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Evaluation of Impact of Tobacco Smoke on Indoor Air Quality

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Abstract

Total particulate matter (TPM), NO_2 and NH_3 were measured simultaneously in the smoking and non-smoking locations during an eleven month period from March 1986 to January 1987 at three sites in Chicago : Illinois Institute of Technology Cafeteria, Rush-Presbyterian St. Lukes Medical Center Cafeteria and a downtown office building. From this study, the mean concentrations of NO_2 and NH_3 were not significantly different between the smoking and non-smoking locations at any sampling site ; however, there was a statistical difference for TPM between the smoking and non-smoking locations. Activity factor was useful for describing the contribution from indoor source. The linear regression analysis was reasonable method for discriminating the individual contribution of source to determine the emission factor. The TPM emission factor determined from this technique was in good agreement with value from the literature.

1. INTRODUCTION

Many people spend large amounts of each day indoors(80~90%). Some individuals-the old, the very young and the infirm-who are most susceptible to the effects of pollutants may spend all their time indoors. Pollutant concentration levels indoors (e.g., residences, public buildings or offices) are sometimes higher than in the outdoor air. Sources of indoor pollution include the influx of polluted outdoor air ; geologic materials around the building and activities of the building's occupants such as cooking, cleaning, smoking and use of appliances ; and materials used in the construction of building and furnishing.

Nearly everyone is exposed to tobacco smoke (cigarette, pipe or cigar). Indirect exposure (i.e., exposure of non-smoker) is referred to as " pas-siveexposure" ," pas-sivesmoking" or" involuntary smoking" . Passive exposure to tobacco smoke will inevitably be in houses, offices and innumerable other locations. Sidestream smoke is primarily the unfiltered smoke emitted from an idl-ing cigarette, cigar or pipe. Tobacco smoke contains a great variety of potentially hazardous gases and particles. Possible adverse health effects of breathing tobacco smoke include lung cancer, respiratory illnesses in young children, decreased pulmonary function, decreased lung growth and exacerbation of angina (Crawford, 1988). Depending on smoking behavior, buring temperature and type of filter, the composition of mainstream smoke exhaled by a smoker varies substantially. A typical cigarette smoker inhales mainstream smoke 8~10 times, for a total of 24~30sec of a total 12 minute burning-time for a cigarette. Hence, the sidestream is produced during 96% of the total time a cigarette is lit, so the

sidestream smoke is the major component of ambient smoking (Neurath and Horstmann, 1973 ; Triebig and Zober, 1984). In a study of respirable particles inside and outside homes, smoking was found to be the major source of indoor particulate matter (Spengler et al., 1981).

The strength and nature of indoor emissions are often the most significant determinants of indoor air quality. The release rate of these emissions can be calculated if the usage rate of the source material and the emission factor associated with the process and material are known. The mass balance concept may also be used to determine emission rates from field data. When several sources of a contaminant are identified, the respective source emission rates may be estimated by multiple regression analysis (Franke and Wadden, 1987).

The scope of this research is to quantitatively measure the effect of tobacco smoke on indoor air quality. Simultaneous measurements of three tracers of tobacco smoke (total particulate matter, nitrogen dioxide and ammonia) were measured to evaluate it.

2. MATERIAL AND METHODS

2.1 SAMPLE COLLECTION

Total particulate matter (TPM), NO_2 and NH_3 were measured simultaneously in the smoking and non-smoking locations during an eleven month period from March 1986 to January 1987 at three sites in Chicago : Illinois Institute of Technology Cafeteria (IIT), Rush-Presbyterian St. Lukes Medical Center Cafeteria (RH) and a downtown office building (DO). The number of people present and number of people smoking were recorded every 15 minutes, which represents total burning-time of a cigarette. Avera-ge sampling time was 6 hours. Average flow rates for TPM, and NO_2 and NH_3 were 1.75 ℓ/min and 0.25 ℓ/min, respectively. During sampling, flow rate through the filter was checked houly with a rotameter, which was calibrated with a wet test-meter. Portable battery charg-ed pumps, sampling tubes for the collection of gases and pre-conditioned filters for the measurement of particulate matter were the essential parts used while sampling (Figure 1).

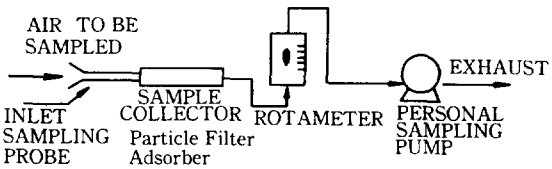

Fig 1. Schematic view of sampling flow train.

2.2 TOTAL PARTICULATE MATTER (TPM)

TPM samples were collected on polyvinyl-chloride membrane filter (0.8㎛ pore size, Gelman Science) in open face cassette with personal sampling pump (MSA company). Filters were conditioned in an incubator (Lab-Line Instruments) before and after sampling at <35℃ and 50% relative humidity for at least 12 hours. Subsequently, they were weighed on a Cahn electrobalance (Cahn Instrument). An additional adjustment of tare and final weights of polyvinylchloride membrane filters using three control filters was required (Neustadter et al., 1975). The masses of three control filters were determined along with the sampling filters. After weighing, filters were placed in petri dishes and left in the incubator prior to sampling. Three filters were used for each sampling session (a blank, a smoking and a non-smoking filter). The control filters were reweighed along with the sampled particle filters after post sampling conditioning.

2.3 NITROGEN DIOXIDE (NO_2)

NO_2 was measured by NIOSH Method (NIOSH, 1984). A known volume of air was drawn through a sampling tube (SKC, Inc.) containing 400mg of triethanolamine (TEA)-impregnated molecular sieves followed by a backup section of 200mg of TEA-impregnated molecular sieves. After sampling, the molecular sieve sections were transferred to a 50mℓ volumetric flask, and NO_2 was desorbed with aqueous TEA solution (15g TEA and 0.5mℓ n-butanol in 1 ℓ of distilled water). A 10mℓ ali-quot was treated with 1.0mℓ of 0.02% hydrogen peroxide, 10mℓ of sulfanilamide solution (10g of sulfanilamide and 25mℓ of phosphoric acid in 500mℓ of distilled water) and 1.4mℓ of NEDA so-

lution (0.5g of N-(1-naphthyl)-ethylenediamine dihydrochloride diluted to 500mℓ of distilled water). The reacted nitrite ion was measured spectrophotometrically (B.L Spectro-nic 70 Spectrophotometer, Fisher Scientific) at 540nm using a reagent blank to set zero absorbance. After calculating the blank corrected absorbances (blank corrected absorbance=meaured absorbance-blank absorbance), the amount of NO_2 collected could be determined from a previously prepared calibration curve. The calibration curve was performed by sampling a known concentration of NO_2 at a variety of flow rates and sampling durations.

2.4 AMMONIA (NH_3)

NH_3 was collected on a caustic carbon-silica gel adsorption tube (SKC, Inc) and quantitatively evaluated with a modified Nessler procedure (Vincent et al., 1978). The sampling tube consists of a 750mg section of caustic treated carbon followed by two sections of silica gel (1.25g for ammonia collection and 250mg for a back-up section). The caustic carbon section acts as a prefilter removing ethylenediamine (EDA) and monoethanolamine (MEA) while not affecting NH_3 concentration. After sampling, the silica gel sections were placed in a 25mℓ flask and desorbed with 10mℓ of 0.1N H_2SO_4. A 1.0mℓ aliquot of desorbed NH_3 solution was transferred to a 50mℓ volumetric flask, Nesslerized with 1.0mℓ of Nessler reagent and the ammonia concentration determined spectrophotometrically at 425nm. The Nessler reagent was prepared by dissolving 100g of mercury II iodide and 70g of potassium iodide in 125mℓ of ammonia-free water, and diluting to 1 ℓ. The calibration curve was also prepared with the same procedure as NO_2.

2.5 EFFECTIVE VENTILATION RATE

The effective ventilation rate was estimated by a tracer decay technique using the decay of sulfur hexafloride (SF_6) concentration. SF_6 is an unreactive substance ; not attacked by water, acids or bases at room temperature. Amount of SF_6 was released in the ambient air in the smoking and non-smoking areas at IIT. Samples were collected using vacutainer tubes (Bland Evacuated Blood Collection Tube) with a hyperdermic needle at hour intervals. SF_6 samples were analyzed with gas chromatograph (Series 3700, Varian) using the electron capture detector (ECD). The carrier gas was 5% methane and 95% argon composition which was run at 30 mℓ/min. The decay rate of tracer gas (SF_6) was described as follows (Wadden and Scheff, 1983) :

$$\frac{kq}{V} = -\ln\frac{C_f}{C_i}t^{-1} \quad (1)$$

where kq/V is the decay rate of SF_6 ($time^{-1}$) ; k is mixing factor ; q in volume/time is actual ventilation rate, V is indoor volume ; C_i and C_f are the initial and final concentrations of SF_6, respectively ; and t is the time interval between the initial and final measurements.

The effective ventilation rate kq (volume/time) can be determined by multiplying the indoor volume by the corresponding decay rate :

$$kq = (\text{Decay rate})\ (\text{Indoor volume}) \quad (2)$$

3. REULTS AND DISCUSSION

3.1 RESULTS

Table 1 lists the concentrations of TPM, NO_2 and NH_3 for the three sampling sites. The mean concentrations for TPM were 49.3, 139.7 and 104.4 $\mu g/m^3$ at smoking areas at IIT, RH and DO, respectively. Similarly, the mean concentrations for TPM at the non-smoking areas were 40.7, 72.2 and 89.4 $\mu g/m^3$ at respective sites. For NO_2, the mean concentrations at the respective smoking locations were : 16.6, 12.9 and 13.6ppb. The mean concentrations for NO_2 at the respective non-smoking sites were : 15.1, 11.1 and 11.9ppb. The mean concentrations of NH_3 for the smoking locations were:2.44, 0.59 and 0.52ppm at the corresponding sites. The mean concentrations for NH_3 at the respective non-smoking sites were : 2.24, 0.58, 0.70ppm. For RH, the smoking and non-smoking locations had the respective mean TPM concentrations of 139.7 and 72.2 $\mu g/m^3$, which shows the largest difference among sampling sites. This can be explained that at RH a physical partition exists between the smoking and non-

Table 1. Average concentration data for each location.

Location	Mean			S D[a]			Volume (m^3)
	TPM ($\mu g/m^3$)	NO_2 (ppb)	NH_3 (ppm)	TPM ($\mu g/m^3$)	NO_2 (ppb)	NH_3 (ppm)	
IIT[b]-S[c]	49.3	16.6	2.44	12.0	6.0	0.47	4650
IIT-NS	40.7	15.1	2.24	19.5	4.8	0.41	1080
RH-S	139.7	12.9	0.59	71.4	7.8	0.32	968
RH-NS	72.2	11.1	0.58	52.6	8.6	0.52	1740
DO-S	104.4	13.6	0.52	25.7	9.2	0.21	660
DO-NS	89.4	11.9	0.70	34.2	10.0	0.56	969

a SD=Standard deviation.
b IIT=Illinois Institute of Technology Cafeteria ; RH=Rush Hospital Cafeteria ; and DO=downtown office.
c S=smoking area ; and NS=non-smoking area.

Table 2. Effective ventilation rate at IIT.

Location	kq/V(hr^{-1})[a]	Volume(m^3)	kq (m^3/hr)[b]
IIT-S	0.61	4650	2836
IIT-NS		1080	659

a Average decay rate.
b Effective ventilation rate.

smoking areas ; where the areas are almost individual rooms themselves. The effective ventilation rates in the smoking and non-smoking areas at IIT were 2836 and 659m^3/hr, respec-tively (Table 2).

3.2 EVALUATION OF TOBACCO SMOKE BY SMOKING LOCATION AND SAMPLING SITE

Analysis of Variance (ANOVA) statistical technique was used to evaluate the concentrations between the smoking and non-smoking, and between sampling sites. ANOVA is to compare how the group means of a dependent variable are affected by the independent variables (Neter et al., 1985). In this study, the independent variables were the " smoking parameter" , which represents the smoking and non-smoking locations, and the sampling site. The dependent variables were the concentrations of TPM, NO_2 and NH_3. Tables 3~5 show TWO-WAY ANOVA results for testing the null hypothesis of no significant difference between group means for the smoking location and the sampling site effects. When the main effects are tested for the three pollutants, the probability of accepting the null hypothesis is that no significant difference exists between the smoking and the non-smoking locations. For TPM, NO_2 and NH_3, the probabilities of accepting the null hypothesis for the respective pollutants were : 0.035, 0.389 and 0.948, listed in the columns " F Prob." in Tables 3~5. These probabilities imply that there is 4%, 39% and 95% chance that the group mean concentrations are eq ual for the smoking locations compared with the non-smoking locations for TPM, NO_2 and NH_3, respec-tively. In other word, there is about 96%, 61% and 5% likelihood of rejecting the null hypothesis. Using the significance level at the α =0.05, as a standard of which statistical decisions are made, the mean concentration for NO_2 or NH_3 is not different between the smoking and non-smoking areas at any sampling site. However, the mean concentration for TPM is different between the smoking and non-smoking locations for at least one site. A similar analysis can be performed to test the effect of the sampling site on the mean concentration. The corresponding probabilities of accepting the null hypo-thesis, that the group mean conce-ntrtions are equal for the three sampling sites, were : 0.00, 0.20 and 0.00 for TPM, NO_2 and NH_3, respectively. From these results, the mean concentrations are significantly different for TPM and NH_3 based on the site of sampling, for at least one of the three pairs of sampling sites. However, the mean concentrations for NO_2 have a 80% chance of not being the same.

Table 3. Two-Way ANOVA of TPM by smoking location and sampling site.

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Ratio	F Prob.
Main Effects	3	42818	14273	8.25	0.000
Smoking[a]	1	8218	8218	4.75	0.035
Sampling[b]	2	34601	17300	10.00	0.000
2-Way Interactions	2	10765	5383	3.11	0.054
Residual	44	76101	1730		
Total	49	129684	2647		

a. For smoking and non-smoking locations.
b. For three sampling sites.

Table 4. Two-Way ANOVA of NO_2 by smoking location and sampling site.

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Ratio	F Prob.
Main Effects	3	237	79	1.37	0.266
Smoking	1	44	44	0.76	0.389
Sampling	2	194	97	1.67	0.200
2-Way Interactions	2	2.72	1.36	0.02	0.977
Residual	42	2428	58		
Total	47	2668	57		

Table 5. Two-Way ANOVA of NH_3 by smoking location and sampling site.

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Ratio	F Prob.
Main Effects	3	22.7	7.57	40.7	0.000
Smoking	1	0.0001	0.001	0.004	0.948
Sampling	2	22.7	61.1	61.1	0.000
2-Way Interactions	2	0.125	0.107	0.578	0.568
Residual	26	4.83	0.186		
Total	31	27.7	0.895		

3.3 DEVELOPMENT OF EMISSION FACTOR FOR TOBACCO SMOKE

Emision factor can be determined by measuring indoor concentrations, observing associated activity factors and interpreting indoor concentrations with a mass balance model (Franke and Wadden, 1987). Equation (3) describes the emission rate using the mass balance(Wadden and Scheff, 1983) :

$$S = C(kq + K_{dep}A) \quad (3)$$

where S is the emission rate in mass/time ; C in mass/volume is average indoor concentration ; kq, which can be calculated from equation (2), is effective ventilation rate in volume/time ; k_{dep} is the deposition velocity in length/time ; and A is area of contact. K_{dep} for particle was estimated to 0.38cm/min(Traynor et al., 1982). Activity factor describing the number of people smoking was recorded through each sampling period. Smokers are an estimate of the total number of cigarettes smoked. With the emission rate and source activity factor, a linear regression model can be used to determine the emission factor(Franke and Wadden, 1987) :

$$S = b_0 + b_1 X \quad (4)$$

where b_1 is the source emission rate per level of activity factor and X the total number of smokers (total number of cigarettes smoked). To arrive at the unit of mass/cigarette, the kq and k_{dep} A terms in equation (3) are multilied by the average indoor concentration, C, the unit of S becomes the total mass emitted during the sampling period. Therefore, the b_1 becomes mass emitted per cigarette, which is called the emission factor. The unit of b_0 represents the mass from other sources and other activity factors.

Table 6 shows the emission factor calculated for TPM which was only significant with associated activity factor. The TPM emission factor (17.1mg/cigarette) at IIT was close to that of the literature (25.8mg/cigarette) (Wadden and Scheff, 1983). The literature value, which was slightly larger, may be explained because the measurement was made directly from the buring ends of the cigarettes in the test chamber. This value, therefore, represents the complete combustion of test cigarettes compared to the field study which measured emissions from the actual fraction of the cigarettes smoked. The emission factors for NO_2 and NH_3 were not significant. Therefore,

Table 6. Source emission factor.

Location	Contaminant	Activity Factor	Emission Factor (㎎/cigarette)	R[a]
IIT	TPM	Cigarette[b]	17.1±6.1[c]	0.73
Literature[d]	TPM	Cigarette	25.8	
Literature[e]	NO_2	Cigarette	1.0±0.43	

a. Correlation coefficient.
b. Total number of cigarettes.
c. Standard error of regression coefficient.
d. Wadden and Scheff(1983).
e. Weber et al.(1979).

future studies should measure other variables that affect indoor concentration such as the outdoor concentrations.

4. CONCLUSIONS

The mean concentrations of NO_2 and NH_3 were not significantly different between the smoking and non-smoking locations at any sampling site ; however, there was a statistical difference for TPM between the smoking and non-smoking locations at least one site. The mean concentrations were significantly different for TPM and NH_3 based on the site of sampling, for at least one of the three pairs of sampling sites. However, the mean concentrations for NO_2 had a 80% chance of not being the same. Activity factor was useful for describing the contribution from indoor source. The linear regression analysis was reasonable method for discriminating the individual contribution of source to determine the emission factor. The TPM emission factor (17.1 ㎎/cigarette) determined from this technique with field data was in good a greement with value (25.8㎎ /cigarette) from the literature.

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