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Trace Metals in Candle Smoke

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Burning candles and incenses is recognized as an important source of indoor air pollution (US EPA, 2001). Thus, US EPA (2001) is currently investigating their potential health risk as well as establishing the possible risk management options. Most of the Taiwanese burn candles and incenses for their religious worship every morning and evening. This behavior is believed to be an important factor for the higher incidence of nasopharyngeal or lung cancer in Taiwan (Chen et al, 1990; Yu et al. 1990). The investigation of health effects resulting from the candle or incense smoke has been focusing on organic compounds (Kao and Lung, 2000; Lin and Lee 1998; Lee and Lin 1996; Lin and Wang 1994; Lin and Tang 1994; Schoenotol and Gibbard 1967). However, some field studies imply that the organic compounds in the candle and incense smoke might not have significant influences on human health as expected (Chao et al. 1997; Lung et al. 2001).

Significant amount of lead, besides organic compounds, was found in candle smoke (Nriagu and Kim 2000; Van Alphen, 1999; Krause 1999). The reported emission rates of lead were substantially different and ranged from 1.1 to 2200 μg/hour (Nriagu and Kim 2000; Van Alphen 1999; Krause 1999). The enormous emission of lead was attributed to the usage of metal-core wicks (Nriagu and Kim 2000; Van Alphen 1999; Krause 1999). Van Alphen (1999) pointed out that only 7.6% to 32.8% (20 ± 8.6%) of lead in metal-core wicks was transferred into air if the wicks had been assumed to be the only source of lead emission during burning of candles. However, lead contamination in wick or wax was suggested as a probable cause as well (Nriagu and Kim 2000). The lead level in a child's blood could elevate significantly with regard to the deposition of lead particle emitted from candle burning through hand-to-mouth activities (ATSDR 1999; US EPA 1998; IPCS 1995). This phenomenon is particular frightening because the offerings will be ingested after worship rituals in Taiwan. The estimated population at risk is approximately four fifths of Taiwanese and continuing to increase owing to religious conversion (Lin 1997). A family engaged in this daily activity regularly burns about 40 g of candles in one day. These candles are cheaply manufactured in family-type factories whereas the total amount of production is unknown. A preliminary study shows that the concentrations of Cr, Mn, Ni, Pb, Zn in candle wax are 0.072 ± 0.057 μg/g, 0.09 ± 0.12 μg/g, 0.05

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0.098 μg/g, 0.57 ± 0.94 μg/g, 0.96 ± 0.95 μg/g, respectively (Lin el al. 2000). This finding reveals that toxic metals released during candle-burning may cause major health effects on Taiwanese. This study aims to evaluate the concentration of trace metals in candle smoke and its potential health risk with regard to religious worship in Taiwan.

MATERIALS AND METHODS

Candles used in this study were obtained from stores located in Hish-Chu City, Taiwan and were all manufactured in Taiwan. These candles were in shape of pillar with various dimensions (diameter: 8 ~ 35 mm; length: 20 ~ 300 mm). They were made of wax and cotton wicks and burned for Taiwanese everyday routine worship. It was noteworthy that the wicks of these candles were not metal-core wicks that were used in those candles studied by Nriagu and Kim (2000) or Van Alphen (1999)

The experimental system consisted of a combustion chamber made of polypropylene (60 x 60 x 60 cm), fresh air supply unit and moisture production unit as well as sample collection units. Before being introduced into the combustion chamber, the air was pumped through prepurifying tubes containing charcoal or molecular sieve in order to provide uncontaminated air for experiments. The moisture production unit was utilized to maintain the relative humidity of testing atmosphere. The airflow was controlled at 9000 ± 500 mL/min by adjusting needle valves. The relative humidity was monitored by a sensor (Cole-Parmer 37950-12), and was set to be 70 ~ 88 % which was similar to the ambient condition in Taiwan. The temperature of combustion chamber during candle burning was approximately 38 °C, which was about 5 to 10 °C above ambient temperature. The trace metals were collected by a 37-mm cassette with polyvinyl chloride membrane filter at a steady state for 120 minutes with a sampling rate of 1000 mL/min. The filters were dissolved by approximately 10 mL of heated concentrated nitric acid for 10 minutes and then the solutions were diluted to 100 mL. Three blanks were processed as the same procedure as that of the samples with the exception of no candle burning in order to estimate any possible contamination. These samples were analyzed using a Perkin-Elmer Elan 5000 ICP-MS. The operation conditions were as followed: 1. Carry gas: 0.8 L/min, 2. Plasma gas: 15 L/min, 3. Auxiliary gas: 0.8 L/min., 4. Pump rate: 1.5 mL/min., 5. Power: 1055 KW.

RESULTS AND DISCUSSION

The average emission rates of Cd, Co, Cr, Mn, Ni, Pb, Zn with regard to candle combustion in the test chamber are 0.18 ± 0.36, 0.05 ± 0.04, 2.9 ± 1.3, 0.37 ± 0.27, 1.5 ± 0.69, 2.0 ± 2.5, 6.5 ± 5.1μg/hour, respectively (Table 1). The emission rates of Pb and Zn vary from 0.16 to 9.68 and from 1.74 to 17.56 μg/hour, respectively, which are significantly lower than those reported by Nriagu et al. (2000) and Van Alphen (1999). The correlation coefficients between trace metals in candle smoke are calculated using a simple linear regression model and presented in Table 2. The relationships between Cr and Mn, Cr and Ni, as well as Pb and Zn are significant ($p < 0.05$). This observation is different from what was reported by Nriagu (2000) in that the emission of Pb does not increase with that of Zn.

Table 1. Heavy metal emission rates from candle combustion. (μg/hour)

Sample ID	Cd	Co	Cr	Mn	Ni	Pb	Zn
P092601	0.072	0.043	3.85	0.48	2.3	2.36	8.79
P092602	0.087	0.016	3.56	0.24	1.48	1.4	4.73
P092701	0.097	0.024	2.22	0.24	0.97	0.16	3.24
P092801	0.085	0.079	3.7	0.31	1.66	1.22	1.74
P010303	0.097	0.0099	1.68	0.14	0.51	0.42	2.45
P101901	1.33	0.023	2.64	0.15	1.03	0.93	2.78
P100301	0.07	0.04	5.09	1.09	2.25	1.63	9.13
P100401	0.021	0.055	4.83	0.31	2.65	2.67	14.6
P100601	0.094	0.03	2.47	0.54	2.16	1.97	6.05
P100901	0.07	0.17	1.7	0.16	0.99	1.67	4.49
P101301	0.085	0.046	2.29	0.5	0.9	9.68	17.56
P102001	0.008	0.058	1.18	0.22	1.04	0.19	2.59
average	0.18	0.05	2.93	0.37	1.50	2.03	6.51
standard deviation	0.36	0.04	1.26	0.27	0.69	2.54	5.10
N	14	14	14	14	14	14	14

Table 2. Correlation between trace metals in candle smoke.

	Cd	Co	Cr	Mn	Ni	Pb	Zn
Cd		0.21	0.08	0.25	0.23	0.13	0.24
Co	0.21		0.15	0.14	0.04	0.05	0.04
Cr	0.08	0.15		0.6*	0.82*	0.06	0.41
Mn	0.25	0.14	0.6*		0.57	0.27	0.45
Ni	0.23	0.04	0.82*	0.57		0.004	0.4
Pb	0.13	0.05	0.06	0.27	0.004		0.84*
Zn	0.24	0.02	0.41	0.45	0.4	0.84*	

*: significance ($p < 0.05$)

The concentrations of these metals in a room can be estimated with their emission rates and the following equation:

$$C_t = \frac{G-(G-QC_0)e^{-\frac{Q(t-t_0)}{V}}}{Q}, \quad (1)$$

where G is the emission rate, Q the ventilation rate, C_0 the concentration at t_0, and C_t the concentration at time t. The typical air exchange rate for home varies from 0.25 to 0.5 (Li et al. 1994; Trayer et al. 1987; Tu and Knutson 1988) except for winter when very little or no air exchange is a very common scenario. Considering that most of Taiwanese burns candle twice per day, the fluctuation of concentrations of Cd, Cr, Mn, Ni, Pb, Zn, at varying air exchange rate, can be simulated with equation (1). The estimated maximum concentrations of these metals in a 40 m^3 room in volume at AER 0 and 0.25, thus calculated, are shown in Table 3, respectively.

Table 3. Estimated maximum concentrations (ng/m^3) of trace metals in a 40 m^3 room at AER = 0.25 or 0.

	AER = 0.25	AER = 0
Cd	14.2	36
Cr	228	580
Co	3.88	9.85
Mn	29.2	74
Ni	118	300
Pb	158	400
Zn	513	1300

*Two candles burning simultaneously

Inhalation of high levels of cadmium oxide fumes causes tracheobronchitis, pneumonitis, and pulmonary edema (Donkin et al. 2000). The exposure to cadmium chloride is persuasively associated with increased frequency of lung tumors ((Donkin et al. 2000). The concentration of Cd obtained from our data is similar to the typical observation in the environment. The exposure to nickel compounds results in several health effects including dermatoses, asthma, hypertrophic rhinitis and nasal sinusitis etc (Costa 2000). Nickel compounds are also classified as Group 1 carcinogens (IARC 1990); the unit risk is determined to be 4.8 x 10^{-4} per ($\mu g/m^3$) (IRIS 1996). The minimum risk level (MRL) for chronic-duration inhalation is suggested as 2 x 10^{-4} mg Nickel/m^3 by ATSDR (1997). Our results show that the exposure to Ni in candle smoke exceeds the MRL during the winter period in Taiwan and the potential risk of lung or nasal cancer is significant higher than 1 x 10^{-4}. Occupational exposure to chromium trioxide vapors results in coughing, expectoration, nasal irritation, sneezing, rhinorrhea, and nose-bleed etc (ATSDR 1993). US EPA's study (1984) also obtained a unit risk of 1.2 x 10^{-2} per ($\mu g/m^3$) for respiratory cancers for Cr(VI). Based on our estimate, the risk owing to Cr exposure could be as great as 7 x 10^{-3}.

It is noteworthy that the candle combustion pattern described above regularly happens in Taiwan, but not the worst scenario. During the religious or traditional holidays, for example, Chinese Lunar New Year, one may burn hundred times as much as the regular amount. This report clearly calls for a detailed exposure assessment of carcinogenic metals, such as Cr, Ni, that may be associated with the regular candle burning behavior.

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