EMISSIONS OF AIR POLLUTANTS FROM BURNING OF INCENSE BY USING LARGE ENVIRONMENTAL CHAMBER

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ABSTRACT
A large environmental chamber with controlled temperature, relative humidity and air flow rate is used to investigate emissions of target air pollutants from incense, before, during and after burning. The target air pollutants include particulate matters ($PM_{10,}$ $PM_{2.5}$), volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2) and total hydrocarbons (THC). $PM_{2.5}$ and PM_{10} concentrations are measured using Dust-Trak portable samplers. Selected volatile organic compounds emitted are identified and quantified by Gas Chromatograph - Mass Selective Detector (GC-MSD). CO is analyzed with a Thermo Electron Gas Filter Correction CO Ambient Analyzer. SO_2 is measured using Pulsed Fluorescence SO_2 Analyzer and nitrogen oxides are monitored with Chemiluminescence NO-NO_2-NOx Analyzer. It is shown that the $PM_{2.5}$ and PM_{10} mass emission rates increased significantly during incense burning. The levels of CO, NO-NO_2-NOx, SO_2 and THC have also increased during the burning of incense. The results confirm that incense is a significant source of indoor pollution.

INDEX TERMS
Burning of incense, $PM_{2.5}$, PM_{10}, VOCs.

INTRODUCTION
The quality of air in non-industrial indoor environments such as houses, offices, schools, restaurants and shopping malls has become a subject of public concern (Lee et al., 2002). There are many sources of indoor air pollution including various outdoor sources, gas cookers, heaters, building and furnishing materials, and smoking (Guo and Murray, 2000). In which indoor combustion sources are one of the major air pollutant emissions. The example is the burning of incense. As a matter of fact, the potential indoor air impacts of burning incense have drawn increased attention in recent years. Burning of incense is a common practice in Hong Kong. They are burned in homes, office, shops, temples and churches.

Burning of incense will release a variety of toxic chemicals. Most incense is made from a combination of fragrant gums, resins, woods and spices. Incense was found to be a significant source of polycyclic aromatic hydrocarbons (PAHs), carbon monoxide, benzene, isoprene and particulate matters (Koo et al., 1992; Li et al., 1993; Madany and Crump, 1994; Li and Ro, 2000; Endo et al., 2000; Fan and Zhang, 2001).

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Some studies have been done in Hong Kong. Tung et al. (1999) found that PM_{10} concentrations in Hong Kong homes were 23% higher with smoking or incense burning. Another study conducted in urban homes in Hong Kong concluded that PAH levels in kitchens and living rooms increased due to incense burning (Koo et al., 1992). These studies were mainly focusing on the field investigations. The contribution of the burning of incense to the indoor air quality was not conducted. The emission rates of air pollutants from the burning of incense were not well characterised. Furthermore, incense burning produces a variety of air pollutants. Previous studies concentrated either particulate aerosols or heavy metals or PAHs and VOCs, few were focused on all of these air pollutants. Therefore, the objectives of this project are to:

- Characterise emissions of air pollutants from the burning of incense using a large environmental chamber; and,
- Qualify and quantify emissions from burning of incense with respect to particulate matters, VOCs, THC, CO, SO_2 and NOx, etc.

MATERIALS AND METHODS

Chamber experiments

The controlled experiments are conducted in a 18.26 m^3 stainless steel environmental test chamber maintained at 23 °C±0.4°C and 50%±5% relative humidity with an air exchange rate of 0.5859 per hour. Air samples can be drawn from the chamber via a suction pump into a canister to determine VOCs. The Dust-Trak portable samplers and IAQ-Trak monitor are put in the centre of the chamber to monitor particulate matters, temperature and relative humidity, respectively. A Telfon tubing connecting with CO analyzer, SO_2 analyzer, NO-NO_2-NO_x amalyzer and THC monitor is put in the chamber.

Sampling methods and analysis

The air pollutants investigated in this study included: carbon monoxide (CO), sulfur oxide (SO_2), nitrogen oxide (NO-NO_2-NO_x), volatile organic compounds (VOCs), airborne particulate matters with aerodynamic diameters less than 10 microns (PM_{10}) and 2.5 microns ($PM_{2.5}$), and Methane, Non-methane hydrocarbons (NMHC) and THC.

The incense tested was weighed using a micro-balance. The weight is 5.43 g. A detailed description of the method can be found in our previous publication (Lee et al., 2002).

Modelling of emissions of air pollutants

The emission rates and emission factors for the burning of incense were determined by using a single-compartment mass balance model (Fan and Zhang, 2001). The concentration of the pollutant in the chamber could be described with the following equations:

$$C = E(1-e^{-kt})/Vk \quad \text{(when } 0 \leq t \leq T), \quad (1)$$
$$C = C_{max}\,(e^{-k(t-T)}) \quad \text{(when } t > T), \quad (2)$$

Where C is the pollutant concentration (mg/m^3) in the chamber, E is the emission rate (mg/h), V is the volume of the chamber (m^3), C_{max} is the maximum pollutant concentration (mg/m^3) in the chamber, i.e., the concentration at the time when fire was extinguished, k is the pollutant removal rate (h^{-1}), t is time (h): t = 0 when the fire was started; t = T when the fire was extinguished.

The burning rate B (g/h) was easily obtained from amount (g) of incense burnt and the duration (h) of the burn, the emission factor E_f (mg/g) can be calculated using the following equation:

$$E_f = E/B \qquad (3)$$

RESULTS AND DISCUSSION

Chamber tests

Carbon monoxide

The temporal change of CO concentrations before, during and after incense burning is shown in Figure 1. CO concentration in the chamber was 0.91 ppm before burning of incense. After the incense was ignited, the CO concentration increased sharply from 0.91 to a maximum value of 34.52 ppm with 64 minutes. When burning of incense was completed, CO concentration was 5.04 ppm after 2 hours.

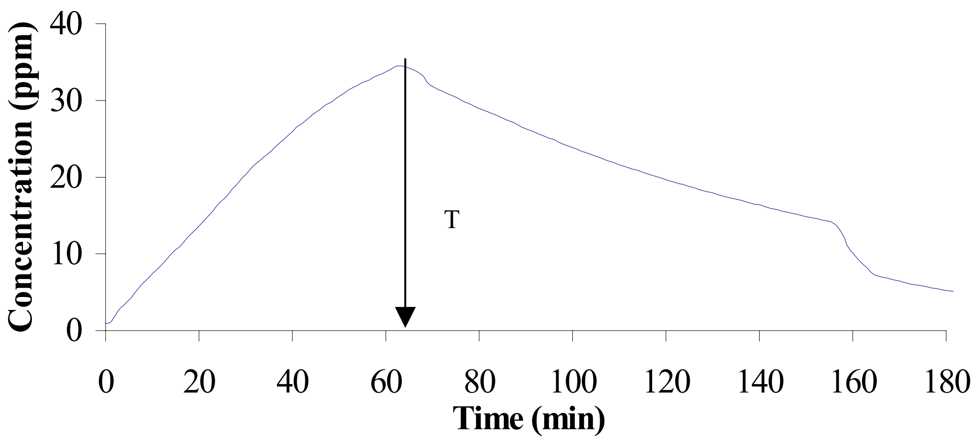

Figure 1 Temporal change of CO concentration with burning of incense

Sulfur dioxide

Figure 2 shows that the change of SO_2 concentration in the chamber with the burning of incense. It was found that the burning of incense increased the level of SO_2 in the chamber. The SO_2 concentration was only 0.001 ppm before the burning of incense. When the incense was ignited, the SO_2 concentration increased to the maximum of 0.092 ppm. One and half an hour after the completion of incense burning, the SO_2 concentration decreased to 0.011 ppm.

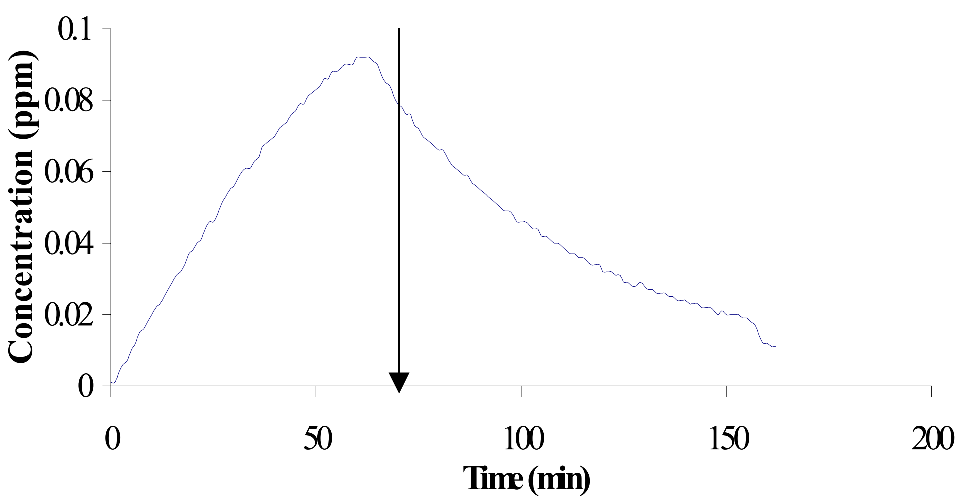

Figure 2 Temporal change of SO_2 concentration with the burning of incense

Nitrogen oxides

The change of NO-NO_2-NO_x concentration with time before, during and after incense burning is presented in Figure 3. Before incense burning, the NO_x concentration was 12.8 ppb. When the incense was ignited, the NO_x concentration increased to a maximum value of 207 ppb. 1.5 hours after the completion of incense burning, the NO_x concentration was still 79.3 ppb.

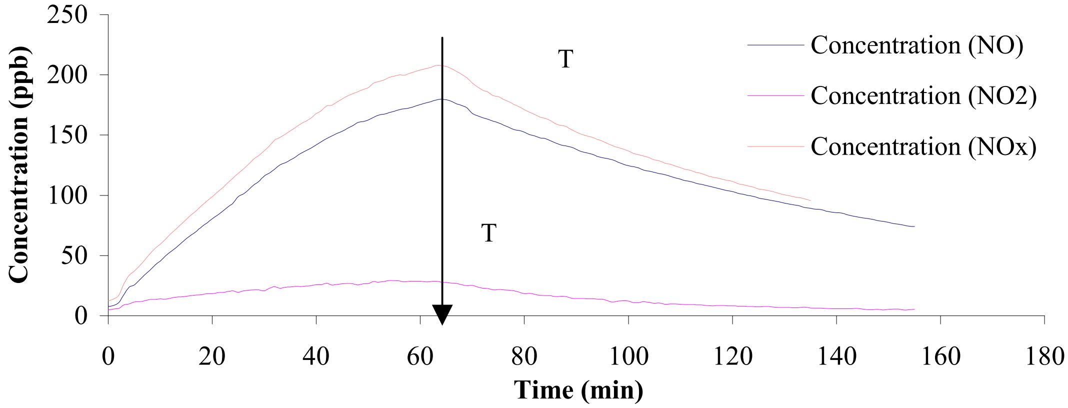

Figure 3 Temporal change of NO-NO_2-NO_x concentration with incense burning

$PM_{2.5}$ and PM_{10}

The mass concentration of $PM_{2.5}$ (particles with aerodynamic diameter less than 2.5 μm) in the chamber increased rapidly from 0.009 to a maximum value of 9.28 mg/m^3 when the incense was ignited (Figure 4). 1.8 hours after the completion of incense burning, the $PM_{2.5}$ mass concentration decreased slowly into 25% of the maximum concentration. PM_{10} mass concentration increased rapidly from 0.016 to the maximum of 13.47 mg/m^3 within 64 minutes with the burning of incense. The PM_{10} mass concentration reduced to 3.44 mg/m^3 1.8 hours after the completion of incense burning.

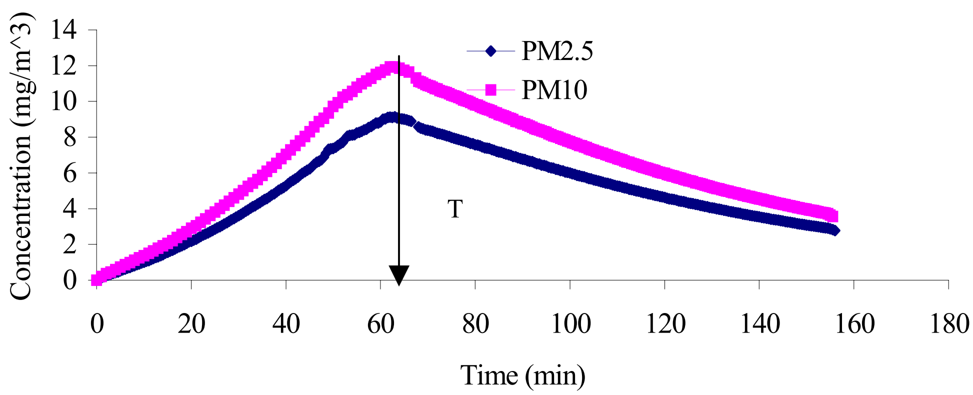

Figure 4 Temporal change of $PM_{2.5}$ and PM_{10} concentrations with incense burning

Total Hydrocarbons (THC)

Figure 5 showed the change of methane and non-methane hydrocarbons (NMHC) concentrations with the burning of incense. The THC concentration increased from approximately 3 ppm to a maximum value of 10.8 ppm during the burning of incense. 1.27 hours after the completion of incense burning, the THC concentration was 6.63 ppm. The change of THC concentration is mainly caused by the change of methane concentration.

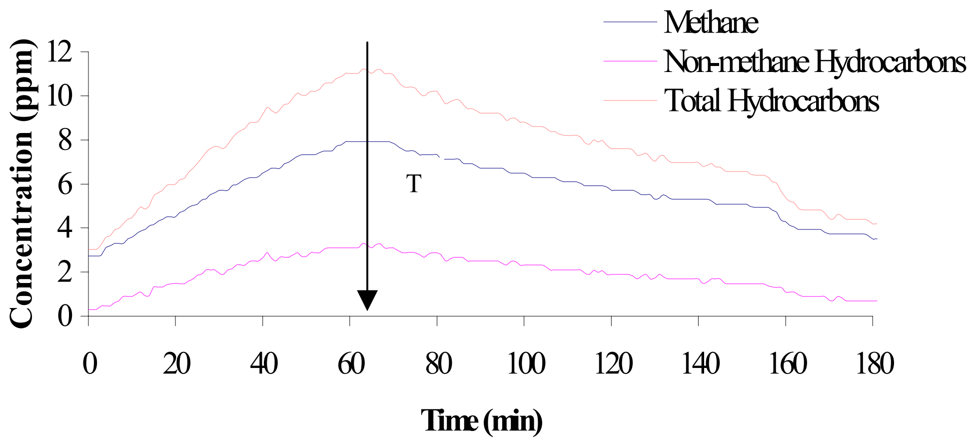

Figure 5 Temporal change of THC concentrations with incense burning

Volatile organic compounds (VOCs)
The sample before burning was a grab sample. Samples during and after burning were drawn at a flow rate of 32.27 ml/min for 64 min., respectively. Table 1 lists the temporal change of VOC concentrations before, during and after burning of incense. It was found that burning incense caused significant increase of benzene, toluene and 1,3-butadiene concentrations. For example, the average concentration of 1,3-butadiene increased from non-detectable to 158.52 ppbv when the incense was burning. The average concentrations of other individual VOCs e.g. ethylbenzene, m,p-xylene, styrene, o-xylene, methylene chloride and so on also increased with the burning of incense. The average concentration for most VOCs was even higher after burning than that during burning, indicating long term adverse effect on indoor air quality.

Table 1 Temporal change of VOC concentrations with the burning of incense

VOCs (ppbv)	Before burning	During burning[a]	After burning
Benzene	5.57	89.98	111.12
Toluene	2.87	35.28	48.30
Ethylbenzene	0.16	2.60	3.84
m,p-xylene	0.06	1.32	2.02
Styrene	0.10	3.82	7.86
o-xylene	0.06	0.46	0.68
1,3,5-trimethylbenzene	0.12	0.62	0.32
1,2,4-trimethylbenzene	0.07	0.42	0.76
1,3-butadiene	N.D.[b]	158.52	198.52
Methylene chloride	5.73	9.70	17.0

a: time between ignition and completion of incense burning. b: not detected.

Emission rates and emission factors

The emission rates and emission factors for the burning of incense are listed in Table 2. The results indicate that CO had the largest emission rate while the NO_2 had the smallest emission rate. The emission factors can be used to estimate total amount of the pollutants emitted from the burning of incense for a given time period.

Table 2 Emission rates and emission factors for the burning of incense

Incense burning	k (h^{-1})	Emission rate (mg/h)	Emission factor (mg/g incense)
CO	0.79±0.23[b]	1151±117.6	216±36.6
SO_2	1.02±0.10	8.03±0.28	1.51±0.16
NO	0.62±0.002	5.67±0.016	1.06±0.08
NO_2	3.12±0.64	2.48±0.16	0.46±0.06
NO_x	0.75±0.008	5.60±1.78	1.04±0.26
$PM_{2.5}$	0.79±0.035	245.7±0.62	46.08±2.99
PM_{10}	0.78±0.011	331.7±21.33	62.1±0.19
CH_4	0.72±0.19	93.07±16.93	17.56±4.36
NMHC[a]	0.77±0.22	141.02±32.09	26.64±7.80
THC	0.75±0.20	233.86±48.76	44.16±12.10

a. NMHC was converted by C_3H_8. b: mean± standard deviation

CONCLUSION

Preliminary chamber experiment indicates that incense burning generated a variety of air pollutants. The levels of CO, SO_2, NO_x, $PM_{2.5}$, PM_{10}, THC and some VOCs were increased due to the burning of incense. The results indicate that incense burning is a potentially significant source of airborne particulates and VOCs in indoor environments. Further investigation on emissions of PAHs and heavy metals will be also conducted.

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