

Characterization and Aliphatic Aldehyde Content of Particulates in Chinese Incense Smoke

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It is known that both wood dust and formaldehyde can impair mucociliary clearance (Black et al, 1974). Epidemiological studies have correlated wood dust and formaldehyde with nasal cancer (Whitehead, 1982; National Research Council, 1981). Wood dust as a carrier of formaldehyde enhances the hazardous properties of formaldehyde when the wood dust is intercepted and dissolved in water in the nasal cavity (Stumph et al, 1986).

Burning Chinese incense for worshipping deities is a daily routine for most Chinese. Burning incense might also generate aerosols and formaldehyde because most materials produce aldehydes and ketones during combustion (Gotze and Harke, 1989). We characterize the aerosol and its aliphatic aldehyde content in this study.

MATERIALS AND METHODS

Four types of stick incense containing sandalwood powder were burned in a chamber. The chamber (68 × 48 × 44 cm) was constructed from polypropylene. A stream of purified air was distributed into the chamber through a tube (680 mm long diameter 5 mm) with 13 holes (diameter 5 mm). The exhaust air was discharged into a hood. A pump (model 224-30, SKC, USA) was used to maintain the dynamic equilibrium between the inlet and the outlet flow rates. A Flow-temperature-humidity control system (HCS-301, MNR, USA) was used to control the humidity in the chamber. A dew point hygrometer (model 91, YSI, USA) was utilized to monitor the relative humidity inside the chamber.

A stick of incense was ignited by a nickle-chrome wire regulated by a transformer after the burning chamber had been purged by purified air with a flow rate of 5 L/min for 30 min.

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The smoke generated from burning Chinese incense was sampled by a Mini Anderson multi-stage cascade impactor (Anderson personnel particle sizing sampler, Anderson, USA) in parallel with a 37 mm cellulose-ester filter (SKC, USA) in a two-piece cassette (37 mm, SKC, USA). The flow rate was 1.4 L/min for the Anderson sampler and 0.5 L/min for the filter. The sampling time varied from 2 min to 10 min depending on the concentration of aerosol generated.

After sampling was completed, the sample collected by the Anderson sampler was conditioned for 24 hr in an electronic desiccator (ED-100, Toyo Living, Japan) with 50% relative humidity and weighed by a balance (M3P-000V001, Sartorius, Germany). Subsequently, each stage was immersed in acetonitrile (5 mL, BDH 152856K, England) for 30 min and the extract was eluted through a 2,4-dinitrophenyl hydrazine-coated Sep-Pak DNPH-silica cartridge (part No. 37500, Millipore). The eluent was collected and then brought up to 5 mL by the addition of acetonitrile. 4-fluorobenzonitrile (Fluka, 46680, Switzerland) in acetonitrile at a concentration of 0.134 g/10 mL which served as an internal standard was added to the eluent. Aldehyde standard solution kit (TK-151) was provided by Alltech.

A high performance liquid chromatograph (Model 590, Waters, USA) equipped with an UV absorbance detector (UV 254 nm, series 400, Waters) was used to determine the 2,4-DNPH derivatives of the aliphatic aldehydes in the extract from aerosol. The injection volume was 10 μ L. The column was Nova-Pak C18(150 mm \times 3.9 mm) and the flow rate of the solvent system (acetonitrile/H₂O; 60/40 V/V) was 1.0 mL/min.

The particulates retained in each cellulose-ester filter were counted and sized. About one-eighth of a filter was cut, mounted on a slide and treated with an acetone vaporizer (Vap-200, BGI, USA) to become transparent. The counting and sizing of the particulates was conducted using a microscope (Alphaphot-2 YSI, Nikon, Japan) interlinked with an image analysis system (PC-meter, Hanka, Taiwan). In addition, the morphology of aerosols was examined by a scanning electron microscope (JSM-300TA, JEOL, Japan).

The above-mentioned methods were also employed for sampling and analyzing field samples which were collected from a site located 150 cm above ground level and 10 cm away from an incense holder in a courtyard of Lungshan Temple, a Chinese temple in Taipei.

RESULTS AND DISCUSSION

Table 1 shows the results obtained by filtration and microscopic examination with an image analysis system. The diameter of the

particles from various kinds of Chinese incense smoke ranged from $0.36 \mu\text{m}$ to $2.88 \mu\text{m}$, and the areas ranged from $0.103 \mu\text{m}^2$ to $6.492 \mu\text{m}^2$. Both the size distribution and the numerical concentration depended on the conditions under which the incense was burned. The concentration of particulates from burning Chinese incense increased with the relative humidity in the burning chamber. The maximum diameter and the maximum area of particles from all kinds of Chinese incense except the Taiwan Yellow incense also increased with the relative humidity. The increase in particle size in high relative humidity is probably due to the coagulation of particles. However, the exception which occurred in the case of Taiwan Yellow incense implies that the hygroscopic properties of particulates may vary with the type of Chinese incense. It is likely that the hygroscopic particulates in high concentrations easily coagulate.

Table 1. Microscopic determination of concentration and size distribution of particulates from incense smoke

Type of stick incense	R.H.(%) & Temp.(°C)*	Conc. (No./cm ³)	Surface area(μm^2)		Diameter(μm)	
			Maximum	Minimum	Maximum	Minimum
Taiwan	50.5;23.8	2617.9	2.267	0.103	1.70	0.36
Yellow	61.0;22.0	3226.0	1.752	0.103	1.49	0.36
	85.0;22.0	4125.8	1.340	0.103	1.31	0.36
Mainland Black	46.1;20.0	2693.8	1.453	0.104	1.36	0.36
	63.0;17.0	2975.8	2.905	0.104	1.92	0.36
	87.8;20.5	4395.4	4.046	0.104	2.27	0.36
Taiwan	50.0;22.0	1512.0	1.349	0.135	1.31	0.41
Black	63.2;24.0	2526.4	1.958	0.103	1.58	0.36
	83.0;19.0	3122.5	2.081	0.104	1.63	0.36
Japan White	45.7;27.0	1583.0	1.134	0.103	1.20	0.36
	65.0;23.0	2742.1	1.958	0.103	1.58	0.36
	78.5;24.5	3232.8	6.492	0.103	2.88	0.36
Field sample**	41.3-46.3; 20.4-23.0	714.6	2.179	0.104	1.67	0.36

*Relative humidity (%) and temperature (°C) in a burning chamber.

**A field sample was collected in a Chinese temple.

Table 2 gives the results of particle size distribution by cascade impactor (Mini Anderson Sampler). The aerodynamic diameter of most particulates generated from burning the stick incenses in the chamber with controlled humidity was smaller than $0.65 \mu\text{m}$. The mass medium aerodynamic diameter (MMAD) for particulates from each kind of incense was not determined, because it was found that when the plot of size distribution was drawn on log-probability paper, the size distribution of particles did not fit a log-normal distribution.

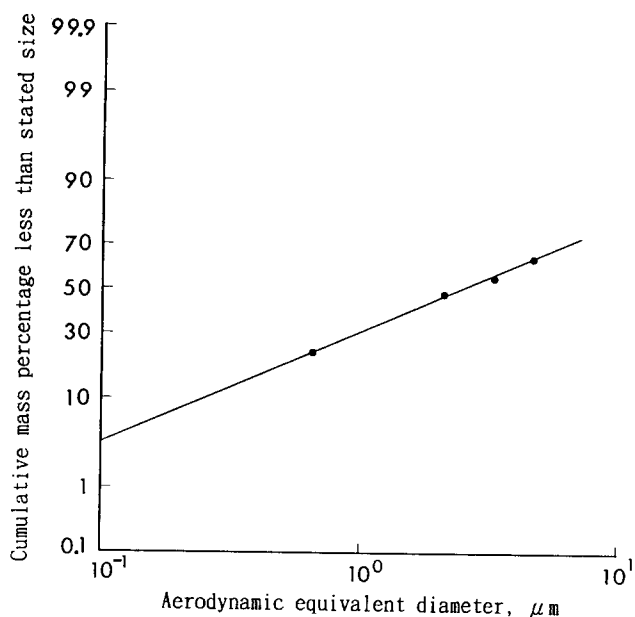


Figure 1. Plot of cumulative mass distribution of particulates collected in a Chinese temple. (MMAD=2.5 μm ; GSD=6.6)

Table 2. Gravimetric determination of mass cumulative percent of particulate collected from incense smoke by Anderson samplers

Type of stick incense	R.H.(%) & Temp.(°C)*	Sample number	Mass cumulative percentage of particulates with size less than effective cut size				Mass conc. mg/m^3
			4.7 μm	3.3 μm	2.1 μm	0.65 μm	
Taiwan Yellow	45.5-50.0%; 23.0-28.0°C	2	99.8	99.5	98.8	88.2	108.2
	58.0-60.0%; 22.0-25.0°C	2	93.4	92.8	92.6	79.8	51.4
	81.0-82.0%; 21°C	2	98.7	98.7	98.3	73.4	59.6
Taiwan Black	48.0-52.0%; 22.0°C	1	99.6	99.6	99.6	43.6	39.3
	60.5-65.8%; 24.0°C	1	98.6	98.6	98.3	98.3	60.9
	82.4-83.6%; 19.0°C	1	98.7	98.5	98.0	94.8	97.8
Japan White	48.0-50.0%; 25.0°C	1	100.0	95.8	94.3	71.5	48.4
	57.5-62.5%; 22.0°C	1	98.1	92.3	92.3	91.4	47.8
	78.0-80.0%; 26.0°C	1	98.3	97.1	97.1	67.4	39.6
Field sample**	41.3-46.3%; 20.4-23.0°C	1	64.0	55.1	47.5	22.9	3.2

*Relative humidity (%) and temperature (°C) in a burning chamber.

**A field sample was collected in a Chinese temple.

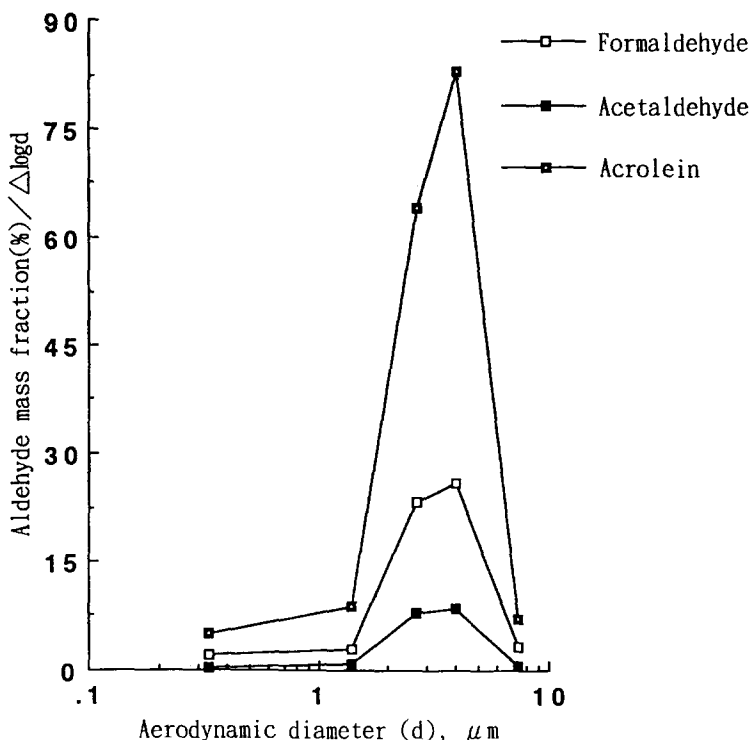


Figure 2. Mass distribution of aliphatic aldehydes on the particulates collected in a Chinese temple. (Aldehyde mass fraction indicates the mass percentage of each aldehyde versus the integral mass for that stated size range.)

However, as shown in Figure 1, the field data from a Chinese temple where Chinese incenses were burning in ambient air results in a linear plot with MMAD of $2.5\ \mu\text{m}$ on log-probability paper. Figure 2 shows that the quantity of various aliphatic aldehydes found in particulates was dependent on particle size in the field sample collected from the Chinese temple. Acrolein, formaldehyde and acetaldehyde were predominantly adsorbed on particulates, especially those with size of $3.3\text{--}4.7\ \mu\text{m}$ and $2.1\text{--}3.3\ \mu\text{m}$. Table 3 shows that when particulates were generated from burning the incense stick in the previously described chamber, the relationship between aldehyde mass fraction and size of particle varied with the type of incense stick. The abundance of aliphatic aldehydes adsorbed on particulates consistently kept the following order: acrolein, formaldehyde, acetaldehyde. A difference between aliphatic aldehydes on particulates and in the gaseous phase was noticed. It was found that formaldehyde predominated in the gaseous phase when an incense stick was burning in the chamber. (Lin and Wang, 1994, in press).

Table 3. Aliphatic aldehydes (acrolein, formaldehyde and acetaldehyde) adsorped on various sizes of particulates from incense smoke

Type of stick incense	R.H. (%)& Temp.(°C)*	Aliphatic aldehydes	Aldehyde mass fraction for the stated size range of particulates, %					
			>4.7 μ m	4.7-3.3 μ m	3.3-2.1 μ m	2.1-0.65 μ m	<0.65 μ m	
Taiwan Yellow	45.5% ; 23°C	Formaldehyde	trace	1.57	1.50	trace	0.03	
		Acetaldehyde	trace	0.28	0.23	trace	trace	
		Acrolein	-	-	2.36	-	0.06	
	61.4% ; 19°C	Formaldehyde	trace	trace	trace	0.02	0.02	
		Acetaldehyde	0.13	0.08	trace	0.01	0.01	
		Acrolein	-	-	-	0.09	0.14	
Taiwan Black	80.0-85.0% ; 22°C	Formaldehyde	trace	trace	trace	0.03	0.02	
		Acetaldehyde	trace	0.09	trace	0.01	0.01	
		Acrolein	-	-	-	0.11	0.10	
		Formaldehyde	12.73	trace	trace	-	-	
Field sample**	48.0-52.0% ; 22.0°C	Acetaldehyde	2.60	trace	trace	-	-	
		Acrolein	18.09	trace	trace	0.25	-	
	60.5-65.8% ; 24.0°C	Formaldehyde	1.75	trace	8.00	45.50	0.01	
		Acetaldehyde	2.03	trace	1.50	11.50	-	
	82.4-83.6% ; 19°C	Acrolein	trace	trace	trace	trace	0.08	
		Formaldehyde	0.93	4.56	1.93	0.45	-	
		Acetaldehyde	0.44	1.67	0.80	0.21	-	
		Acrolein	2.66	8.89	4.80	0.78	0.07	
Field sample**	41.3-46.3% ; 20.4-23.0°C	Formaldehyde	1.06	4.00	4.56	1.47	1.67	
		Acetaldehyde	0.24	1.33	1.56	0.43	0.13	
		Acrolein	2.34	12.76	12.72	4.43	4.11	

*Relative humidity (%) and temperature (°C) in a burning chamber.

**A field sample was collected in a Chinese temple.

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