smoke is believed to be dissolved and purified in the water within the shisha bowl (Martinasek et al., 2011)

Nonetheless, research has shown that the amount of smoke inhaled by the smoker smoking shisha is greater than smoking cigarettes; hence the consumer ends up taking large amount of contaminants from the shisha (Eissenberg et al., 2008). Knishkowy and Amitai (2005) research illustrates that shisha smoking exposes people to similar health risks as cigarette smoking (Knishkowy and Amitai, 2005). A recent study by Maziak (2011) illustrated that shisha tobacco smoking is a leading preventable cause of mortality and morbidity, and also a leading cause of premature death in million of smokers worldwide. The most important health effect associated with acute toxicity after shisha smoking is due to the effects of high CO during the smoking session (Fromme and Schober, 2015). Several cases of CO poisoning have been reported worldwide associated with shisha smokers (Arziman et al., 2011; Enghag et al., 2011). Other acute health effects associated with shisha smoking have been linked to short-term effects on the pulmonary function (Kiter et al., 2000; Raad et al., 2011) and changes in the oxidative and inflammatory markers in the lung (Khabour et al., 2012; Fromme and Schober, 2015). Smoking shisha is also associated with increased cardiovascular risk (Al-Kubati et al., 2006; Blank et al., 2011; Hakim et al., 2011; Kadhum et al., 2015), as it produces acute increase of blood pressure, heart rate (Kadhum et al., 2014), reduction of heart rate variability (Cobb et al., 2012), reduction of high-density lipoprotein (HDL)-cholesterol and apolipoprotein (apo) A1, whilst increasing low-density lipoprotein (LDL)-cholesterol, apo B, triglycerides and malondialdehyde (Al-Numair et al., 2007). There is also increased risk of infection with herpes, hepatitis and tuberculosis after smoking shisha (Kadhum et al., 2015). Epidemiological evidence around the world also shows that there are statistically significant associations between smoking shisha and long term health effects. For instance, shisha smoking doubles the risk to develop lung cancer, respiratory illness and low birth weight (Akl et al., 2010). A recent study in the Kashmir valley of India has shown that shisha smoking increased the risk of lung cancer by 6- fold as compared to non-smoking (Koul et al., 2011).

Moreover, shisha smoke within shisha premises is not only a risk to the smokers, but also to employees, members of public and non-smokers who are exposed to environmental tobacco smoke (ETS) emitted from lit shisha tobacco and charcoal. A recent field based research conducted in Florida (USA) has shown the amount of CO concentrations in personal breathing of non-smoker subjects visiting shisha places was significantly higher (28.5 ppm) as compared to non-smokers visiting traditional bars (8.0 ppm) (Barnett et al., 2011). Similarly, carboxyhaemoglobin concentrations in shisha smokers were greater (10%) compared with cigarette smokers (6.5%) and non smokers (1.6%) (Fauci et al., 2012). This is consistent with studies that shown that shisha ETS consists of a mixture of various harmful pollutants such as carbon monoxide (CO), ultrafine particles (UFP), particulate matter ($PM_{2.5}$ and PM_{10}), black carbon (BC), nitrogen oxide (NO) and nitrogen dioxide (NO_2), volatile organic compounds, volatile aldehydes – including the carcinogens formaldehyde and acrolein-, polycyclic aromatic hydrocarbons – including the carcinogen benzo-a-pyrene–, nicotine, furans and phenols (Al Mutairi et al., 2006; Sepetdjian et al., 2008; Fromme et al., 2009; Daher et al., 2010; Cobb et al., 2012; Fromme and Schober, 2015; Kadhum et al., 2015).These pollutants are at higher concentrations in shisha premises compared with outdoor environments (Fromme and Schober, 2015), as evidenced by a recent study in Canada which found mean concentrations of 1,419 $\mu g/m^3$ for $PM_{2.5}$ and 17.7ppm (20.3 mg/m^3) for CO inside shisha premises whereas in outdoor patios levels reported were 80.5 $\mu g/m^3$ for $PM_{2.5}$ and 0.5 ppm (0.57 mg/m^3) for CO for 2-hour period (Zhang et al., 2015). Fromme et al (2009) found significant concentrations of carcinogenic elements in shisha ETS environments during smoking compared to non smoking periods, such as arsenic, cadmium (<0.1 vs. 0.38 ng/m^3), thallium (<0.1 vs. 1.14 ng/m^3) and lead (<3 vs. 11.2 ng/m^3). High levels of all of these pollutants within an enclosed area creates a poor indoor air quality and exposes the public (including the non- smoker and employees) to serious risks including carbon monoxide poisoning, low birth rate in pregnant women, harmful cardiac arrest and cardiovascular diseases, bronchial asthma, lung cancer and other respiratory associated illness (Fromme et al., 2009; Akl et al., 2010).

This study aimed to assess the public health situation by evaluating the extent of shisha environmental tobacco smoke exposure among those that work in, and are customers of shisha businesses. This study measured the levels of several ETS pollutants such as $PM_{2.5}$ and CO in shisha premises, background nearby sites and other hospitality indoor premises; and assessed the risk perception within patrons and managers of shisha premises in order to determine harm reduction interventions and measures to minimise the effect of shisha ETS on those that are exposed to such environments.

2. MATERIALS AND METHODS

2.1. Sampling methodology

Concentrations of CO and $PM_{2.5}$ were collected simultaneously for 60 minutes in twelve shisha premises during the busy working hours between March and June 2014. Environmental Health officers at the local city council requested permission to conduct sampling to the shisha premises managers 24 hours prior to visits. Concentrations of both compounds were collected first inside and then background ambient levels were measured at the fire assembly areas of the premises (20-30 m far). Problems were experienced with the $PM_{2.5}$ sensor, and concentrations of $PM_{2.5}$ are only available for nine premises. Number of customers smoking shisha and number of shisha pipes alight was also recorded during the sampling period.

During the same period concentrations of both pollutants were also collected for 60 minutes inside five pubs/restaurants with similar characteristics, but where no smoking was undertaken.

2.2. Sampling Equipment

CO concentrations were collected using an Aeroqual sensor 500 (Aeroqual Ltd, New Zealand) fitted with a CO gas sensitive semiconductor head at 1 minute interval. The sensor is capable of measuring CO from 0 to 1000 ppm with a 1ppm resolution providing an accuracy of ±10%.

$PM_{2.5}$ concentrations were measured using a RTI MicroPEM nephelometer light-scattering sensor (RTI International, USA) at 10 second interval (Rodes, 2011). The sensor contains an inner 25mm Teflon filter used for internal correction of the sensor readings. The internal filters were weighted prior and after sampling collection according to standard procedures in the laboratory (Delgado-Saborit, 2013). The sensor has a limit of detection of 3.6 µg/m^3 (Rodes, 2011).

2.3. ETS risk perception among owners/managers

Owners and managers of shisha premises were administered a structured questionnaire to determine levels of ETS knowledge and its associated health risks. The questionnaire contained questions such as “Are you aware of second hand smoke exposure to your employees and consumers?”; “Does the shisha premises have suitable ventilation to prevent the build up of toxic/hazardous gases?”; and “Do you have proper risks assessments for toxic gases or any other hazards within your premises?” (See Appendix 1 SI).

2.4. Statistical analysis

Data analysis was completed using the statistical software SPSS version 20.0. Kolmogorov-Smirnov test (K-S test) was used to test for normality. Paired t-tests were used to analyse significant differences between the CO and $PM_{2.5}$ concentrations inside and outside shisha premises. Independent t-tests were used to analyse any significant statistical differences between the concentrations of CO and $PM_{2.5}$ inside shisha premises and inside pubs/restaurants. Pearson correlation was used to determine the extent of linear relationship between CO and $PM_{2.5}$

measured inside and in the corresponding background locations. Linear regression was employed to describe relationships between CO and $PM_{2.5}$ concentrations with potential explanatory variables, such as the number of active shisha pipes during the visit. The level of significance for the tests was set at 0.05 (95% confidence level).

3. RESULTS

3.1. $PM_{2.5}$ and CO concentrations

Concentrations of $PM_{2.5}$ and CO measured inside shisha premises and outside shisha premises at the fire assembly areas are shown in Table 1 and 2 respectively. Table 3 shows concentrations of $PM_{2.5}$ and CO indoors in local pubs/restaurants.

It is noticeable a reduction of $PM_{2.5}$ concentrations from locations sampled during March, which record the highest concentrations, to concentrations measured in April - medium concentrations - and in May/June, where the lowest concentrations are measured. This suggests that the shisha smoking activity has decreased during the summer time as compared to winter period and/or that the premises sampled during the summer months were better ventilated.

Table 1 and 2 show large differences between $PM_{2.5}$ and CO concentrations measured indoors in shisha premises and background locations. On average, 60-min concentrations inside shisha premises are 8 times ($PM_{2.5}$) and 11 times (CO) higher than outdoor background levels ($PM_{2.5}$: 287 vs 34 μg/m^3; CO: 6.96 vs 0.65 mg/m^3) and 13 times ($PM_{2.5}$) and 9 times (CO) higher than pub/restaurant concentrations ($PM_{2.5}$: 287 vs 23 μg/m^3; CO: 6.96 vs 0.75 mg/m^3). Paired sample t-test confirms that there are significant differences between $PM_{2.5}$ and CO concentrations measured inside shisha premises and adjacent outdoors by the fire exit for any 15-min (CO), 30-min ($PM_{2.5}$) interval or 60-min (CO and $PM_{2.5}$) with a p-value <0.01.

Pearson coefficient also confirms that $PM_{2.5}$ concentrations measured indoors and outdoors of the shisha premises are strongly correlated (R=0.957, p=0.000) as shown in Figure 1, suggesting that indoor air is leaking outdoors and contributing to enhanced $PM_{2.5}$ concentrations in nearby outdoor locations. Concentrations of $PM_{2.5}$ measured at several urban background and urban traffic sites within the UK ambient reference monitoring network are considerably lower than those measured outdoors of the shisha premises during the same sampling period. Acocks Green and Tyburn, two urban background sites located 8.6 km SE and 7.8 km NE respectively of the location of the shisha premises, measured an average of 5.2±1.4 $\mu g/m^3$ and 5.8±0.6 $\mu g/m^3$ respectively. Tyburn Roadside, which is an urban traffic reference site located 7.8 km NE of the shisha premises, measured an average of 5.9±1.9 $\mu g/m^3$ for the same period. The three ambient reference monitoring network sites show remarkably similar concentrations of $PM_{2.5.}$ The fact that these sites are located across Birmingham -10 km apart- and that they represent different types of monitoring stations (i.e. background and traffic roadside) suggests that the $PM_{2.5}$ concentrations in Birmingham show little spatial variability, as observed in other cities (Adgate et al., 2002; Lee et al., 2011). No correlation was observed between $PM_{2.5}$ concentrations measured at reference sites and $PM_{2.5}$ concentration measured at the outdoor background locations nearby shisha premises.

No correlation was observed between CO concentrations measured inside shisha premises and those concentrations measured at adjacent ambient background locations.

Independent t-test results ($p<0.01$) show statistical significant differences between $PM_{2.5}$ and CO concentrations measured inside shisha premises and indoors in pubs/restaurants with similar number of customers and cooking facilities, suggesting a strong effect of smoking shisha to poor indoor quality inside shisha premises.

3.2. Association between indoor air quality with number of active shisha pipes

All shisha premises (n=12) were found enclosed with a fixed roof and surrounded walls with windows and doors not complying with the 50% rule of Smoke free Regulations 2006 (Public_Health_England, 2006). On average shisha smoking sessions lasted around 60 minutes with 1 shisha pipe being shared between 3 to 4 customers (Table S2 Supplementary Information).

The highest number of active shisha pipes and customers was found in shisha lounge C, which also featured the highest number of $PM_{2.5}$ (Table 1) and CO concentrations (Table 2).

Results of a regression analysis (Figure 2) suggest that the number of active shisha pipes is a strong predictor of the concentrations of $PM_{2.5}$ inside the shisha premises explaining 76% of the variability of $PM_{2.5}$ concentrations indoors. The number of active shisha pipes was less correlated with CO concentrations and was only able to explain 30% of the variability of CO concentrations inside shisha premises.

3.3. Risk perception of shisha smoking

Out of 12 shisha premises owners only 3 owners/managers from A, F and J shisha premises knew about the secondhand smoke (ETS) and their associated health risks. The remainder 75% of the managers of shisha premises did not recognized ETS from shisha smoking as a hazard, nor were aware of the importance of ventilation to prevent the building up of toxic and hazardous gases. This indicates a poor health and safety management and awareness level by the shisha premises owners and managers.

4. DISCUSSION

Results of this study have revealed elevated concentrations of CO and $PM_{2.5}$ inside shisha premises, which create a significant public health risk. This is consistent with results published around the world which show increased concentrations of $PM_{2.5}$, CO and other pollutants including polycyclic aromatic hydrocarbons, black carbon, airborne nicotine, nitrogen oxides and volatile organic compounds (Fromme et al., 2009; Zhang et al., 2015).

4.1. Impact of shisha smoking on $PM_{2.5}$ levels inside shisha premises

Inside the studied shisha premises, customers and employees were exposed to higher concentrations (Table 1) than those reported in a study across Europe conducted inside hospitality venues, such as night bars, restaurants and bars, where tobacco smoking was permitted ($PM_{2.5}$

median =120 μg/m^3) (López et al., 2012). A similar study measured $PM_{2.5}$ levels for 30 minutes and found average concentrations of 198 μg/m^3 with only one reading exceeding 220 μg/m^3, which are much lower than our research findings for 30 minutes average(Table 1) (Fiala et al., 2012). On the other hand, higher concentrations were measured in a similar study in Canada (1,419 μg/m^3) for a 2-hour session inside shisha premises (Zhang et al., 2015), consistent with a recent study in shisha bars in New York city (Zhou et al., 2014), where real time $PM_{2.5}$ concentrations was 1,180 ± 940 μg/m^3. A study conducted in Germany (Fromme et al., 2009) also reported mean $PM_{2.5}$ concentrations of 406 μg/m^3 with a range between 125 and 737 μg/m^3. These three studies represent examples of the high levels of $PM_{2.5}$ concentrations that might be found inside shisha premises potentially raising health concerns. A recent review by the World Health Organization found supporting evidence to link peak exposure to combustion related particulate matter with acute health effects (WHO, 2013). This is consistent with a study that found associations between short term exposure to combustion aerosol with a decrease of heart rate variability in healthy older adults (Fan et al., 2008). It is also consistent with a study conducted in Beijing, which found an association between peak $PM_{2.5}$ exposure and cases of influenza (Liang et al., 2014), in where the authors attributed the findings to an association between disorder in the host defenses and increased inflammation in the respiratory tract (Pinkerton et al., 2000; Yin et al., 2005; Xie et al., 2013).

Findings of this research also show a strong correlation (R=0.935) between the inside and the background $PM_{2.5}$ levels (adjacent outdoors) of shisha premises. Indoors vs background readings from the Canadian research are consistent with our results (Table 1), showing concentrations in the background around 21 μg/m^3 against 1,419 μg/m^3 $PM_{2.5}$ inside the shisha premises for a 2-hour session (Zhang et al., 2015). The fact that ambient $PM_{2.5}$ measured by the national air quality monitoring network in several locations across Birmingham - including sites representative of traffic, such as Tyburn Roadside - are considerably lower than those concentrations measured outdoors nearby the shisha premises, combined with the strong correlation between indoor and outdoor nearby $PM_{2.5}$ concentrations, suggests that shisha smoke indoors is leaking out into the environment and contributing to increased $PM_{2.5}$ concentrations in nearby outdoor locations. No other possibly local sources contributing to high levels of $PM_{2.5}$ nearby shisha premises (including traffic) were identified in further investigations. The leakage of indoor air from shisha premises outdoors could affect the health of local public causing potential harm to neighborhood and environment and might raise environmental issues for local communities.

4.2. Impact of shisha smoking on CO levels inside shisha premises

Statistical analysis show significant differences between CO concentrations measured inside shisha premises and those measured in ambient air adjacent to the shisha premises (Table 2), as well as different from those measured in local pubs/restaurants of similar characteristics (Table 3), indicating that smoking shisha inside shisha premises causes a detriment of the indoor air quality. WHO indoor air quality guideline recommends maximum limits for indoors CO exposure of 35 mg/m^3 for 1 hour average and 100 mg/m^3 for 15 minutes (WHO, 2010). Workplace exposure limits set up by the Health and Safety Executive (HSE) in UK recommends 232 mg/m^3 for 15 minutes and 35 mg/m^3 for 8-hour reference periods (HSE, 2011). Similarly, Health Canada's Residential Indoor Air Quality Guideline recommends 28.6 mg/m^3 of CO for 1-hour average (Health_Canada, 2014). According to our average concentrations (Table 2) no serious risks can be found inside shisha premises associated to CO exposure levels at 15 minutes and 1-hour average (WHO, 2010; HSE, 2011; Health_Canada, 2014). However, considerably higher CO concentrations were found in New York City shisha bars (Zhou et al., 2014), where CO concentrations were reported to be 40±20 mg/m^3. This is also consistent with a study by Daher et al (2010) where concentrations of 2,269 mg of CO in shisha side stream smoke was recorded per number of water pipe smoked(Daher et al., 2010). Although the concentration of CO measured in this study show no serious risk to health, the high levels of CO reported in other studies (Daher et al., 2010; Zhou et al., 2014) suggest that smoking shisha in indoor spaces is likely to exceed current guidelines and become a significant health risk for shisha employees and shisha premises customers.

4.3. Association between levels of $PM_{2.5}$ and CO with number of active shisha pipes

In order to determine any relationship associated between the exposure levels of $PM_{2.5}$ and CO inside the shisha premises with active shisha pipes, linear regression analysis was carried out for CO (n=12) and $PM_{2.5}$ (n=9) 60-min concentrations against the number of active shisha pipes observed during the visits. Figure 2 shows a positive relationship between the levels of $PM_{2.5}$ and CO with number of shisha pipes, although stronger for $PM_{2.5}$ (R^2=0.757, $p<0.05$) as compared to CO (R^2=0.297, p=0.062). This analysis shows that shisha smoking is the main source emitting $PM_{2.5}$ matter inside shisha premises, which is consistent with physical observations during the visits as the indoor air within the shisha premises was always found to be very smoky. This result is consistent with data reported by Shihadeh and Saleh (2005) where a linear correlation was found between mass of tobacco consumed during shisha smoking and total particulate mass measured in the shisha mainstream smoke aerosol (Shihadeh and Saleh, 2005).

On the other hand, the relationship between the levels of CO and the use of active shisha pipes inside the shisha premises shows a positive weak but not statistically significant correlation, which might be a consequence of the small number of samples considered in the analysis. Overall, the results suggest that the number of shisha pipes, as a source of CO emissions, could be marginally contributing to CO concentrations indoor shisha premises. This is consistent with a study by Shihadeh and Saleh (2005) where they reported 143 g of CO emitted by a session of 171-puffs of shisha pipe consuming 4.7 g of tobacco.

On the other hand, the amount of CO within the shisha premises could also be associated to tobacco smoke burning, as evidence of cigarette butts were observed in the premises (see SI).

Nonetheless, the most likely source of CO emissions in shisha premises might arise from charcoal. A research carried out by the aerosol research laboratory in the American University of Beirut showed that ca 90% of the CO emissions are due to charcoal burning inside the shisha premises (Monzer et al., 2008). During our data collection, it has been observed that all charcoal cubes were prepared on barbeque stands with the help of hairdryers and bowl shaped vessels were used to hold the burning charcoal for shisha use (see Figures S1-S3). The presence of CO potentially associated with charcoal combustion manifest the relevance of additional health risks associated with socialising in shisha smoking premises far beyond those directly attributable to tobacco smoking, consistent with trends observed elsewhere (Knishkowy and Amitai, 2005; Martinasek et al., 2011).

5. CONCLUSION

According to the results of this study, customers (including any non-smokers) and employees within shisha premises are exposed to consistently elevated concentrations of $PM_{2.5}$ and CO levels. These high levels might pose a health risk for those working or socializing inside shisha premises according with recent studies (Fan et al., 2008; Liang et al., 2014). The elevated concentrations of pollutants inside the shisha premises are significantly associated to the use of shisha pipes and charcoal preparation procedures. In addition, the amount of $PM_{2.5}$ levels has been identified as a potential local community environmental issues according to the statistical correlation between indoors and adjacent outdoor $PM_{2.5}$ concentrations. Therefore, there is strong evidence that shisha premises are contributing towards pollution of the local environment, which might seriously affect the health of local people, especially those groups considered at risk leaving nearby shisha premises. This research has found that shisha smoking has been practiced inside confined spaces, having less than 50% open space as required by current UK regulations. It also found that only 25% of the shisha premises managers demonstrated awareness of shisha smoking contributing to environmental tobacco smoke and its associated health harms. Overall findings of this research suggest that shisha smoking not only poses a general health and safety problem for employees and customers of such premises, but also to the general public in nearby environments.

Shisha premises differ from most businesses in that their sole business is from smoking. With such high levels of indoor pollutants found within these premises that have the potential to cause short and long term harm to employees and customers, these businesses should undertake interventions to ensure the safety of its workforce and customers.

There is a general lack of shisha related policies and regulations in many developed countries, and there is lack of resources for enforcement of policies in developing countries (Maziak et al., 2014). Public health policies, such as regulations to reduce tobacco consumption in indoor public spaces and increased tobacco taxes have also been very successful to reduce cigarette smoking and protect the general public from tobacco exposure(Maziak et al., 2014).

Although the current research was conducted in UK, these results are likely to be representative of the situation experienced elsewhere due to the increased popularity of shisha smoking in countries around the world.

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Table 1 – $PM_{2.5}$ concentrations recorded at the different shisha premises inside and outside at the fire assembly areas of the shisha premises (background levels).

Shisha premises (n=12)	**Date visited**	**Inside**			**Outside**		
		$PM_{2.5}$ (μg/m^3) (30 min)[(a)]	**$PM_{2.5}$ (μg/m^3) (1 hr)**	**$PM_{2.5}$ Range (μg/m^3)**	**$PM_{2.5}$ (μg/m^3) (30 min)[(a)]**	**$PM_{2.5}$ (μg/m^3) (1 hr)**	**Range (μg/m^3)**
A (1)	20/03/2014	513	561±390	34 - 3278	51	51±6	43 – 116
B (2)	20/03/2014	381	399±413	3 - 2902	48	48±5	41 – 74
C (3)	20/03/2014	445	647±1,079	3 - 9928	46	46±4	41 -72
D (4)	27/03/2014	420	441±814	83 - 11452	49	49±12	43 -109
E (5)	03/04/2014	250	234±142	110 - 1071	33	29±10	13 – 115
F (6)	03/04/2014	141	159±78	69 - 977	26	26±6	13 – 56
G (7)	10/04/2014		-	-		-	-
H (8)	06/05/2014		-	-		-	-
I (9)	06/05/2014		-	-		-	-
J (10)	22/05/2014	41	37±30	3 - 196	24	24±16	3 – 98
K (11)	12/06/2014	55	56±20	3 - 102	17	17±29	3 -187
L (12)	26/06/2014	46	46±9	28 - 82	18	18±9	3 - 55
	Mean	**255**	**287±330**	**37 – 3332[(b)]**	**35**	**34±11**	**22 – 98[(b)]**

(a) Concentration representative of the first 30 minutes of sampling. (b) average min – average max (b) Average min – average max

Table 2 – CO concentrations recorded at the different shisha premises inside and outside.

Shisha premises (n=12)	Date visited	Inside			Outside		
		CO (mg/m^3) (15 min)[a]	**CO (mg/m^3) (1 hr)**	**Range (mg/m^3)**	**CO (mg/m^3) (15 min)[a]**	**CO (mg/m^3) (1 hr)**	**Range (mg/m^3)**
A (1)	20/03/2014	7.5	6.8±2.9	2.4-13.2	1.7	0.9±0.8	0.0-2.4
B (2)	20/03/2014	3.8	4.5±2.8	1.1-13.6	1.7	0.9±0.8	2.4-31.0
C (3)	20/03/2014	8.3	13.7±7.3	3.2-35.0	0.0	0.0±0.0	0.0-0.1
D (4)	27/03/2014	10.4	7.9±4.9	2.0-23.5	0.2	0.1±0.5	0.0-3.9
E (5)	03/04/2014	7.3	6.9±4.3	1.4-21.4	0.9	1.2±1.7	0.0-6.1
F (6)	03/04/2014	4.4	4.3±3.6	0.1-14.6	0.3	1.7±2.9	0.0-10.0
G (7)	06/05/2014	8.6	6.7±3.1	0.3-12.8	0.5	0.3±0.9	0.0-3.4
H (8)	06/05/2014	10.1	6.3±3.8	1.3-18.7	1.7	0.9±1.3	0.0-4.3
I (9)	15/05/2014	4.7	5.2±3.8	1.7-20.4	1.7	0.8±1.3	0.0-3.9
J (10)	22/05/2014	9.5	8.6±3.3	4.4-21.6	0.7	0.2±0.7	0.0-3.4
K (11)	12/06/2014	8.3	8.7±2.6	4.4-13.6	0.1	0.6±1.2	0.0-4.1
L (12)	26/06/2014	4.5	3.9±1.6	1.6-8.0	0.4	0.2±0.4	0.0-1.2
	Mean	**7.3**	**7.0±3.7**	**2.0-18.0[b]**	**0.9**	**0.7±1.0**	**0.0-3.8[b]**

(a) Concentration representative of the first 15 minutes of sampling. (b) average min – average max

Table 3 – Indoor $PM_{2.5}$ and CO concentrations measured indoors in pubs/restaurants

Pubs (n=5)	**Date visited**	**$PM_{2.5}$ (µg/m^3) (1 hr)**	**$PM_{2.5}$ Range (µg/m^3)**	**CO (mg/m^3) (15-min)[(b)]**	**CO (mg/m^3) (1 hr)**	**CO Range (mg/m^3)**
1	21/03/2014	49 ±4	43 - 78	0.046	0.064±0.05	0 – 0.19
2	27/03/2014	40 ±13	2 - 132	0.31	1.73±2.92	0 – 10.04
3	26/05/2014	10 ±21	3 -266	0.71	0.19±0.67	0- 3.37
4	05/06/2014	7 ±5	3 – 26	0.89	0.6±0.26	0.24- 1.01
5	21/06/2014	9 ±5	3 – 37	1.32	1.15±1.05	0-3.34
	Mean	**23 ±9**	**9- 108[(a)]**	**0.65**	**0.75±0.99**	**0.05- 3.6[(a)]**

(a) Average min – average max (b) Concentration representative of the first 15 minutes of sampling.

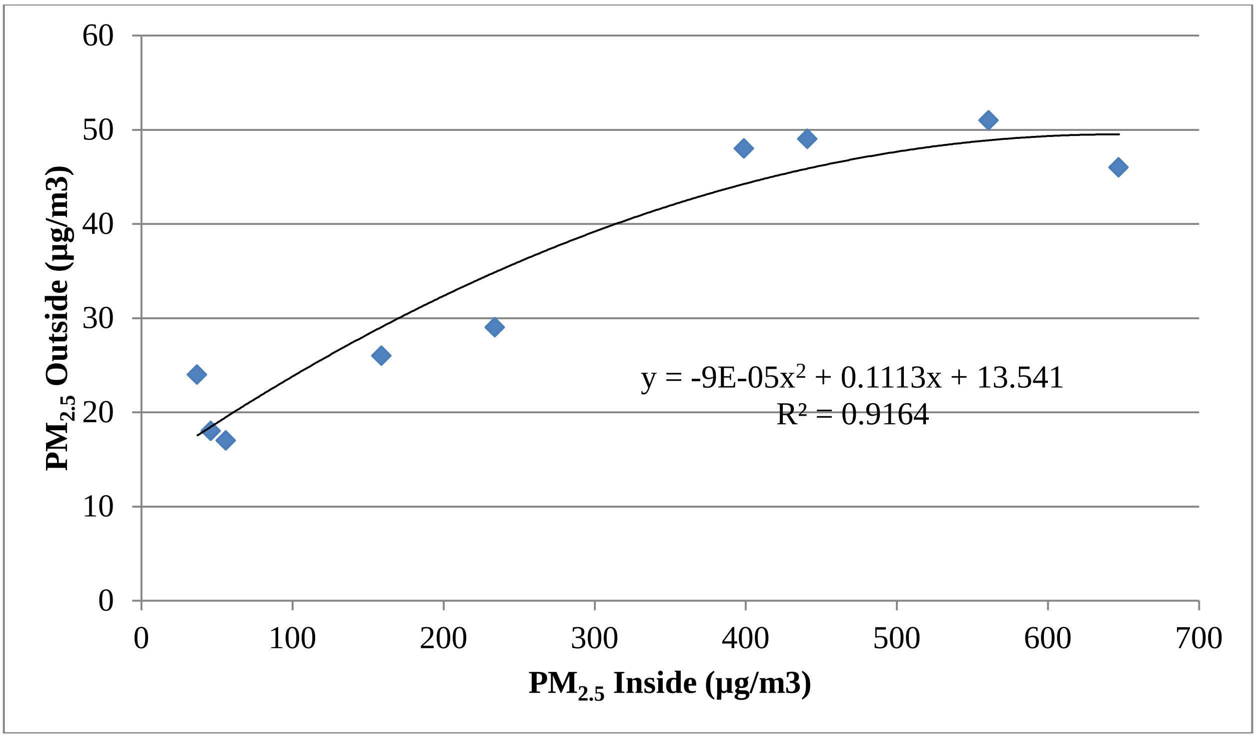

Fig.1 – Scatter graph showing the correlation between 60-min $PM_{2.5}$ levels (µg/m^3) inside shisha premises and background levels (outside shisha premises by the fire exit)

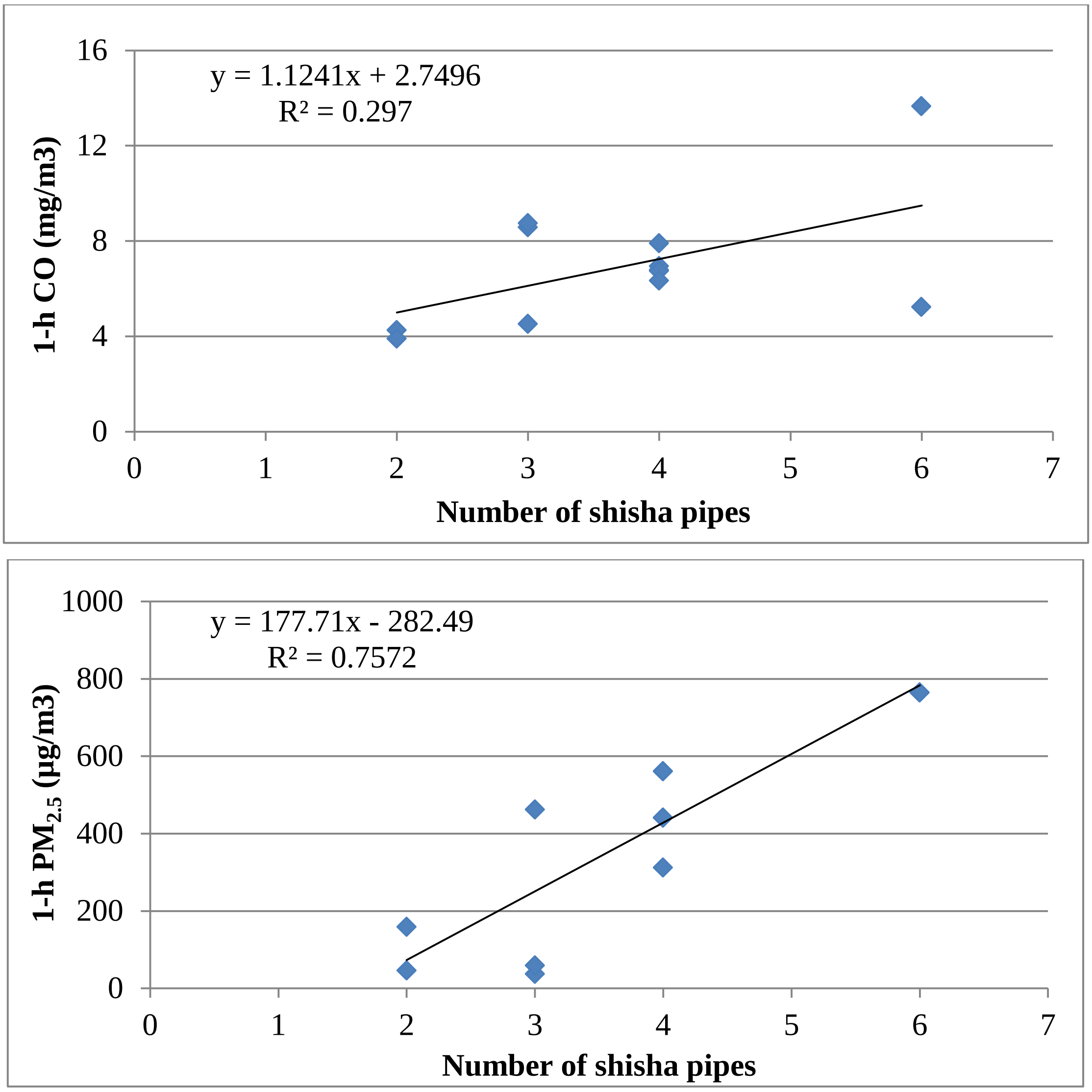

Fig.2 Linear regressions analysis between CO (top) and $PM_{2.5}$ (bottom) 1-hour concentrations and number of active shisha pipes.