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Full Length Research Paper

Effect of addition of Asiatic clam (*Corbicula fluminea*) shell in incense material on mitigating air pollutants

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Particulate matter (PM) and polycyclic aromatic hydrocarbons (PAHs) emissions of burning incense have been investigated on the quality of surrounding air. However, the reduction of PM and PAHs from burning incense has received little attention. In the present study, two types of incense were made in the laboratory. Five to thirty percent of Asiatic Clam Shell (ACS) was added to Liao and Chen wood flours, which are popular incense materials. Experimental results indicate that the reduction of emissions of PM and PAHs from burning incense increased with increasing amount of ACS additive. Mean PM reductions for 5.0, 10.0, 20.0, and 30.0% of ACS were 11, 15, 26, and 40%, respectively. Mean PAH reductions were 9, 15, 22, and 28% for particle-phase PAHs, respectively, and 5, 21, 22, and 30% for benzo[a]pyrene equivalent concentration, respectively. These results may be attributed to ACS acted as filler in the burning incense. ACS was substituted for organic material in the incense reducing PM and PAHs emissions from the smolder. The findings of this study may serve as a guide to producing safer and less-polluting incense.

Key words: Incense, Asiatic Clam Shell, PM, PAHs, benzo[a]pyrene equivalent concentration.

INTRODUCTION

Incense is burned in temples and widely used during temple activities in Asia. It was estimated that there were 11,796 legal temples in Taiwan in 2009. The temple density was roughly 1 temple per 2,000 residents or 1 temple per 260 ha; these figures exclude unregistered temples and altars (Department of Statistics, MOI, 2010). There are 6.1 million families in Taiwan (Department of Statistics, MOI, 2010), with 45% burning incense twice per day (Lung et al., 2007). Cancer, asthma, dermatitis, and genotoxic effects are related to exposure to incense smoke (Dawod and Hussain, 1995; Jetter et al., 2002; Yang et al., 1997). Chiang et al. (2009) indicated that the incremental lifetime cancer risk is greater than the acceptable level of 10^{-6} for temple workers exposed through the inhalation route. Burning incense in an enclosed room results in a suspended particle concentration of 390 - 730 μg/m^3, which is 4 - 7 times higher than the indoor air particulate standard of the Taiwan EPA (100 μg/m^3) (Kao and Lung, 2000).

In our previous study, it was found that the PM emission factor from nine types of incense ranged from 15 - 47 mg/g with an average of 33 mg/g. In addition, we found that most of the suspended particulates in the incense smoke were smaller than 5.6 μm, with 95% of them smaller than 1.0 μm, and that the average mass median aerodynamic diameter (MMAD) of the smoke aerosol was 0.262 μm (Yang et al., 2007). Moreover, small particles are more likely to harm the respiratory system as they can easily be inhaled and deposited in the respiratory tract and alveolar region (Harrison et al., 2000; USEPA, 2002; Voutsa and Samara, 2002).

Several studies concluded that PAHs in indoor air mainly originated from incense burning in temples (Chiang and Liao, 2006; Lu et al., 2008). In our previous study, gas-phase PAH (G-PAH) and particle-phase PAH (P-PAH) emission factors ranged from 10 - 29 and 4.5 - 6.9 μg/g-incense, respectively (Yang et al., 2007).

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However, the particle-phase benzo[a]pyrene equivalent concentration (BaP_{eq}) emission factor was found to be consistently more than 40-fold higher than that of the corresponding gas-phase BaP_{eq}. These results clearly suggest that in terms of carcinogenic potency, the control of P-PAH emissions is more important than the control of G-PAHs (Yang et al., 2007). Many studies have suggested that PAHs are environmental immunosuppressive contaminants. PAHs, especially benzo(a)pyrene, not only harm the respiratory and immune system but also cause cell mutation and cancer, including lung and skin cancer (Hecht, 1999; Knize et al., 1999; Laupeze et al., 2002; Page et al., 2002; van Grevenynghe et al., 2003; Yousef et al., 2002). Unfortunately, the reduction of PAHs and PM from burning incense has received little attention. In our previous study, we investigate nine types of incense and found that calcium carbonate, commonly added as a filler during production to lower the cost of incense, has an unexpected benefit that incense with higher $CaCO_3$ content had lower PM and PAH emissions (Yang et al., 2006).

Asiatic clam is the third of the economic shellfish of Taiwan, just behind oyster and clam. The most of economic shellfish's discarded shell were being throwing without reusing effectively and it could cause environmental and sanitation problems. Chu (2003) indicated that the major elemental composition of oyster shell and ACS is $CaCO_3$. Li (2007) indicated that calcium carbonate in Asiatic clam, Oyster and clam shells are 95.3, 94.6 and 94.1%, respectively. The information from the Fisheries Statistical Yearbook (2009) indicated that the annual production of Asiatic clam in Taiwan was 27,395 tons. According the clam shell and meat ratio was 3:1. The amount of clam shell discarded on an annual basis was 20,500 tons. This study will add discarded ACS to incense raw materials in order to reuse and improve environmental sanitation.

In addition, there were variations in the proportion of bamboo, adhesive and wood flour in incense sticks, the size of powder, and the composition of individual additives due to manufacturing differences. All of these factors influence the characteristics of air pollution from burning incense. Therefore, the incense used in the present study was made in our laboratory. In order to control the variations of incense characteristics, we added ACS and identified the reduction of PM and PAH emissions in burning incense. The findings of this study may serve as a guide to producing safer and less-polluting incense.

MATERIALS AND METHODS

Manufacture of ACS powder

According to the results of Song's study (Song, 2003), 6% NaOCl was mixed with deionized water (1:10, v/v) and added Asiatic clam samples. The mixture was vibrated with ultrasonic vibration for 30 min and cleared the meat from shell. Then ACS was cleaned with plenty of water and heat-dry to make semi finished shell. The ACS was made after grinded and sieved using a No. 50 screen mesh (0.300 mm).

Manufacture of test incense

The raw materials of incense used in this study include bamboo and powder (adhesive, wood flour and ACS). Most of the bamboo was Makino bamboo (*Phyllostachys makinoi* Hay). The natural adhesive was made of the bark of *Machilus kusanoi* Hay (a species of Lauraceae), which becomes sticky when mixed with water. The wood flour was made of pulverized powder of various woods. Incense is named after its wooden materials; popular incense includes Liao and Chen.

In this study, we choose the most popular incense quantity in Taiwan as experimental materials, which length and weight of the bamboo stick were 39.5 cm and 0.55 g. Then, wood flour and adhesive were sieved using a No. 50 screen mesh (0.300 mm). The bamboo stick, wood flour, and adhesive were equilibrated with 50% humidity for 24 h before the manufacture of test incense. Each batch of test incense used 100 g of powder. Users prefer incense with a long burning time. We pre-tested the ACE additive in powder and ensured incense burning time at above 60 min. The percentages by weight of ACS in the powder were 5, 10, 20, and 30%. The powder was then mixed with 100 g of deionized water. Aquiferous powder was pressed onto the bamboo stick with a hydraulic press machine to make semi-finished incense. The length of the compressed sticky powder part (combustion part) was 28.0 cm. The combustion part of the bamboo was about 0.39 g. The semi-finished incense was then dried in air for 2 days. The finished samples were conditioned in a carriage at 25°C under a relative humidity of 50% for 24 h before being weighed. Various types of incense with various amounts of additive were made. The weights of the samples were 1.01±0.02 g. The weights of chosen incense samples were exactly 1.00 g in order to control the variation from the physical characteristics of incense. The detailed compositions of the test incense with various amounts of ACS additive are listed in Table 1. Each incense stick combustion part was 0.84 g, including 0.45 g of powder and 0.39 g of bamboo.

Sampling program

A schematic diagram of the sampling apparatus and configuration is shown in Figure 1 (Tsai et al., 2010). Three lab-made sticks of the same type were burned simultaneously during each run. The sticks were ignited with a propane flame which was immediately extinguished to produce smoldering sticks that were inserted into a pre-weighted drilled metallic plate inside the chamber of the sampling apparatus, a glass tube. Before each run, the glass tube was purged with air that was first filtered through a high-efficiency particulate air (HEPA) filter.

Total particulate matter was collected on a quartz filter (102 mmΦ, Pall) by drawing air out of the glass tube at 30.0 L/min using a modified mid-volume air sampler fastened to the top of the tube. The air flow was monitored every third run using a panel-mounted flow meter calibrated with an infrared soap bubble calibrator (Gilibrator-2, Gilian Instrument Corp.). Finally, the outlet air was pumped out of the laboratory. A panel-mounted flow meter was installed in front of a 187-W (1/4-hp) air pump. Our experience has demonstrated that PM is released long after the incense burning appears complete. Hence, to ensure complete collection of PM in each run, the pump was operated for four minutes after the combustion appeared complete. A total of 12 samples of particulate matter, 6 for each type of incense, were collected.

Table 1. Composition of test incense for various amounts of Asiatic clam shell additive.

Test incense[a]	ACS in powder (%)	Powder (g)			Bamboo[b] (g)
		ACS additive	Wood flour	Adhesive	
AC00	0	0	0.36	0.09	0.55
AC05	5.0	0.0225	0.4275	0.09	0.55
AC10	10.0	0.045	0.405	0.09	0.55
AC20	20.0	0.09	0.36	0.09	0.55
AC30	30.0	0.135	0.315	0.09	0.55

a: the weight of one stick of all types of test incense was 1.00 g (0.45 g powder and 0.55 g bamboo stick). b: the weight of each stick bamboo burned was 0.39 g.

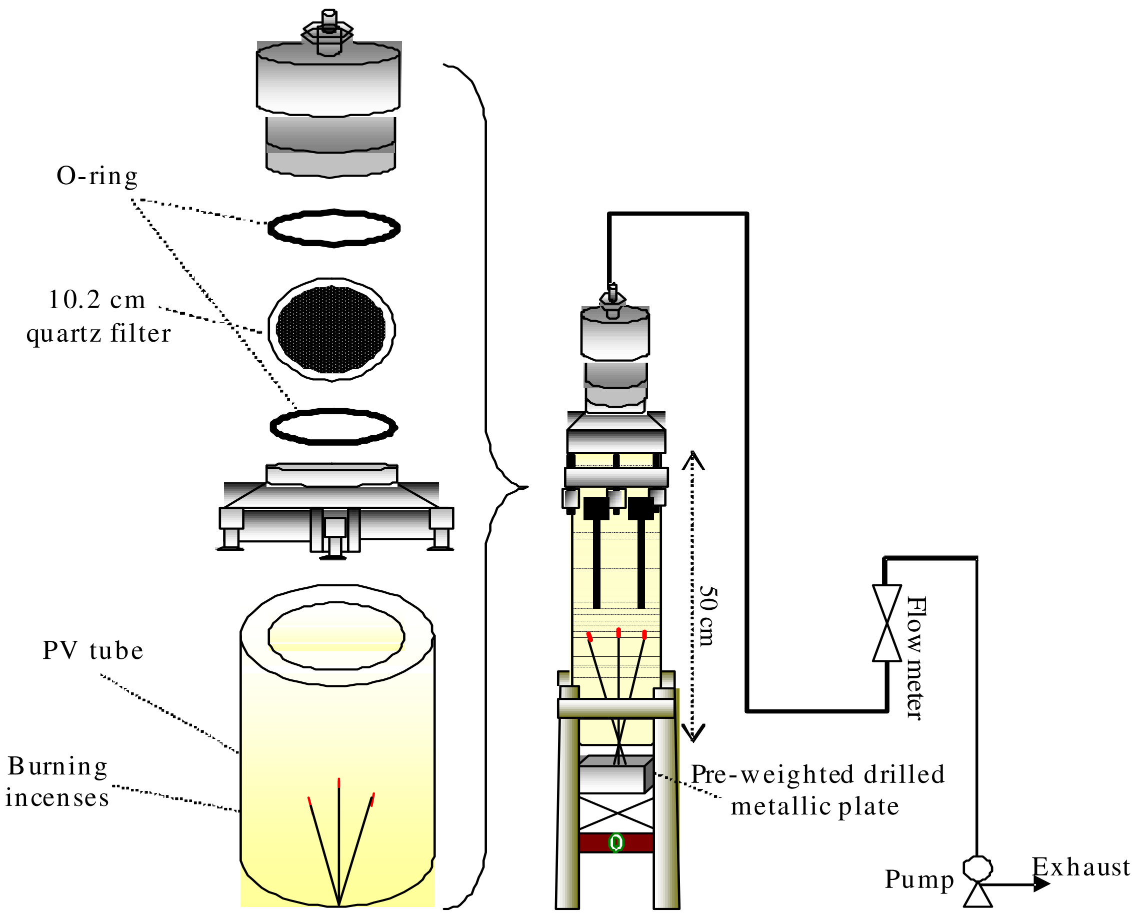

Figure 1. Diagram of incense burning simulation with emitted particulate matter sampling apparatus.

Each quartz filter was cleaned by extraction with a mixed solvent (1:1 n-hexane and dichloromethane) for 24 h in a Soxhlet extractor and allowed to equilibrate in a dry box at 25°C and under 50% humidity for at least 24 h. The quartz filter samples were gathered and temporarily stored in a dry and dark carriage at 25°C under a relative humidity of 50% for 24 h before being weighed.

Analyses of PAHs

After final weighing, all filters were separately placed in appropriate Soxhlet extractors and extracted with 600 mL of a dichloromethane /n-hexane mixture (v/v = 1:1) for 24 h. The extract was then concentrated under ultra-pure nitrogen, cleaned, and re-concentrated to exactly 1.0 mL. All extracts were analyzed with a gas chromatograph/mass selective detector (GC/MSD) (GC-6890N with MSD-5973, Agilent Technologies, USA) with a J&W Ultra2 capillary column (50 m × 0.314 mm × 0.17 μm). A computer-controlled automatic sampler (Model 3365, Hewlett Packard, USA) was used in conjunction with the GC/MSD system. All injections were splitless with an injection volume of 1 μL. The injector and the detector temperatures were 300 and 325°C, respectively. The

Table 2. Burning time and burning rate of test incense for various amounts of Asiatic clam shell additive.

Test incense	ACS content of combustion part[a] (%)	Burning time (min)		Burning rate (mg/min)	
		Liao	Chen	Liao	Chen
AC00	0	94±1	87±2	27±1	29±1
AC05	2.68	89±2	82±1	29±1	31±1
AC10	5.36	84±1	77±2	32±0	33±2
AC20	10.7	72±1	70±3	35±1	36±2
AC30	16.1	66±2	61±1	39±1	42±1

a: only 0.39 g bamboo was burned, implying that 0.16 g bamboo was left after combustion. N = 6 for each type of incense

temperature program included an immediate fast initial increase from 50 - 100℃ at 20℃/min, followed by a milder increase from 100 - 290℃ at 3℃/min, and finally a hold at 290℃ for 20 min.

The concentrations of the following PAHs were determined: naphthalene (Nap) for 2-ring; acenaphthylene (AcPy), acenaphthene (Acp), fluorine (Flu), phenanthrene (PA), and anthracene (Ant) for 3-ring; fluoranthene (FL, Fl), pyrene (Pyr), benzo[*a*]anthracene (BaA), and chrysene (CHR) for 4-ring; benzo[*b*]fluoranthene (BbF), benzo[*k*]fluoranthene (BkF), benzo(*a*)pyrene (B*a*P), dibenzo[*a,h*]anthracene (DBA) for 5-ring; and indeno[1,2,3,-*cd*]pyrene (IND), benzo[*ghi*]perylene (Bghip) for 6-ring.

The GC/MSD was calibrated with a diluted standard solution of 16 PAH compounds (PAH mixture-610M from Supelco). The standard solution concentrations were 0.001, 0.005, 0.01, 0.05, 0.1, 0.5, 1, 5 and 10 µg/mL. PAH recovery efficiencies were determined by processing a solution containing known PAH concentrations through the same experimental procedure used for the samples. The recovery efficiencies of PAHs varied from 69.1 (Nap) to 98.3% (BaA), with an average of 87.6%. Analysis of serial dilutions of PAH standards showed that the limit of detection of the GC/MSD was between 0.071 and 0.936 ng/mL for individual PAH compounds. Ten consecutive injections of a PAH 610-M standard yielded an average relative standard deviation (RSD) of the GC integration area of 3.0%, with a range of 0.8 - 5.1%. The blank tests for PAHs were accomplished using the same procedure as that used for the recovery-efficiency tests without adding the known standard solution before extraction. Analyses of the blank quartz filter revealed no significant contamination (GC/MSD integrated area < detection limit).

Data analysis

The 16 individual PAHs were divided according to their molecular weight into three categories: low molecular weight (LM-PAHs containing two- and three-ringed PAHs); middle molecular weight (MM-PAHs containing four-ringed PAHs); and high molecular weight (HM-PAHs containing five- and six-ringed PAHs). The total PAH concentration was the sum of the concentrations for the 16 PAH compounds in each collected sample. Moreover, considering that several PAH compounds are known human carcinogens, the carcinogenic potencies of PAH emissions from each emission source were also determined. In principle, the carcinogenic potency of a given PAH compound is assessed on the basis of its BaP_{eq}. The calculation of the BaP_{eq} concentration for a given PAH compound is determined by its toxic equivalent factor (TEF), which represents the relative carcinogenic potency of the given PAH compound, using benzo[a]pyrene as a reference compound to adjust its original concentration. This study applied the TEFs completed by Nisbet and LaGoy (1992) to asses the carcinogenic potency of total PAHs (that is total BaP_{eq}) using the sum of the BaP_{eq} concentrations estimated for each PAH compound with a TEF in the total PAHs.

RESULTS AND DISCUSSION

Burning time and burning rate of test incense

The effect of ACS additive on the burning time and burning rate of the test incense, Liao and Chen incenses is shown in Table 2. It was found that the burning times of original (AC00) Liao and Chen incenses were 94±1 and 87±2 min, respectively. For Liao incense, the mean reductions of burning time for AC05, AC10, AC20, and AC30 were 5.3, 11, 23, and 30%, respectively. For Chen incense, the mean reductions were 5.7, 11, 20, and 30%, respectively. The mean reductions of burning time were 5.5, 11, 21, and 30%, respectively, for AC05, AC10, AC20, and AC30. However the ACS content was 2.68, 5.36, 10.7, and 16.1% in the combustion part, respectively, for AC05, AC10, AC20, and AC30. For each test of incense, the percentage of burning time reduction was more than the addition of ACS in the incense combustion part. These results indicate that the addition of ACS significantly reduces the burning time. For the burning rate, results similar to those obtained in our previous study, which investigated nine types of incense and found that incense with higher $CaCO_3$ content had higher burning rates, were obtained (Yang et al., 2006). These results may be attributed to $CaCO_3$ (the main substance of ACS), which may trap the heat energy generated at the burning tip during combustion. Moreover, $CaCO_3$ has refractory characteristics, and therefore prevents air convection and maintain the temperature during incense combustion, increasing the burning rate. Furthermore, one of the major reasons for the reduction of burning time is that the powder contains $CaCO_3$, which was noncombustible falls into the ashes during burning. Generally speaking, it would be worthless if the burning time of incense is too short. In this study, we controlled the process variations and added accurate amounts of ACS to help verify the reduction of burning time. The results can be applied to the commercial production of incense.

PM emission factor

The PM emission factor results are shown in Figure 2. It was found that the PM emission factor values of original

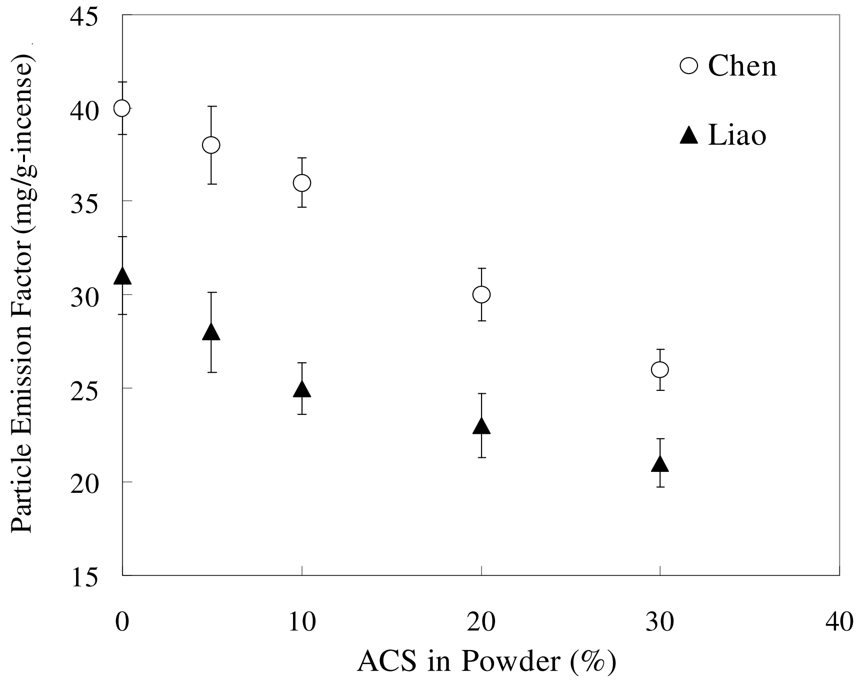

Figure 2. PM emission factor of test incense for various amounts of Asiatic clam shell additive (each error value equals one standard deviation).

(AC00) Liao and Chen incenses were 31±2.1 and 40±1.4 mg g/incense, respectively. For Liao incense, the mean PM reductions for AC05, AC10, AC20, and AC30 were 10, 19, 26, and 32%, respectively. For Chen incense, the mean reductions were 5.0, 10, 25, and 35%, respectively. The mean reductions of two types incense PM were 7.3, 15, 25, and 34%, respectively, for AC05, AC10, AC20, and AC30. The correlations of the PM emission factor and the ACS in powder with regression analysis (r^2 = 0.92, p<0.01 for Liao; r^2 = 0.99, p<0.01 for Chen) were strongly negative. These results indicate that the reduction of PM emissions increases with increasing amount of ACS additive. Moreover, the ACS content was 2.68, 5.36, 10.7, and 16.1% in the burning part, respectively. These results indicate that the addition of ACS significantly reduces PM emissions.

PAH emission factor

The emission factor results of P-PAHs are shown in Figure 3 and Table 3. It was found that the P-PAH emission factors for original (AC00) Liao and Chen incenses were 7.9±0.7 and 7.5±0.5 μg/g-incense, respectively. For Liao incense, the mean P-PAH reductions for AC05, AC10, AC20, and AC30 were 2.9, 7.0, 12, and 19%, respectively. For Chen incense, the mean reductions were 5.2, 8.7, 15, and 21%, respectively. Similar results were found for BaP_{eq}. The BaP_{eq} emission factor values for original Liao and Chen incenses were 1.5 and 1.4 μg/g-incense, respectively. For Liao incense, the mean BaP_{eq} reductions for AC05, AC10, AC20, and AC30 were 10, 23, 19, and 20%, respectively. For Chen incense, the mean reductions were 0.8, 3.5, 21, and 23%, respectively. The correlations of the P-PAHs emission factor and the ACS in powder with regression analysis (r^2 = 0.99, p<0.01 for Liao; r^2 = 0.81, p<0.05 for Chen) were strongly negative. These results indicate that P-PAH emissions from incense can be reduced using ACS additive.

As mentioned, ACS content was 2.68, 5.36, 10.7, and 16.1% in the burning part, respectively, for AC05, AC10, AC20, and AC30, which are less than the means of P-PAH reductions (4.1, 7.8, 14, and 20%, respectively) and BaP_{eq} reductions (5.6, 13, 20, and 21%, respectively) for the two types of test incense. These results strongly suggest that the addition of ACS significantly reduces P-PAH emissions.

Profiles of PAHs

The 16 individual PAHs were divided according to their molecular weight into three categories: LM-PAHs, MM-PAHs and, HM-PAHs. Table 3 and Figure 4 shows that the emission factor values for original (AC00) Liao incense were 0.97, 3.44, and 3.53 μg/g-incense, respectively, accounting for 12, 43, and 45% of total P-PAHs. The LM-PAHs, MM-PAHs, and HM-PAHs emission factor values from Liao incense for AC05,

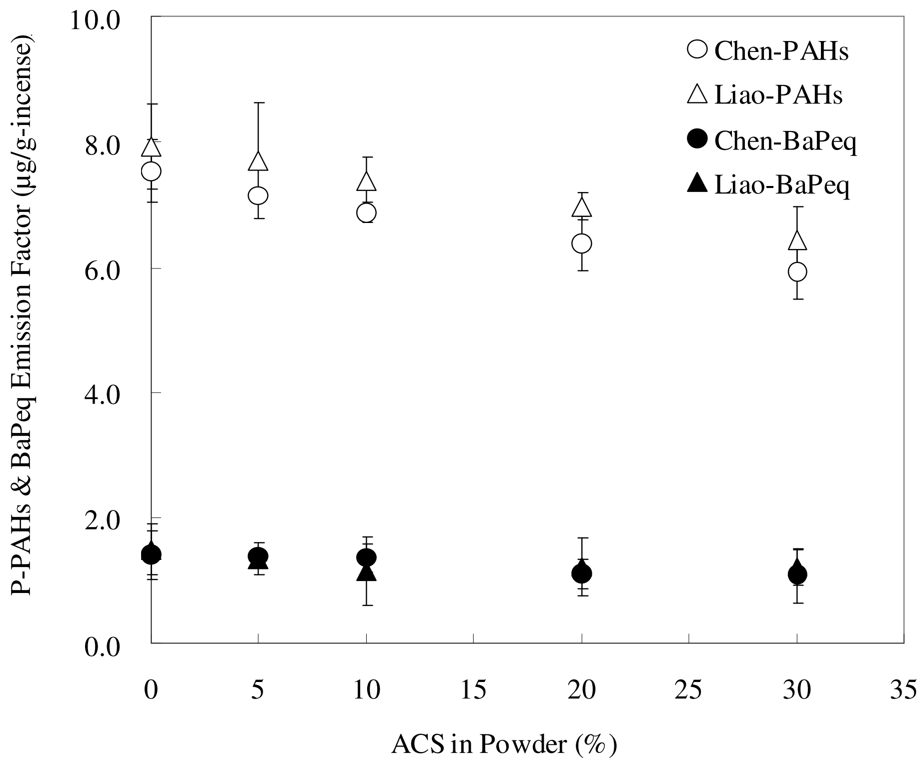

Figure 3. P-PAHs emission factors of test incense for various amounts of Asiatic clam shell additive (each error value equals one standard deviation).

Table 3. Individual 16 P-PAH emission factors of test incense for various amounts of Asiatic clam shell additive.

P-PAHs	Liao incense					Chen incense				
(μg/g-incense)	AC00	AC05	AC10	AC20	AC30	AC00	AC05	AC10	AC20	AC30
Nap	0.11	0.06	0.07	0.08	0.07	0.15	0.09	0.09	0.10	0.12
Acpy	0.12	0.18	0.16	0.10	0.10	0.30	0.07	0.11	0.19	0.16
Acp	0.02	0.03	0.02	0.01	0.01	0.03	0.01	0.03	0.02	0.02
Flu	0.04	0.05	0.05	0.03	0.03	0.04	0.03	0.04	0.03	0.03
Pa	0.49	0.61	0.56	0.49	0.40	0.65	0.39	0.49	0.51	0.46
Ant	0.19	0.26	0.65	0.30	0.16	0.29	0.14	0.23	0.29	0.19
Fl	0.63	0.67	0.62	0.57	0.51	0.61	0.54	0.53	0.51	0.48
Pyr	0.67	0.72	0.66	0.61	0.54	0.61	0.55	0.54	0.51	0.48
BaA	0.81	0.74	0.62	0.65	0.65	0.65	0.71	0.69	0.56	0.50
CHR	1.33	1.18	0.99	1.04	1.06	1.00	1.22	1.04	0.86	0.83
BbF	0.54	0.46	0.41	0.43	0.44	0.52	0.57	0.51	0.43	0.43
BkF	0.34	0.28	0.40	0.39	0.28	0.39	0.36	0.31	0.40	0.33
BaP	1.11	0.98	0.83	0.89	0.88	0.97	1.02	0.99	0.78	0.77
IND	0.71	0.67	0.61	0.63	0.61	0.59	0.69	0.59	0.56	0.51
DBA	0.13	0.13	0.09	0.09	0.11	0.19	0.12	0.13	0.11	0.11
BghiP	0.70	0.67	0.63	0.66	0.60	0.53	0.62	0.55	0.52	0.49
∑LM-PAHs	0.97	1.20	1.51	1.01	0.78	1.46	0.74	0.99	1.14	0.99
∑MM-PAHs	3.44	3.31	2.90	2.87	2.75	2.87	3.02	2.80	2.44	2.29
∑HM-PAHs	3.53	3.19	2.98	3.09	2.91	3.19	3.38	3.09	2.80	2.65
Total PAHs	7.94	7.71	7.39	6.97	6.43	7.53	7.14	6.88	6.38	5.92

P-PAHs: Particle-phase PAHs, LM-PAHs: Low Molecular Weight PAHs (2-3ring), MM-PAHs: Median Molecular Weight PAHs (4rings), HM-PAHs: High Molecular Weight PAHs (5-6rings).

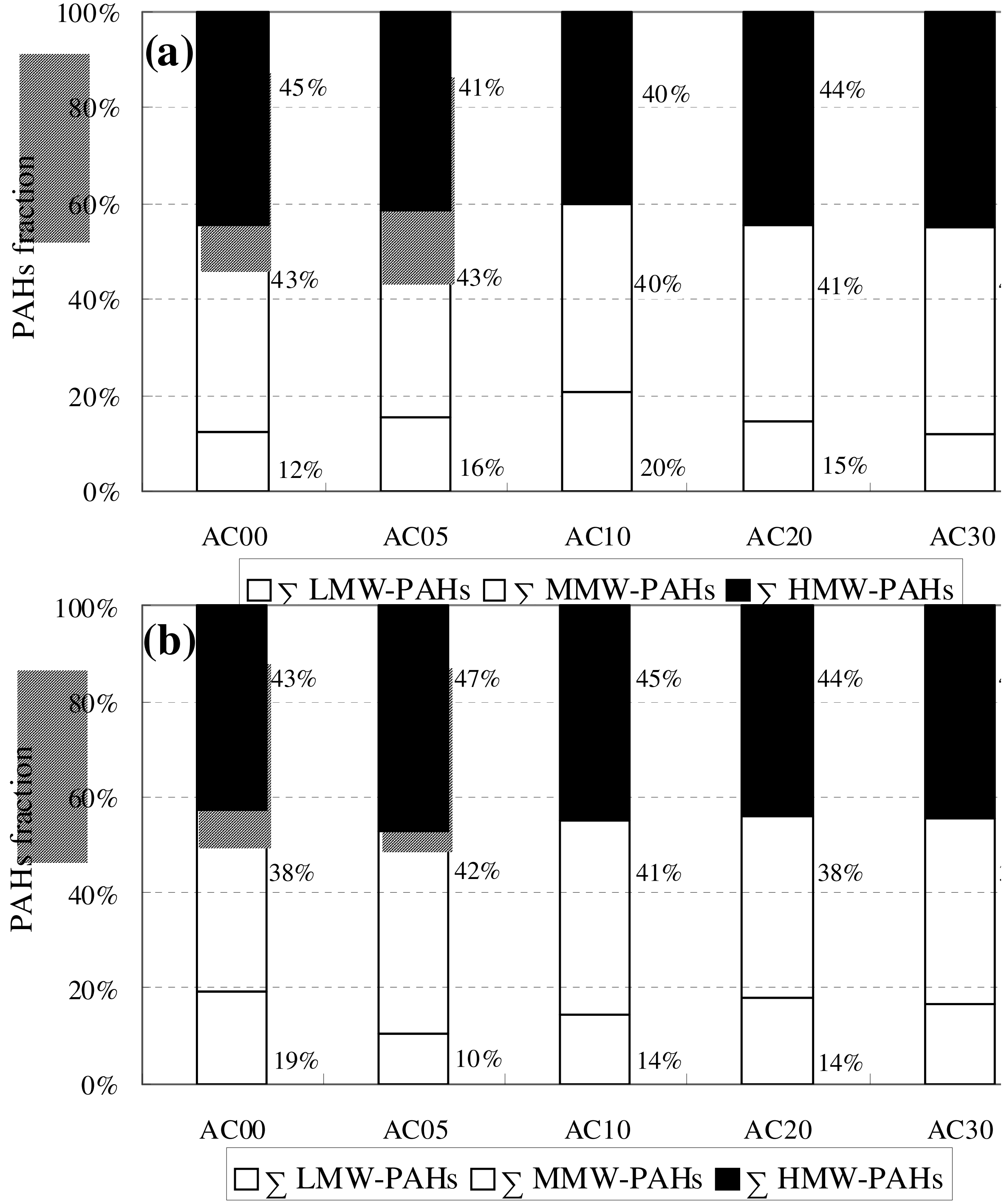

Figure 4. Fractions of P-PAH classifications of test incense for various amounts of ACS additive: (a) Liao incense, (b) Chen incense (ACS: Asiatic clam shell; AC30: thirty percentages by weight of ACS in the incense powder).

AC10, AC20, and AC30 were 0.78 - 1.51, 2.75 - 3.31, and 2.91 - 3.19 μg/g-incense, respectively, accounting for 12 - 20, 41 - 43, and 40 - 45% of total P-PAHs. For original (AC00) Chen incense, the values were 1.46, 2.87, and 3.19 μg/g-incense, respectively, accounting for 19, 38, and 43% of total P-PAHs. For Chen incense, the values were 0.74 - 1.14, 2.29 - 3.02, and 2.65 - 3.38 μg/g-incense, respectively, accounting for 10 - 19, 38 - 42, and 43 - 45% of total P-PAHs. The PAH emission profiles of the two original types of incense are similar. The results are consistent with our previous study, which found that emission profiles of PAHs from nine types of incense shared a common pattern (Yang et al., 2006). In addition, it may be concluded that individual PAH

Table 4. Effect of 10% ACS additive in powder on incense combustion characteristics and emissions after regression analysis.

	Liao		Chen		Average
Burning time (min)	-9.7	(0.99)[a]	-8.5	(0.99)	-9.1
Burning rate (mg/min)	+4.1	(0.97)	+4.2	(0.96)	+4.1
Particle (mg/g-incense)	-3.2	(0.92)	-4.8	(0.99)	-4.0
P-PAHs (µg/g-incense)	-0.50	(0.99)	-0.52	(0.81)	-0.51
Total-BaP_{eq} (ng/g-incense)	-81	(0.48)	-130	(0.91)	-110

ACS: Asiatic Clam Shell, [a], r^2 value of linear regression analysis.

emission profiles of various types of incense are similar and thus independent of ACS content.

Summary of above-mentioned, these results may be attributed to a lower amount of organic wood materials, such as bamboo, adhesive, and wood flour, being burned in incense with $CaCO_3$ additives. $CaCO_3$ prevented air convection and maintained the temperature at the burning tip, which decreased the smolder effect during incense combustion. Therefore, the addition of $CaCO_3$ efficiently decreases genotoxic P-PAHs. In additional, one of the reasons might be that although the incense with ACS burned less organic material, it was still a wood combustion type.

PM and PAHs reductions from incense with ACS in Taiwan

Table 4 shows the effect of 10% ACS content in powder on the burning time, burning rate, and emissions of both PM and PAHs after regression analysis. It was found that the addition of 10% ACS reduced the burning time by 9.1 min, increased the burning rate by 4.1 mg/min, reduced PM by 4.0 mg/g-incense, and reduced P-PAHs by 0.51 µg/g-incense and BaP_{eq} by 11 ng/g-incense. There are 6.1 million families in Taiwan (Department of Statistics, MOI, 2010), with 45% burning incense twice per day (Lung et al., 2007). If it is assumed that three sticks (the weight of one stick is 1.0 g) are used each time, domestic incense consumption is 6,012 tons. 4,000 tons of incense is used in temples per year (Hu et al., 2009). The total consumption of incense in Taiwan is thus 10,012 tons per year. Therefore, using incense with 10% ACS additive instead of traditional incense can reduce PM by 40.1 tons, P-PAHs by 5.1 kg, and BaP_{eq} by 1.1 kg.

Conclusion

Experimental results indicate that the addition of ACS, from 10.0 to 30.0% in powder, for two types of commonly used incense decreased PM emissions by 10 - 35%, P-PAH emissions by 7.0 - 21%, and particle phase-BaP_{eq} by 3.5 - 23%. These results may be attributed to $CaCO_3$ (the main substance of ACS) having a high boiling point and refractory characteristics, which may trap the heat energy generated at the burning tip during combustion. $CaCO_3$ acts as filler in the burning incense. $CaCO_3$ replaced organic wood materials, such as bamboo, adhesive, and wood flour, that discharge air pollutants during incense combustion. Therefore, incense with $CaCO_3$ burned less organic material, but the type of combustion remained the same.

It was also found that adding 10% ACS to incense can reduce PM by 40.1 tons, P-PAHs by 5.1 kg, and BaP_{eq} by 1.1 kg in Taiwan per year. These reductions seem very small when compared to the total air pollution in Taiwan. Nevertheless, burning incense is a source of air pollution that is very close to people. Although the quality of incense, in terms of fragrance and burning time, may be slightly compromised due to enhanced burning efficiency, the addition of ACS effectively reduces emissions that are harmful to human health. This method in this study contributes to reuse with discarded ACS. Furthermore, the findings of this study may serve as a guide for producing safer incense.

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