CHAPTER 3

RESULTS AND DISCUSSION

3.1 Analysis of Nitrogen Dioxide (NO_2)

3.1.1 Analytical characteristics of spectrophotometer

The lab made passive sampler has been used to monitor nitrogen dioxide inside the selected shrines in Chiang Mai City. The samples were extracted and analyzed by spectrophotometer.

1) Calibration curve of nitrite ion (NO_2^-) for NO_2 analysis

Ambient NO_2 trapped in a diffusion tube of passive sampler was in the form of nitrite (NO_2^-). The NO_2^- concentration of samples was calculated using a linear regression equation obtained from a calibration curve prepared from different concentrations of nitrite standard solutions in the range of 0.01-1.00 mg/L preparing each time of the analysis. The example of calibration curve is shown in Figure 3.1.

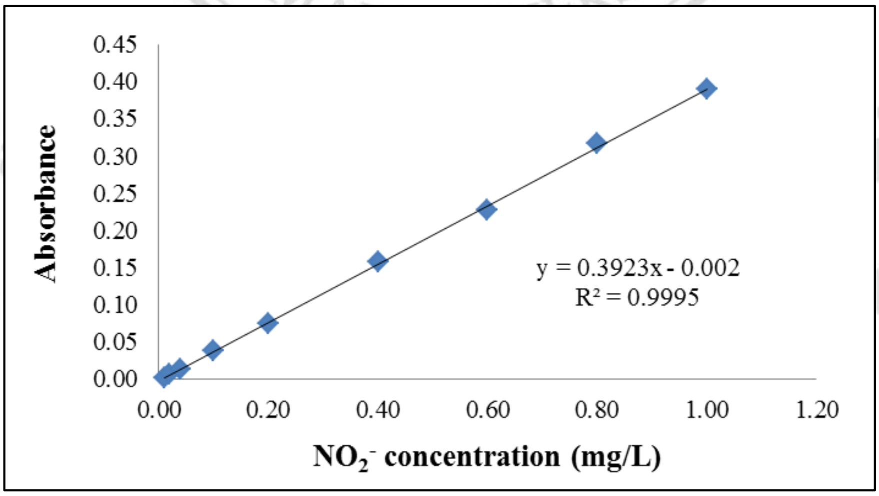


Figure 3.1 Calibration curve of nitrite standard solution

2) Limit of detection and limit of quantification

The limit of detection (LOD) of the analyste was obtained by use of calibration curve of nitrite standard concentration with high correlation (r^2 >0.99). LOD was calculated using the equation by Christian (2001) and the result is shown in Table C-1. Ten measurements of the lowest concentration standard solution (0.01 mg/L) were done and absorbances obtained were calculated back into concentrations. Values of LOD and limit of quantification (LOQ) were calculated by 3 times and 10 times of standard deviation (SD) obtained from those ten measured concentrations. LOD and LOQ of spectrophotometry for nitrite measurement were 0.003 and 0.009 mg/L, respectively.

3) Repeatability and reproducibility

The repeatability of the system was determined by repeating measurements of 0.2 mg/L nitrite solution for 7 times. The reproducibility of the system was pursued by preparing 7 solutions of 0.2 mg/L nitrite solution followed by analysis in the same manner. The results obtained are summarized in the Table C-2. The repeatability and reproducibility of the method were reported in terms of % relative standard deviation (RSD). They were 1.5 and 1.3 %, respectively, representing high repeatability and reproducibility.

3.2 Analysis of $PM_{2.5}$-bound PAHs

PAHs were extracted from $PM_{2.5}$ samples collected in the selected sampling shrines. They were analyzed by GC-MS.

3.2.1 Analytical characteristics of GC-MS

1) Standard calibration curves of 16-PAHs

The 16-PAHs concentration was determined using the linear regression equation of the calibration curve. 16-PAHs mixed standard in the range of 0.004-0.1 mg/L were injected into GC-MS and their chromatograms were obtained. The linear regression analysis and values of variation coefficient (R^2) of the 16-PAHs mixed standard ranged from 0.9986 to 0.9994. The individual calibration curve was constructed based on chromatographic peak areas obtained from 10 concentrations (0.002-0.100 mg/L). Figure 3.2 is a chromatogram of 2 mg/L of 16-PAHs and internal standards. The calibration curve was constructed by using a ratio of peak area between standard and internal standard (Std./IS) in the y axis and PAH concentrations in the x axis. Linear equations and values of variation coefficient (R^2) were obtained (Fig. 3.3). Values of R^2 ranged from 0.9953 to 0.9994.

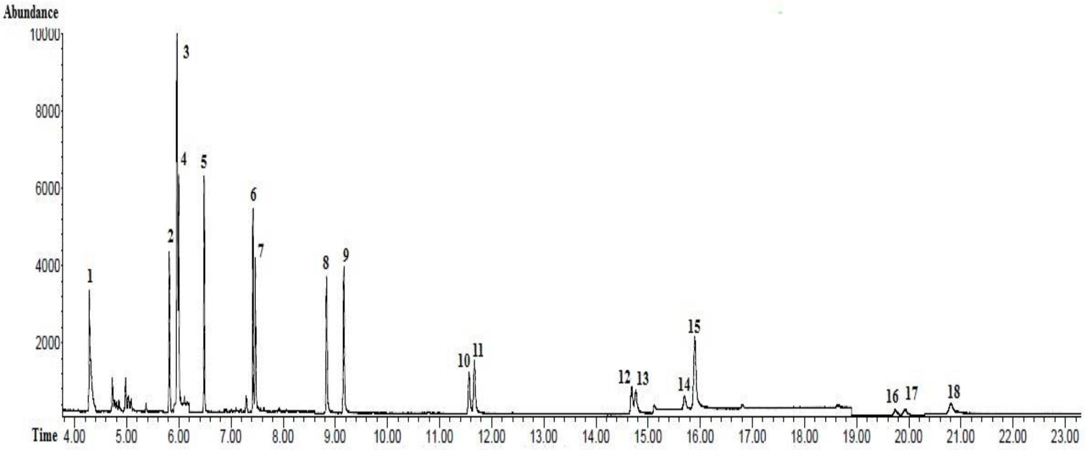


Figure 3.2 A typical chromatogram of 0.2 mg/L of 16-PAHs standards obtained from GC-MS. Where, the internal standards are marked with asterisk. Peaks: 1=NAP, 2=ACY, 3= D_{10}-ACE*, 4=ACE, 5=FLU, 6=PHE, 7=ANT, 8=FLA, 9=PYR, 10=BaA, 11=CHR, 12=BbF, 13=BkF, 14=BaP, 15= D12-PER*, 16=IND, 17=DBA and 18=BPER

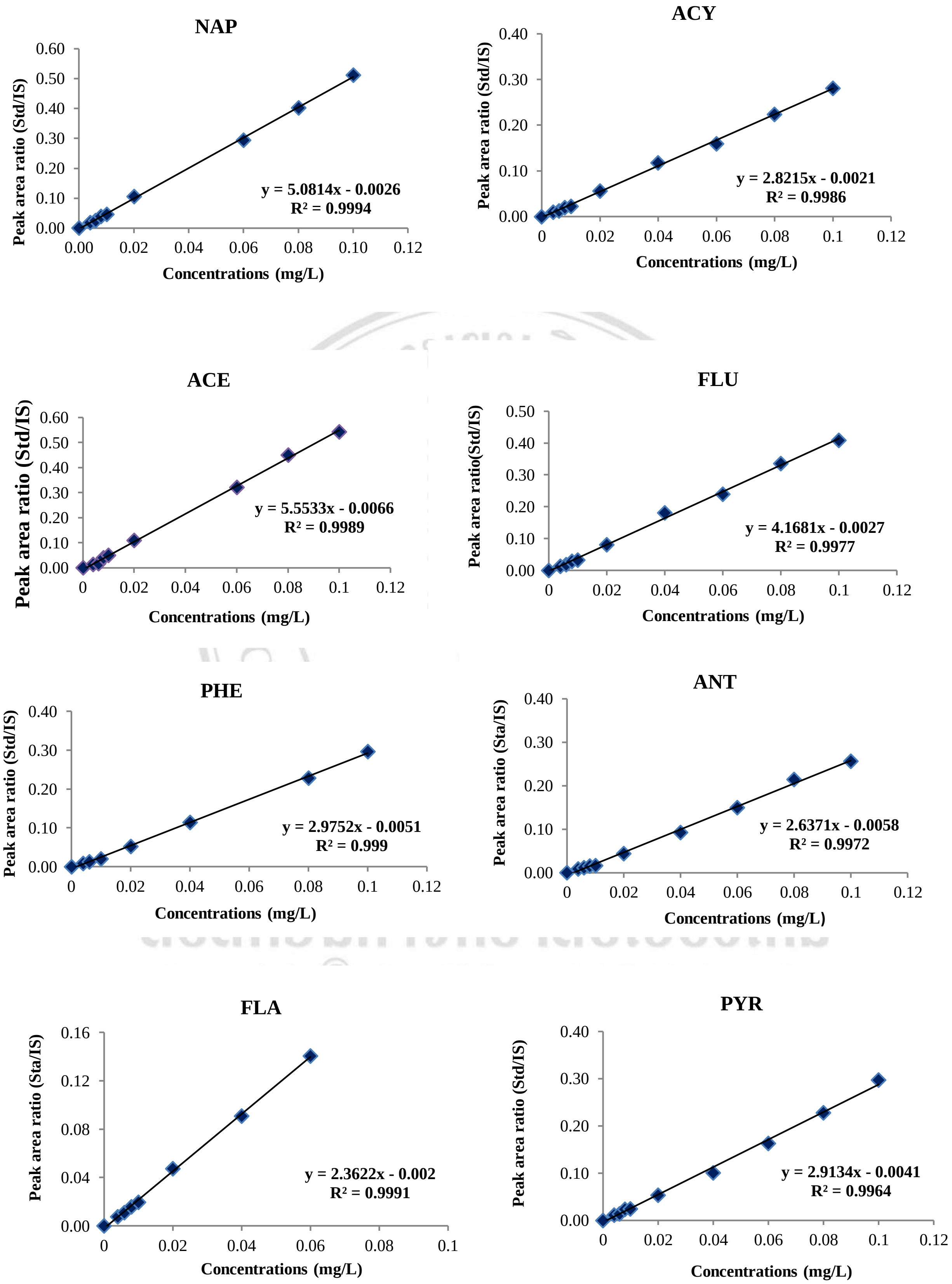


Figure 3.3 Standard calibration curves of 16-PAHs

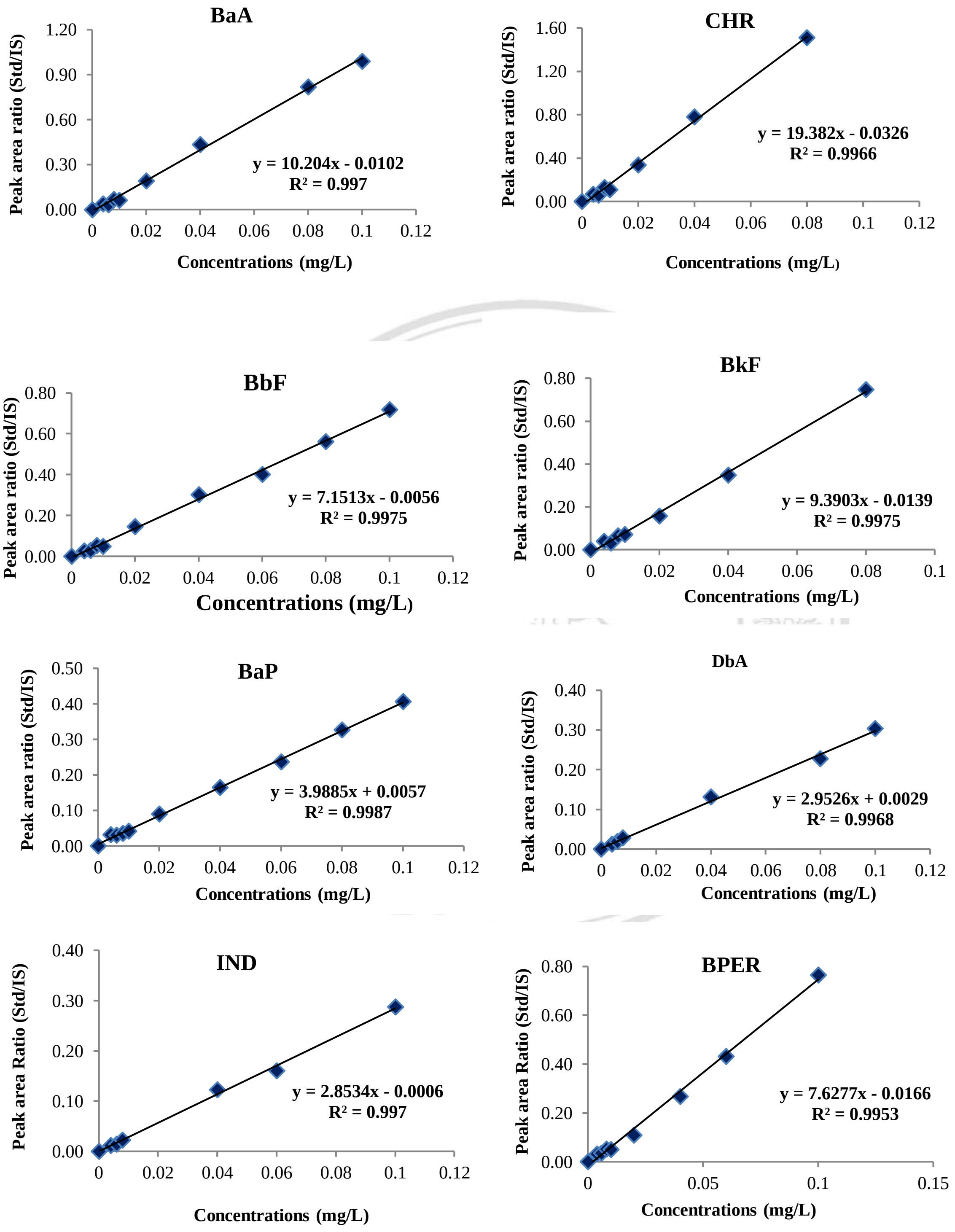


Figure 3.3 Standard calibration curves of 16-PAHs (continued)

2) Limit of detection and limit of quantification

The limit of detection (LOD) values of GC-MS for PAHs analysis were obtained by using seven measurements of 0.004 mg/L, the second lowest PAHs concentration. LOD and limit of quantification (LOQ) were calculated by 3 times and 10 times of standard deviation (SD), respectively. LOD of GC-MS for 16 PAHs measurement ranged from 0.30 – 2.33 ng/mL or 0.08 – 0.66 ng/m^3 while LOQ ranged from 1.00 – 6.75 ng/ml or 0.28 – 2.19 ng/m^3 (Table 3.1).

Table 3.1 The limit of detection and limit of quantification of GC-MS

PAHs	**Limit of detection (LOD)**			**Limit of quantification (LOQ)**		
	ng/mL	**ng/m^3 ***	**mg/kg****	**ng/mL**	**ng/m^3 ***	**mg/kg****
NAP	0.58	0.16	0.0006	1.93	0.54	0.002
ACY	0.35	0.10	0.0003	1.15	0.32	0.001
ACE	1.77	0.50	0.002	5.88	1.66	0.006
FLU	0.62	0.17	0.001	2.06	0.58	0.002
PHE	0.47	0.13	0.0005	1.58	0.45	0.002
ANT	0.30	0.08	0.0003	1.00	0.28	0.001
FLA	0.60	0.17	0.0006	1.99	0.56	0.002
PYR	0.59	0.17	0.0006	1.96	0.55	0.002
BaA	0.35	0.10	0.0004	1.17	0.33	0.001
CHR	0.70	0.20	0.001	2.32	0.65	0.002
BbF	0.88	0.25	0.001	2.93	0.83	0.003
BkF	0.72	0.20	0.001	2.41	0.68	0.002
BaP	2.33	0.66	0.002	7.76	2.19	0.008
IND	1.73	0.49	0.002	5.75	1.62	0.006
DbA	2.03	0.57	0.002	6.75	1.90	0.007
BPER	1.63	0.46	0.002	5.43	1.53	0.005

* The LOD of PAHs in air (ng/m^3) = *[(LOD in solution (ng/mL)) x (final volume of solution (2mL))] / (average volume of air (7.1 m^3))*

** D=m/V (**[**1000g (kg) × LOD in solution (μg/ml)] /density of mixed solvent (0.992 g/ml))

3) Repeatability and reproducibility

The repeatability of the system was determined by repeated measurements of 0.02 mg/ L for 7 injections (Table C-3). The reproducibility of the system was pursued by preparing 7 replications of 0.02 mg/L of mixed PAHs standard solution followed by analysis in the same manner (Table C-4). The obtained results of repeatability and reproducibility of the method were reported in terms of % relative standard deviation (RSD), which ranged from 5.7 (ACY) to 15 % (CHR) and 3.1 (PYR) to 10.4 % (DbA), respectively.

3.2.2 Quality control of PAHs analysis by GC-MS

Quality control of PAHs analysis by GC-MS was conducted prior to sample analysis. Three replications of the NIST 1649b standard reference material (SRM) urban dust and spiked samples were prepared, extracted and analyzed by GC-MS under the optimum conditions. The recovery of individual PAHs was calculated and presented as the method accuracy.

1) Use of the standard reference materials (Urban dust NIST 1649b)

The standard reference material (SRM SRM; Urban Dust 1649b, U.S.A.) provided by the National Institute of Standards and Technology (NIST) was used for the quality control of PAHs analysis in this study, which is an atmospheric particulate material collected in an urban area using 50 mg for preparing 3 replications. It was extracted using 25 ml dichloromethane:n-hexane (1:1) for 45 minutes ultrasonication and analyzed by GC-MS. The recoveries of 16-PAHs in the SRM were 21% (NAP) – 126 % (ANT), which were in the ranges of the EPA quality control criteria from multiple-laboratory (US-EPA, 1996), except fluorine (FLU) (44%) as shown in Table 3.2. The low recovery of PAHs, which was less than 70 %, were NAP (21%), ACY (66%), ACE (65%), FLU (44%), BaA (69 %), CHR (61%) and IND (64%).

2) Use of spiking method

Two concentrations of mixed PAHs standard solution; 0.08 mg/L representing low concentration and 2 mg/L representing high concentration were chosen for spiking method. Specific amount (0.5 ml) of those concentrations were spiked onto a Teflon fiber filter (n=3) and extracted using 25 ml DCM : n-hexane (1 : 1) for 45 minutes by using ultrasonicator. The final PAHs concentrations were 0.02 and 0.5 mg/L, respectively. The recoveries of 16 PAHs obtained from 3 replications of extraction were 82-103 % (low concentration) and 85-106 % (high concentration), respectively (Table 3.2).

Table 3.2 Percent recoveries of 16-PAHs from extraction of the SRM (Urban dust NIST 1649b) and spiking method**.**

Compounds	**SRM 1649b**			**Spiking Method**		**Range of %recovery US-EPA ***
	Certified value (mg/kg)	**Measured value (n=3)**	**% Recovery (n=3)**	**% Recovery 0.02 mg/L (n=3)**	**% Recovery 0.5 mg/L (n=3)**	
NAP	1.120 ± 0.42	0.23 ± 0.04	21	87	85	21-133
ACY	0.184 ± 0.026	0.12 ± 0.02	66	90	90	33-145
ACE	0.192 ± 0.036	0.12 ± 0.03	65	98	92	47-145
FLU	0.222 ± 0.016	0.10 ± 0.01	44	95	95	59-121
PHE	3.941 ± 0.047	3.00 ± 0.62	76	93	99	54-120
ANT	0.403 ± 0.002	0.54 ± 0.11	126	103	94	27-133
FLA	6.140 ± 0.12	5.96 ± 0.95	97	90	100	26-137
PYR	4.784 ± 0.029	3.67 ± 0.63	77	91	100	52-115
BaA**	2.092 ± 0.048	1.42 ± 0.18	69	84	97	33-143
CHR**	3.008 ± 0.044	1.71 ± 0.41	61	82	99	17-168
BbF**	5.990 ± 0.20	5.32 ± 1.01	89	85	100	24-159
BkF**	1.748 ± 0.083	1.28 ± 0.11	73	92	106	11-162
BaP**	2.470 ± 0.17	1.87 ± 0.60	76	80	94	17-163
IND**	2.960 ± 0.17	1.89 ± 0.38	64	90	98	D-171
DbA**	0.290 ± 0.004	0.32 ± 0.15	111	94	97	D-227
BPER	3.937 ± 0.052	3.45 ± 0.57	88	89	100	D-219

D = Detected; result must be greater than zero

* US-EPA (1996)

** represent carcinogenic PAHs (c-PAHs)

3.3 Emission of $PM_{2.5}$ and $PM_{2.5}$-bound PAHs from Burning of incenses and their raw materials in a chamber

3.3.1 Emission factors (EFs) of pollutants emitted from incense burning

The characteristics and compositions of incense are shown in Table 2.1. Incenses were divided into three groups including 1) traditional incense sticks, 2) aromatic incense sticks and 3) aromatic incense cones. In each group, the types of incense were separated based on ingredient or raw materials for producing incense. Traditional incense is common used in worship, while aromatic incense is claimed to have synthetic perfume and used for aromatherapy. Ten types of incense were coded from A-J. Incense code A, B, C, D, and E are traditional incense sticks, while F, G, H and J are aromatic incense sticks and the last one (I) is an aromatic incense cone. Incense B, C, D, E, H and J are hand-made incense, while the rest are machine-based incense (A, F, G). Dried flower/fruit peel based incenses are C, D, E, while H is claimed smoke-free incense. Raw materials of incense including sawdust, wood powders (Chan Kao), plant-based glutinous powders, bamboo and dye powders were also collected for burning experiment. Three replications of the burning experiment of each incense type as well as the incense raw materials were performed.

1) $PM_{2.5}$ emitted from incense burning

The $PM_{2.5}$ samples emitted from the burning of various types of incense in the experimental chamber were collected and analyzed for PAHs. Figure 3.4 shows $PM_{2.5}$ samples emitted from incense burning collected on quartz fiber filters. The color of incense D filter was more deeply brown than incense C and H, which might be because it was composited by dye. Therefore, color and concentration of particles were mainly affected from different raw materials for producing incense (Wu et al., 2009).

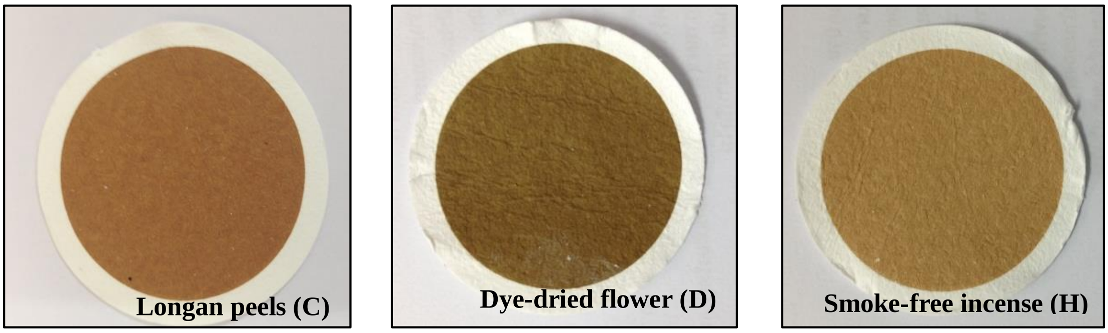

Longan peels (C)
Dye-dried flower (D)
Smoke-free incense (H)

Figure 3.4 $PM_{2.5}$ samples emitted from incense burning (E, F and G)

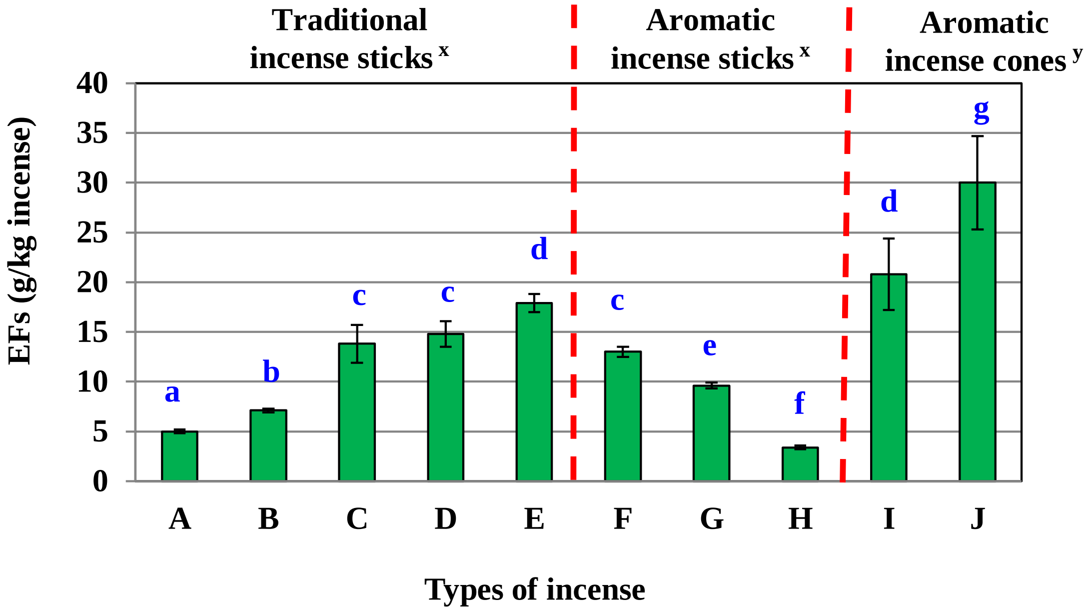
Emissions of $PM_{2.5}$ from incense are shown in Table 3.3. Emission factors (EFs) of $PM_{2.5}$ in a descending order were aromatic incense cones (20.8±3.6 to 30.0±4.7 g/kg) > traditional incense sticks (5.0±0.2 to 17.9±0.9 g/kg) > aromatic incense sticks (3.4±0.2 to 13.0±0.5 g/kg). The EFs of $PM_{2.5}$ of this study was the same with the results of incense burning from Lee and Wang (2004), in which $PM_{2.5}$ EFs were church incense (rocks) (205.4 g/kg) > traditional incense sticks (9.6 to 99.7 g/kg) > aromatic incense sticks (7.7 to 12.6 g/kg).

One-Way ANOVA was used to differentiate the $PM_{2.5}$ concentrations between various types of incense. The concentrations of $PM_{2.5}$ were log–transformed to achieve normal distribution. The EFs values of $PM_{2.5}$ emitted from traditional incense sticks burning and aromatic incense sticks were not found to be significantly different ($p < 0.05$), but both values was significantly lower than aromatic incense cones. Emissions of $PM_{2.5}$ from different types of incense are shown in Figure 3.5. The aromatic incense cones (I and J) emitted higher $PM_{2.5}$ than others. Among then, the chili-shape liked (J) has emitted the highest $PM_{2.5}$ (30.0±4.7 g/kg). The values of $PM_{2.5}$ emission factors emitted from aromatic incense sticks (G and H) were significantly lower than those traditional incense sticks (incenses C, D and E) ($p < 0.05$). The EFs of $PM_{2.5}$ emitted from hand-made incenses (incenses C, D and E) were significantly higher than those machine-based incenses (incenses A and G).

Furthermore, the EFs of $PM_{2.5}$ emitted from aromatic incense cones (I and J) was significantly different than those incense sticks (A, B, C, D, E, F, G and H) ($p<0.05$). The smoke-free incense stick emitted lowest amount of $PM_{2.5}$ comparing to all tested incense types, while eco-friendly incenses emitted higher $PM_{2.5}$ than other stick types but less than cone type.

The EFs values of $PM_{2.5}$ emitted from traditional incense sticks burning in various designed chambers. The values in this study (5.0±0.2 to 17.9±0.9g/kg) was lower than the study of Lee and Wang (2004) (9.6 to 104 g/kg) and Yang et al. (2012b) (47.1±1.45 g/kg), while the values were higher than Nonthakanok, (2013) (0.11±0.01 to 6.86±0.15 g/kg). Comparing with the studies in Taiwan (Kuo et al., 2015), where four types of traditional incenses were burned in the chamber. EFs of $PM_{2.5}$ (22.55±3.09 to 28.58±0.41 g/kg) were higher than those found in this study (5.0±0.2 to 17.9±0.9 g/kg). Kuo et al. (2016) investigated the EFs values of $PM_{2.5}$ emitted from four brands of traditional incense sticks in Taiwan and Thailand. They found that EFs of $PM_{2.5}$ emitted from incenses made in Taiwan (11.37±0.73 and 23.38±2.02 g/kg) were higher than those made in Thailand (11.08±1.27 and 13.93±0.61 g/kg). Moreover, the EFs values of Thai incenses were in the middle range of the values found in this study (5.0±0.2 to 17.9±0.9g/kg). Comparing aromatic incense sticks burning with the study in Hong Kong (Lee and Wang, 2004), where $PM_{2.5}$ samples were collected in a chamber, the EFs of $PM_{2.5}$ (7.7 and 11.8 g/kg) were lower than those in this study (3.4±0.2 to 13.0±0.5 g/kg). In USA, EFs of $PM_{2.5}$ emitted from aromatic incense cone burning that manufacturing from many countries were studied (Jetter et al., 2002). The EFs of $PM_{2.5}$ from the incense cone in descending order were 35.3 g/kg (Mexico), 33.2 g/kg (India), 15.8 g/kg (New Mexico, USA), and 11.5 g/kg (Thailand). The EFs values of $PM_{2.5}$ from Mexico and India were much higher than aromatic incense cones burning in this study (20.8±3.6 to 30.0±4.7 g/kg).

Jetter et al. (2002) and Lee and Wang (2004) reported the emission of $PM_{2.5}$ from sandalwood odor incense stick burning (made in Thailand). It was found that the values of EFs in our study (13.0±0.5 g/kg) were higher than the value obtained the previous work from Canada (9.6 g/kg) and Macau (9.6 g/kg), while EFs values from India (36.5 g/kg) and Hong Kong (71.8 g/kg) was higher than in this study. In Singapore (See and Balasubramanian, 2011), sandalwood odor incense stick was burned in a chamber. The values of $PM_{2.5}$ EFs (18.3±3.7 and 23.8±6.7 g/kg) were higher than the value obtained in this study (13.0±0.5 g/kg). Lee and Wang (2004) reported that EFs of $PM_{2.5}$ emitted from eco-friendly incense burning were 62.4 and 9.6 g/kg, which were higher than the values from dried flower/fruit peel based incense (C, D and E) (13.8±1.9 to 17.9±0.9 g/kg). The smoke-free incense stick burning (H) emitted low $PM_{2.5}$ (3.4±0.2 g/kg), however, it was still much higher than that of See and Balasubramanian (2011) (0.4±0.0 g/kg). The incense stick base material was made from sawdust. The ranges of $PM_{2.5}$ EFs in this study (D, E, F and G) were 9.6±0.3 to 17.9±0.9 g/kg, which were lower than the previous work from Mahasarakham, Thailand (66 to 252 g/kg) (Ongwandee and Pipithakul, 2010). Moreover, the EFs of dyed incense and essence in this study (incense G and J) were 9.6±0.3 and 30.0±4.7 g/kg, while blue dyed-incense and essence-less (D) was 14.8±1.3 g/kg. It was found that the values were higher than dye-less and essence-less incense (A, B, and C) (5.0±0.2 to 13.8±1.9 g/kg). Therefore, incense added with essence and dye could have been the cause of increased $PM_{2.5}$ emissions.



Note: a, b, c, d, e, f and g = Significant differences ($p < 0.05$) among types of incense

x, y = Statistically significant for grouping of incense ($p<0.05$)

Figure 3.5 Emission factors of $PM_{2.5}$ from incense burning

Table 3.3 Emission of PM$_{2.5}$ from incense burning

Types of incense	Code (n=3)	Details of incense	Weight of incense (g)	PM$_{2.5}$ (Mean±SD)	
				mg	EFs (g/kg incense)
Traditional incense sticks^{x}	A	Machine based	10.07±0.10	50.8±1.6	5.0±0.2^{a}
	B	Hand-made	1.19±0.02	8.5±0.3	7.1±0.2^{b}
	C	Longan peel based incense, hand-made	0.84±0.03	11.5±1.4	13.8±1.9^{c}
	D	Flower based incense, hand-made, blue dye	0.75±0.07	11.1±1.1	14.8±1.3^{c}
	E	Flower based incense, hand-made	0.67±0.04	12.0±0.4	17.9±0.9^{d}
Aromatic incense sticks^{x}	F	Machine based, Sandalwood odor	1.95±0.04	25.3±1.3	13.0±0.5^{c}
	G	Machine based, citronella oil odor, mixed dye	4.94±0.04	47.6±1.5	9.6±0.3^{e}
	H	Smoke-free incense, hand-made, Jasmine odor	0.71±0.04	2.4±0.1	3.4±0.2^{f}
Aromatic incense cones^{y}	I	Hand-made, citronella oil odor	2.44±0.03	50.7±8.2	20.8±3.6^{d}
	J	Hand-made, white musk odor, red dye	0.73±0.08	21.7±2.0	30.0±4.7^{g}

Note: a, b, c, d, e, f and g = Significant differences ($p < 0.05$) among types of incense

x, y = Statistically significant for grouping of incense ($p<0.05$)

2) PM$_{2.5}$–bound PAHs emitted from incense burning

The samples of PM$_{2.5}$ collected from the burning of incense in a chamber were analyzed for 16-PAHs by GC-MS. The mean and standard deviation (SD) of emission of PAHs are shown in Table 3.4. The profiles of individual PAHs and relative percentage emitted from incense burning in a chamber are shown in Figures 3.6-3.9.

The EFs of total PAHs (t-PAHs) from incense burning were 1.14±0.35 mg/kg (A), 2.19±0.11 mg/kg (B), 1.55±0.13 mg/kg (C), 4.04±0.05 (D), 3.90±0.37 mg/kg (E), 2.72±0.02 (F), 2.04±0.59 (G), 1.42±0.05 (H), 3.56±0.21 (I) and 3.60±0.49 (J). Kruskal-Wallis test was used to differentiate the t-PAHs concentrations between various types of incense. The concentrations of t-PAHs emission factors were not normal distribution. The EFs of t-PAHs released from incense burning in descending order were tradition incense sticks (1.14±0.36 to 4.04±0.05 mg/kg) > aromatic incense cones (3.56±0.21 to 3.60±0.49 mg/kg) > aromatic incense sticks (1.42±0.05 to 2.72±0.02 mg/kg). However, the EFs of $PM_{2.5}$ emitted from traditional incense sticks burning were not significantly different with aromatic incense sticks, while the both group of incense burning were significantly lower than those aromatic incense cone ($p<0.05$).

The EFs value of t-PAHs emitted from flower based incense (dye-dried flower incense (D) and dye-dried flower incense) were significantly different from all those other incense stick burning ($p<0.05$). The incense that has highest EFs of average t-PAHs was incense D (dye-dried flower incense), while that has lowest EFs was incense H (smoke-free incense). The EFs of PAHs of dye-dried flower incense (D) and dried flower incense (E) was significantly higher than longan peel based incense (C) ($p>0.05$). The EFs of t-PAHs values emitted from hand-made incense (B, C, D, E, H and J) ranged 1.42±0.05 to 4.04±0.05 mg/kg, which were higher than those of machine-based incense (A, F and G) (1.14±0.36 to 2.72±0.02 mg/kg). The reason might be due to PAHs formation is sensitive to temperature because they were well formed at high temperature (excess of 500 °C) (Conde et al., 2005) However, high moisture content in fuels might decrease temperature and efficiency in combustion which it possibly inhibited PAHs formation (Korenaga et al., 2001).

In comparison with the study in Hong Kong (Lui et al, 2016), The EFs of $PM_{2.5}$-bound PAHs emitted from traditional incense sticks in chamber (100 to 136 mg/kg) was ~34-88 times higher than the results of this study (1.14±0.36 and 4.04±0.05 mg/kg), while EFs values of t-PAHs emitted from eco-friendly incense burning (246 and 321 mg/kg) were ~ 79-159 times higher than flower/fruit peel based incense in this study (1.55±0.13 to 4.04±0.05 mg/kg). Moreover, they revealed the EFs values of 5 - 6 rings PAHs released from eco-friendly incense burning (53.2±9.6 and

65.6±13.0 mg/kg) were higher than traditional incense (28.9±6.1 to 48.5±10.2 mg/kg), while the EFs of $PM_{2.5}$ of the eco-friendly incense was lower than those traditional incense. Comparing with the study in Taiwan (Yang et al., 2012b), where $PM_{2.5}$ samples were collected from traditional incense sticks burning in a chamber. The t-PAHs emission factor (0.032±0.006 mg/kg) was lower than in this study (1.14±0.36 and 4.04±0.05 mg/kg). Moreover, the EFs of t- PAHs released from low-smoke incense (0.011±0.003 g/kg) and very low smoke incense (0.016±0.011 g/kg) were lower than smoke-free incense in this study (1.42±0.05 mg/kg).

Moreover, The $PM_{2.5}$-bound PAHs emission factor from mosquito incense stick (G) in our study (2.04±0.59 mg/kg) was lower than mosquito coils burning (5.74±0.85 to 13.43±0.23 mg/kg) reported by Yang et al. (2015b). EFs of t-PAHs from sandalwood odor incense (F) (2.72±0.02 mg/kg) was ~ 3 times lower than the values reported by Yang et al. (2012a) (7.26±0.53 and 8.90±1.16 mg/kg). The EFs of t-PAHs from smoke-free incense with jasmine odor (H) (1.42±0.05 mg/kg) was found to be similar kind of incense made in Taiwan (1.20±0.04 mg/kg) (Yang et al., 2012a). However, there are a lot of possible factors, which could affect the results in each study. Therefore, more details such as types of incense, their ingredient and elemental composition (C, H, N), type of chamber, combustion conditions (T, RH) are needed, when comparing data from various conditions of experiment (Lung and Hu, 2003; Yang et al., 2007a; See et al., 2007; Yang et al., 2012a; Yang et al., 2013).

Table 3.4 Emission factors of PAHs (mg/kg $_{incense}$) from incense burning in a chamber

Compounds (n=3)	**Traditional incense sticks^{x}**					**Aromatic incense sticks^{x}**			**Aromatic incense cones^{y}**	
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
PM$_{2.5}$ (g/kg)	5.0±0.2	7.1±0.2	13.8±1.9	14.8±1.3	17.9±0.9	13.0±0.5	9.6±0.3	3.4±0.2	20.8±3.6	30.0±4.7
NAP	0.003±0.001	0.03±0.00	0.07±0.01	0.09±0.04	0.06±0.02	0.05±0.00	0.01±0.00	ND	0.01±0.00	0.08±0.00
ACY	0.01±0.00	0.03±0.00	0.07±0.01	0.05±0.02	0.04±0.03	0.04±0.00	0.01±0.00	ND	0.01±0.00	0.06±0.01
ACE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FLU	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PHE	0.13±0.06	0.11±0.02	0.02±0.00	0.42±0.05	0.31±0.11	0.17±0.05	0.17±0.03	ND	0.43±0.10	0.18±0.06
ANT	0.08±0.03	0.10±0.00	0.07±0.00	0.95±0.04	0.75±0.14	0.13±0.02	0.06±0.01	0.03±0.01	0.19±0.03	0.22±0.02
FLA	0.17±0.06	0.20±0.01	0.07±0.02	0.15±0.07	0.20±0.03	0.43±0.04	0.36±0.11	0.04±0.02	0.54±0.02	0.38±0.10
PYR	0.15±0.06	0.18±0.00	0.06±0.02	0.07±0.02	0.18±0.09	0.40±0.03	0.30±0.08	0.02±0.01	0.51±0.02	0.38±0.10
BaA	0.08±0.02	0.24±0.01	0.20±0.01	0.22±0.13	0.20±0.03	0.37±0.03	0.25±0.10	0.17±0.01	0.42±0.03	0.32±0.02
CHR	0.08±0.02	0.26±0.02	0.24±0.03	0.16±0.05	0.14±0.03	0.35±0.04	0.29±0.11	0.26±0.06	0.40±0.04	0.32±0.02
BbF	0.05±0.03	0.21±0.03	0.14±0.02	0.13±0.06	0.10±0.02	0.18±0.02	0.15±0.06	0.29±0.04	0.20±0.02	0.12±0.00
BkF	0.03±0.02	0.17±0.00	0.16±0.01	0.14±0.02	0.19±0.03	0.16±0.02	0.10±0.04	0.15±0.02	0.17±0.00	0.11±0.00
BaP	0.08±0.03	0.24±0.04	0.20±0.03	0.24±0.03	0.27±0.05	0.23±0.01	0.15±0.05	0.19±0.04	0.37±0.02	0.22±0.02
IND	0.05±0.02	0.19±0.02	0.09±0.01	0.80±0.10	0.76±0.07	0.11±0.00	0.06±0.01	0.15±0.01	0.15±0.02	0.08±0.01
DbA	0.02±0.00	0.09±0.01	0.05±0.01	0.18±0.04	0.19±0.02	0.03±0.00	0.02±0.00	0.01±0.00	0.02±0.00	0.02±0.00
BPER	0.22±0.02	0.14±0.00	0.10±0.02	0.43±0.09	0.51±0.06	0.06±0.01	0.12±0.03	0.10±0.01	0.14±0.02	1.11±0.18
t-PAHs	**1.14±0.36** ^{a}	**2.19±0.11** ^{b}	**1.55±0.14** ^{ab}	**4.04±0.04** ^{c}	**3.90±0.38** ^{c}	**2.72±0.02** ^{d}	**2.04±0.59** ^{b}	**1.42±0.05** ^{a}	**3.56±0.21** ^{c}	**3.60±0.49** ^{c}
c-PAHs	**0.39±0.13** ^{a}	**1.39±0.08** ^{b}	**1.08±0.10** ^{c}	**1.88±0.09** ^{d}	**1.86±0.05** ^{d}	**1.43±0.11** ^{bc}	**1.01±0.35** ^{c}	**1.22±0.04** ^{bc}	**1.73±0.10** ^{d}	**1.20±0.06** ^{b}
nc-PAHs	**0.75±0.23**	**0.79±0.03**	**0.47±0.04**	**2.16±0.06**	**2.04±0.32**	**1.28±0.11**	**1.03±0.24**	**0.20±0.02**	**1.84±0.17**	**2.40±0.46**

a, b, c, d, and e = Significant differences ($p < 0.05$) among group incense types and x and y = Statistically significant for grouping of incense (*p*<0.05) based on t-PAHs; ND = Not detected

Figures 3.6-3.8 show the PAHs profile, carcinogenic PAHs (c-PAHs) and non - carcinogenic PAHs (nc-PAHs) of incense burning in a chamber. The c-PAHs were BaA, CHR, BkF, BbF, BaP, IND, and DbA, while nc-PAHs were NAP, ACY, ACE, FLA, PHE, ANT, FLU, PYR and BPER (USEPA, 2008). The dominant PAHs species (their concentrations per weight of incense) found from incense burning experiment were FLA (0.07±0.02 to 0.54±0.02 mg/kg), PYR (0.06±0.02 to 0.51±0.02 mg/kg), BaP (0.08±0.03 to 0.37±0.02 mg/kg), BaA (0.08±0.02 to 0.42±0.03 mg/kg) and CHR (0.0.08±0.02 to 0.40±0.04 mg/kg), for most incense burning. Nonthakanok (2013) reported that BaA, BbF, CHR, BaP and ANT were the dominant PAHs bounded on $PM_{2.5}$ emitted from incense sticks in Thailand, while the dominant 16-PAHs released from 9 kinds of incense were produced from Taiwan were CHR, BaP and BaA (Yang et al., 2007a). Yang et al. (2012b) revealed the majors $PM_{2.5}$-bound PAHs emitted from traditional incense burning were FLU, BaP, PYR and PHE. Moreover, Yang et al. (2013) reported that the smoldering incense burning emitted the dominant PAHs (BaP, BaA, NAP, BbF and DbA) on particle phase in a test chamber. Some previous studies reported a low percentage (2-11%) of NAP, ACY, ACE and FLU found in the particulate phase, while they were not found in this study. A good correlation between the percentage of particle-bound PAHs and both molecular weight and vapor pressure of PAHs was also reported (Possanzini et al., 2004 and Kim et al., 2013). The ratios of c-PAHs and nc-PAHs in t-PAHs are shown in Figure 3.9.

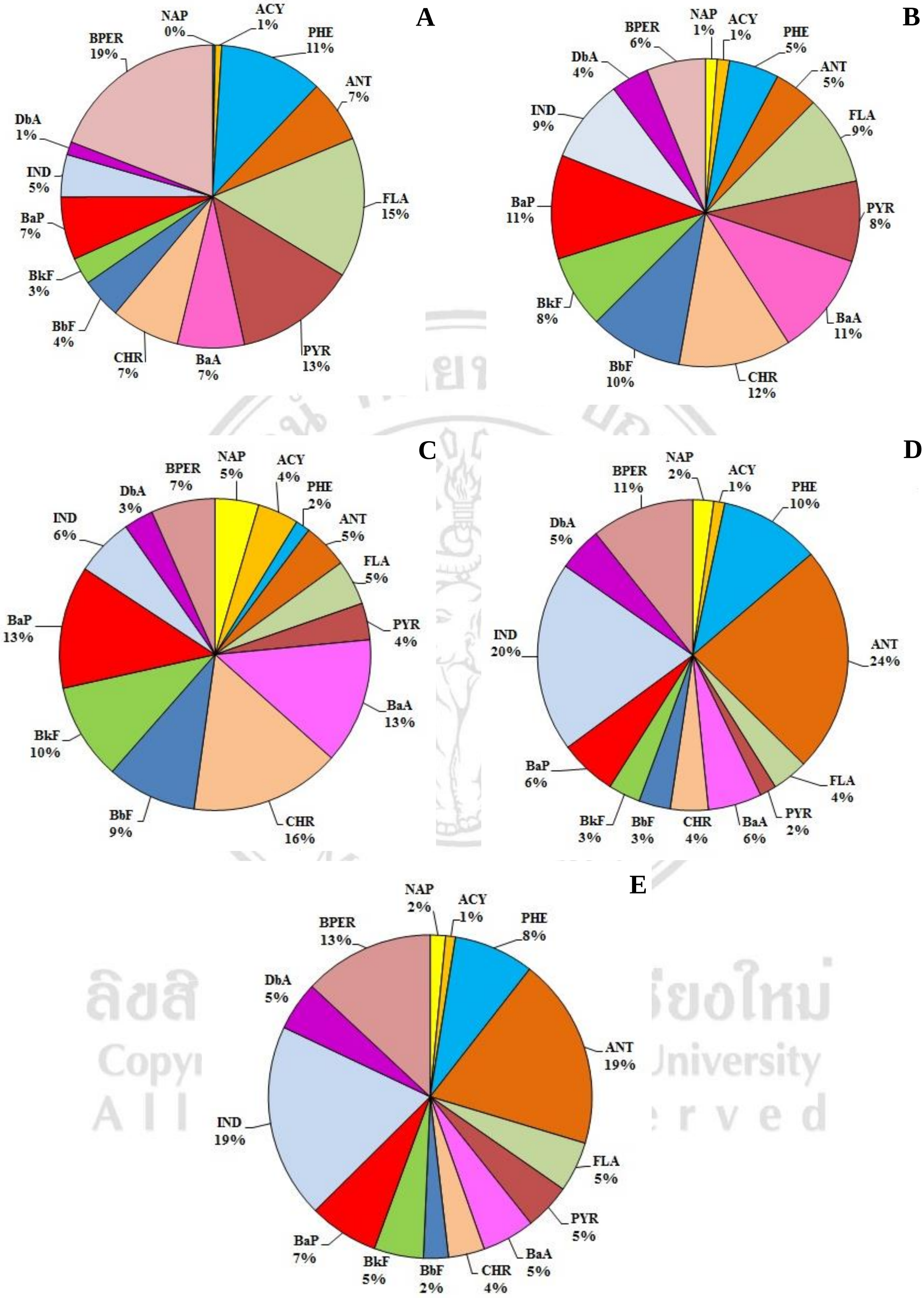


Figure 3.6 Percentage of PM$_{2.5}$ -bound PAHs emitted from traditional incense burning (Types A-E).

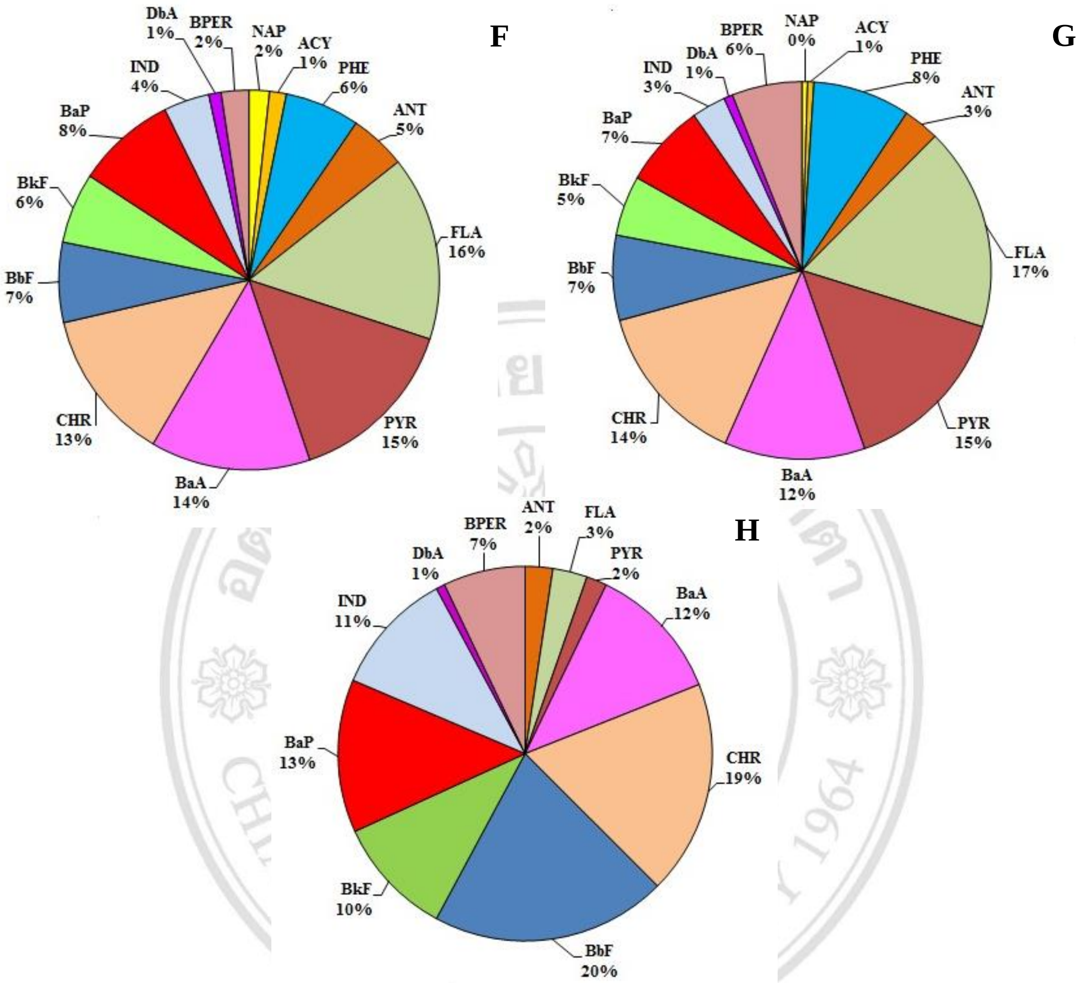


Figure 3.7 Percentage of $PM_{2.5}$ -bound PAHs emitted from aromatic incense burning (Types F-H).

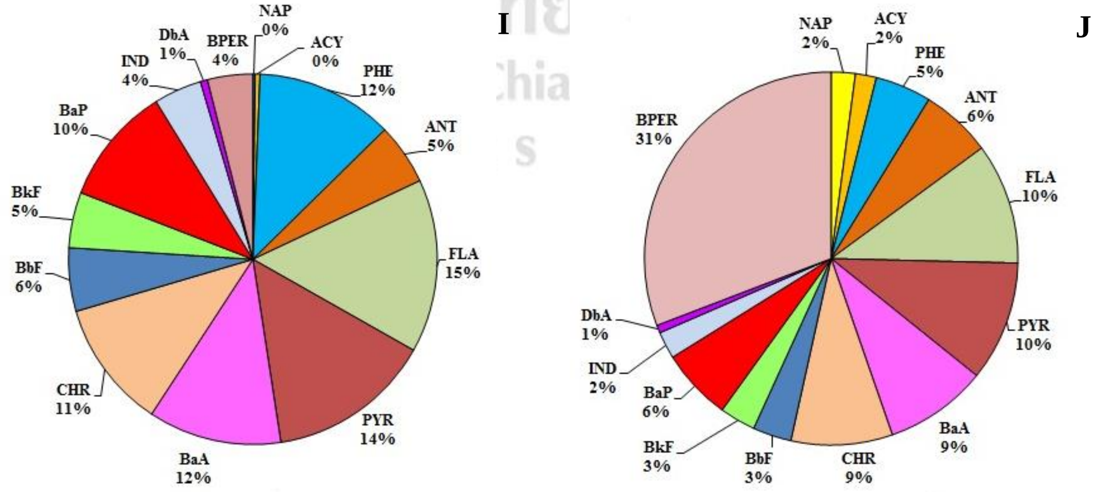


Figure 3.8 Percentage of $PM_{2.5}$ -bound PAHs emitted from aromatic incense cone burning (Types I and J).

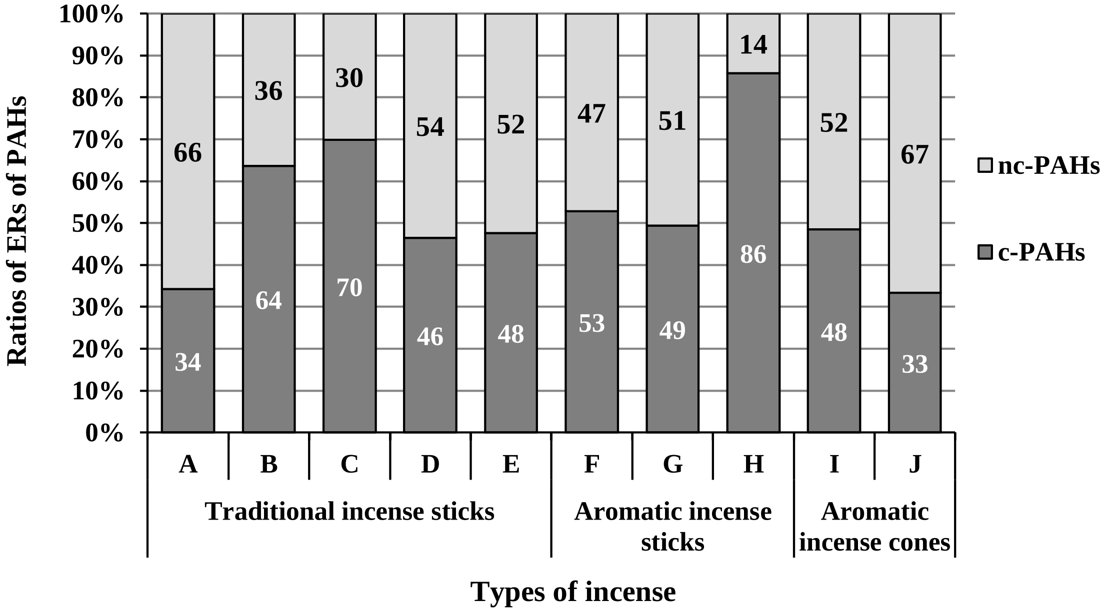


Figure 3.9 Ratios of c-PAHs and nc-PAH from burning of various incense types

The average c-PAH and nc-PAHs ranges emitted from all types of incense burning were 0.39±0.13 to 1.88±0.09 mg/kg (33-86 %) and 0.20±0.02 to 2.40±0.46 mg/kg (14-67 %), respectively. The highest EFs of c-PAHs was found in dye-dried flower incense (D) (1.88±0.09 mg/kg).

The 16-PAHs were clustered based on the number of aromatic rings in their structures (2, 3, 4, 5 and 6 rings) and plotted as the percentage of compounds emitted from the incense burning (Fig. 3.10). The EFs of PAHs from the burning of most of incense types (except D and E) in descending order were 4 rings (35 – 58 %) > 5 rings (13 – 45 %) > 3 rings (2 – 18 %) > 6 rings (6 – 33 %) > 2 rings (0-5 %). The dominant PAHs emitted from incense burning was 4-5 rings. Burning of incenses D and E emitted 3 and 6 rings in almost equal amount (28-35 %). Yang et al. (2007a, 2012a and 2013) studied particle–bound PAHs emitted from incense burning in a chamber in Taiwan and found that the dominant PAHs were in the form of 3 rings and 4 rings (50-56 %) and predominant PAHs were in the form of 4 rings (57.4 %). The EFs of $PM_{2.5}$-bound PAHs in this study was different from those values of TSP-bound

PAHs from mosquito coils burning reported by Lung and Hu (2003) and Yang et al. (2015b). They found that predominate 3 rings PAHs were 73.9-74.3 % (Lung and Hu, 2003) and 49.3-60.0 % (Yang et al., 2015b). Wu et al. (2009) reported that 5 and 6 rings of TSP- bound PAHs emitted from incense burning inside and outside a temple were 97.6 %. Yang et al. (2013) reported that high molecular weight PAHs with high carcinogenic potency are dominant in the particulate phase from incense burning. Wu et al. (2006) mentioned that mid-high molecular weight of PAHs (MW: 202-278) were mainly associated with diameter of particle less than 2 μm. Moreover, the smoldering conditions of incense burning could release 4-5 rings (Dewangan et al., 2014).

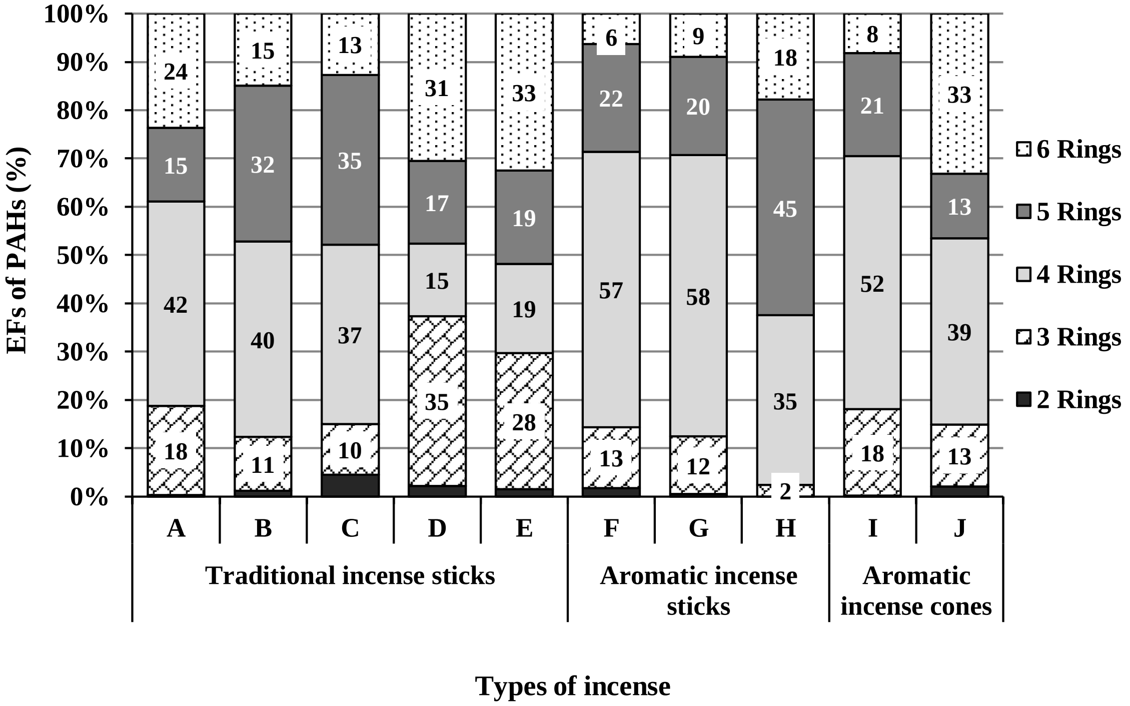


Figure 3.10 Ratio of PAHs containing 2-6 rings in $PM_{2.5}$ emitted from incense burning

3) Pollutant gases emitted from incense burning

Gas concentrations were continuously measured by gas analyzer during incense burning in a chamber. Table 3.5 show the gas EFs of SO_2 was not detected from all types of incense burning. The ranges of EFs of CO and NO emitted from incense burning were 92±3 to 174±8 g/kg and ND to 2.9±0.5 g/kg, respectively. The EFs of CO from burning of incenses in a descending order were traditional incense sticks (92±3 to 174±8 g/kg) > aromatic incense sticks (136±5 to 142±4 g/kg) > aromatic incense cones (112±6 to 129±11 g/kg). The EFs of CO of this study was the same with the results from (Lee and Wang, 2004), in which CO EFs were church incense (rocks) (228 g/kg) > traditional incense sticks (110 to 176 g/kg) > aromatic incense sticks (106 to 110 g/kg). EFs of CO emitted from incense stick burning (242 to 454 g/kg) were much lower than the values reported by in Thailand (Ongwandee and Pipithakul, 2010) and by Lee and Wang, 2004 at Kowloon, Hong Kong (106.6 to 217.0 g/kg).

Emission factors of NO in a descending order were traditional incense sticks (1.3±0.1 to 2.9±0.5 g/kg) > aromatic incense cones (2.0±0.5 to 2.3±0.0 g/kg) > aromatic incense sticks (ND to 2.0±0.1 g/kg). However, the EFs values of NO measured from traditional incense sticks burning in this study were almost the same with the values found in Hong Kong (0.4 to 2.6 g/kg). Similarly, EFs of NO released from aromatic incense sticks burning was higher than the concentration (0.3 to 1.5 g/kg) reported in the previous study (Lee and Wang, 2004).

The highest value of CO emission was from incense A (174±7.83 g/kg), while that of NO was incense E (2.9±0.5 g/kg). EFs values of CO and NO emitted from eco-friendly incense in this study were 92±3 to 142±7 g/kg and 1.3±0.1 to 2.9±0.5 g/kg, respectively. Moreover, Lee and Wang (2004) reported that the EFs values of CO (184.9 and 217.0 g/kg) were higher than the obtained values in this study, while values of NO (1.3 and 2.6 g/kg) was lower than the values from this study. The component of incense stick was made from sawdust in this study (D, E, F and G) found that EFs of CO concentrations was 92±3 to 142±4 g/kg, which the values were ~3 times lower than with Ongwandee and Pipithakul (2010) (242 to 454 g/kg).There was no NO emission from smoke-free incense (H).

Table 3.5 Concentrations of gas species emitted from incense burning

Type of incense	Code (n=3)	Concentrations (Mean±SD)			
		ppm (mg/L)		Emission factors (g/kg $_{incense}$)	
		CO	**NO**	**CO**	**NO**
Traditional incense sticks	A	5,385±152	72.7±5.4	174±8	1.4±0.8
	B	688±43	19.0±3.4	143±14	2.1±0.4
	C	695±55	9.2±0.8	142±7	2.0±0.2
	D	620±78	8.4±1.1	92±3	1.3±0.1
	E	682±68	4.9±2.8	99±8	2.9±0.5
Aromatic incense sticks	F	1,546±61	16.9±1.4	136±7	1.6±0.1
	G	4,096±133	55.1±3.7	142±4	2.0±0.1
	H	564±31	ND	136±5	ND
Aromatic incense cones	I	1,588±90	30.4±0.6	112±6	2.3±0.0
	J	546±54	7.6±1.3	129±11	2.0±0.5

3.3.2 Emission rates (ERs) of pollutants emitted from incense burning

The emission rates (ERs) were calculated by using Equation 2.4. The mass of pollutant emitted per burning time of incense types in the chamber were referred by Jetter et al. (2002). Table 3.6 presents ERs of PM$_{2.5}$ from incense burning. Due to different sizes and weight of incenses, their burning duration varied. Burning of traditional incense sticks took about 50 mins (except type A, which took 120 mins). Incense A was the biggest and heaviest among all types of incenses. Weight of incense J was almost the same as incense D and H, but the burning duration of incense J was ~2 times less than that of incense D (~38 mins) and H (~30 mins).

1) ERs of PM$_{2.5}$ emitted from incense burning

ERs of PM$_{2.5}$ from incense burning in a unit of incense weight per time of burning are shown in Table 3.6. ERs of PM$_{2.5}$ in a descending order were aromatic incense cones (86.7±8.2 to 179±29 mg/hr) > aromatic incense sticks (4.9±0.2 to 43.9±1.4 mg/hr) > traditional incense sticks (14.6±0.5 to 25.4±0.8 mg/hr). The ERs of PM$_{2.5}$ of this study was different from Lee and Wang (2004), in which ERs of PM$_{2.5}$

of traditional incense sticks (28.4 to 372.6 mg/hr) were higher than aromatic incense sticks (9.8 to 85.4 mg/hr).

Kruskal-Wallis test was used to differentiate the ERs of $PM_{2.5}$ concentrations between various types of incense (Table 3.6). The ERs values of $PM_{2.5}$ emitted from burning of traditional incense sticks and aromatic incense sticks were not significantly different ($p < 0.05$), but they were significantly lower than aromatic incense cones. ERs of $PM_{2.5}$ were highest from aromatic incense cones presented the highest values and incense I presented the highest value (179±29 mg/hr). The ERs of $PM_{2.5}$ of aromatic incense sticks (F and G) were significantly higher ($p<0.05$) than those of traditional incense sticks (incenses B, C, D and E). Moreover, the ERs of $PM_{2.5}$ emitted from hand-made incenses (incenses C, D, E and H) were significantly lower than those machine-based incenses (incenses A, F and G).

Furthermore, the ERs of $PM_{2.5}$ of aromatic incense cones (I and J) were significantly higher than those of incense sticks (A, B, C, D, E, F, G and H) ($p<0.05$). The smoke-free incense stick (H) emitted lowest amount of $PM_{2.5}$ comparing to other incense types, while dried flower/fruit peel based incense stick (C, D and E) emitted lower $PM_{2.5}$ than cone type.

The ERs of $PM_{2.5}$ of traditional incense sticks burning in various designed chambers were compared. The values in this study (14.6±0.5 to 25.4±0.8 mg/hr) were lower than those of Lee and Wang (2004) (28.4 to 373 mg/hr). Moreover, ERs of aromatic incense stick burning in Hong Kong (9.8 and 85.4 mg/hr) were higher than those of this study (4.9±0.2 to 43.9±1.4 mg/hr) (Lee and Wang, 2004). Comparing with Jetter et al. (2002), where four types of aromatic incense cones manufactured in many countries were burned in the chamber. ERs of $PM_{2.5}$ from the burning of incense cone in descending order were 198 mg/hr (Mexico), 119 mg/h (India), 34.9 mg/hr (Thailand), and 18.0 mg/hr (New Mexico, USA). The ERs of $PM_{2.5}$ of the products from Thailand and USA were much lower than those in this study (86.7±8.1 to 179±29 mg/hr). The reason might be from different ingredient of those incense cones.

The ERs of $PM_{2.5}$ of sandalwood odor incense stick burning in this study (23.3±1.1 mg/hr) were lower than the value obtained the previous work (Jetter et al., 2002 and Lee and Wang, 2004) from India (42.9 mg/hr), Hong Kong (243 mg/h) and Macau (28.4 mg/hr), while those of Canada (22.0 mg/hr) was almost same with this study. In Singapore, sandalwood odor incense sticks were burned in a chamber and the ERs of $PM_{2.5}$ (18.5±4.6 and 21.7±5.7 mg/hr) (See and Balasubramanian, 2011) were almost same with the value obtained in this study. Lee and Wang (2004) reported that ERs of $PM_{2.5}$ of eco-friendly incenses burning were 28.4 and 205 mg/hr, which were higher than the values from dried flower/fruit peel based incense (C, D and E) (16.1±1.9 to 17.4±1.8 mg/hr). The smoke-free incense stick burning (H) emitted low $PM_{2.5}$ (4.9±0.2 mg/hr), however, it was much higher than that of See and Balasubramanian (2011) (0.6±0.0 mg/hr).

Table 3.6 Burning duration, weight of incenses and $PM_{2.5}$ emission from incense burning

Types of incense	Incense code (n=3)	Burning duration (min)	Weight (g) of incense (Mean±SD)	$PM_{2.5}$ (Mean±SD)		
				mg	EFs ($g/kg_{incense}$)	ERs (mg/hr)
Traditional incense sticks ^{x}	A	120	10.07±0.10	50.8±1.6	5.0±0.2^{a}	25.4±0.8^{a}
	B	35	1.19±0.02	8.5±0.3	7.1±0.2^{b}	14.6±0.5^{ac}
	C	43	0.84±0.03	11.5±1.4	13.8±1.9^{c}	16.1±1.9^{ac}
	D	38	0.75±0.07	11.1±1.1	14.8±1.3^{c}	17.4±1.8^{ac}
	E	42	0.67±0.04	12.0±0.4	17.9±0.9^{d}	17.2±0.6^{ac}
Aromatic incense sticks ^{x}	F	65	1.95±0.04	25.3±1.3	13.0±0.5^{c}	23.3±1.2^{a}
	G	65	4.94±0.04	47.6±1.5	9.6±0.3^{e}	43.9±1.4^{b}
	H	30	0.71±0.04	2.4±0.1	3.4±0.2^{f}	4.9±0.2^{c}
Aromatic incense cones ^{y}	I	17	2.44±0.03	50.7±8.2	20.8±3.6^{d}	179±29^{d}
	J	15	0.73±0.08	21.7±2.0	30.0±4.7^{g}	86.7±8.2^{e}

Note: a, b, c, d, e, f and g = Significant differences ($p < 0.05$) among types of incense

x, y = Statistically significant among groups of incenses ($p<0.05$).

The incense based material was made from sawdust. The ranges of ERs of $PM_{2.5}$ in this study (D, E, F and G) (17.1±0.6 to 43.9±1.4 mg/hr) were lower than the previous work from Mahasarakham, Thailand (154±2 to 255±11 mg/hr) (Ongwandee and Pipithakul, 2010). Moreover, the ERs of dyed incense and essence added incense (G and J) were 43.9±1.4 and 86.7±8.1 mg/hr, while that of blue-dyed and essence-less incense (D) was 17.4±1.8 mg/hr. They were higher than dye-less and essence-less incenses (A, B, C and E) (14.6±0.5 to 25.4±0.8 mg/hr). Essence and dye used incense production could have been the cause of increased $PM_{2.5}$ emissions. Noticeably, selection of smoke-free incense is an alternative to reduce $PM_{2.5}$ emission in indoor environment.

2) ERs of $PM_{2.5}$–bound PAHs emitted from incense burning

The ERs of total PAHs (t-PAHs) from incense burning are shown in Table 3.7. One-Way ANOVA was used to differentiate the t-PAHs concentrations between various types of incenses. The t-PAHs emission rates (ERs) were 1/square root-transformed to achieve normal distribution. The ERs of t-PAHs released from incense burning in descending order were aromatic incense cones (10.5±1.7 to 30.7±1.5 µg/hr) > aromatic incense sticks (2.03±0.04 to 9.32±2.73 µg/hr) > tradition incense sticks (1.82±0.16 to 5.73±1.79 µg/hr). However, the ERs of PAHs emitted from traditional incense sticks burning were not significantly different from aromatic incense sticks, while those of aromatic incense cone were significantly higher than both groups.

The highest ERs of average t-PAHs was obtained from incense I (aromatic incense cone), while the lowest was incense C (longan peel based incense). The ERs of t-PAHs of smoke-free incense (H) was not significantly different ($p>0.05$) from longan peel based incense burning. The ERs of t-PAHs of dye-dried flower incense (D) and dried flower incense (E) were not significantly different. However, they were significantly higher than longan peel based incense (C). The ERs of t-PAHs values of hand-made incense sticks (B, C, D, E and H) ranged between 1.82±0.16 to 4.46±0.21 µg/hr, were lower than those of machine-based incense sticks (A, F and G) (5.73±1.79 to 9.32±2.72 µg/hr).

The lowest ERs of carcinogenic PAHs (c-PAHs) was obtained from longan peel based incense (C), but it was not significantly different from smoke-free incense (H) ($p>0.05$). Moreover, the highest ERs of c-PAHs was aromatic incense cones. In comparison with the study in Taiwan (Yang et al, 2012a), ERs of t-PAHs of smoke-free incense sticks (2.40±0.07 and 5.54±0.53 µg/hr) was almost same with this study (2.03±0.04 µg/hr), while those of sandalwood odor incense burning (5.33±0.19 to 5.79±0.34 µg/hr) were higher than this study (4.88±0.09 µg/hr).

It can be concluded that smoke-free incense and longan peel based incense have low emission of $PM_{2.5}$ and c-PAHs, indicating long-term exposure to PAHs may have less affect to human health. The ERs of both $PM_{2.5}$ and t-PAHs of machine-based incense sticks were higher than those of hand-made incense sticks. The results were opposite from EFs (mg/kg). The reasons might be from burning duration. Based on the same weight of incense (1 kg), burning of machine-based incense sticks was 2-4 times longer than that for hand-made incense sticks. Therefore, burned quantity for 1 hr burning duration of hand-made incense sticks was 2 times higher than those of hand-made incense sticks. Consequently, amount of pollutants emitted in 1 hr (ERs) from hand-made incense was higher than those of machine-base incense.

3) ERs of pollutant gases emitted from incense burning

Table 3.8 presented ERs of gases from all types of incense burning in the chamber. The ranges of ERs of CO and NO emitted from incense burning were 161±8 to 962±54 mg/hr and ND to 19.7±0.4 mg/hr, respectively. The ERs of CO from burning of incenses in a descending order were aromatic incense cones (375±37 to 962±54 mg/hr) > aromatic incense sticks (194±11 to 649±21 mg/hr) > traditional incense sticks (161±8 to 462±13 mg/h). The ERs of CO of this study was opposite from (Lee and Wang, 2004), in which ERs were traditional incense sticks (401 to 795 mg/hr) > church incense (rocks) (653 mg/hr) > aromatic incense sticks (140 to 150 mg/hr). ERs of CO of incense stick burning (161±8 to 649±21 mg/hr) were lower than those reported in Thailand (378±12 to 790±47 mg/hr) (Ongwandee and Pipithakul, 2010) and in Hong Kong (140 to 795 mg/hr) (Lee and Wang, 2004) However, the ERs values obtained from aromatic incense cones in this study were higher than those reported by Jetter et al. (2002) (144 to 531 mg/hr).

Table 3.7 Emission rates (ERs) of PAHs (µg/hr) from incense burning in the chamber

Compounds (n=3)	**Traditional incense sticks^{x}**					**Aromatic incense sticks^{x}**			**Aromatic incense cones^{y}**	
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
PM$_{2.5}$(mg/hr)	25.4±0.8	14.6±0.5	16.1±1.9	17.4±1.8	17.2±0.6	23.3±1.2	43.9±1.4	4.9±0.2	179±29	86.7±8.2
NAP	0.02±0.00	0.05±0.00	0.08±0.01	0.08±0.04	0.06±0.02	0.08±0.00	0.04±0.00	ND	0.06±0.02	0.22±0.02
ACY	0.04±0.00	0.06±0.01	0.08±0.01	0.04±0.02	0.04±0.03	0.07±0.00	0.05±0.01	ND	0.12±0.02	0.19±0.02
ACE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FLU	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PHE	0.63±0.31	0.23±0.04	0.03±0.00	0.40±0.06	0.34±0.13	0.31±0.09	0.78±0.15	0.000	3.70±0.83	0.51±0.18
ANT	0.38±0.15	0.20±0.00	0.09±0.00	0.91±0.05	0.80±0.16	0.23±0.03	0.29±0.03	0.05±0.02	1.64±0.23	0.65±0.12
FLA	0.86±0.32	0.42±0.01	0.08±0.01	0.14±0.07	0.21±0.04	0.77±0.08	1.62±0.49	0.06±0.02	4.65±0.14	1.10±0.30
PYR	0.74±0.31	0.38±0.01	0.07±0.02	0.07±0.02	0.20±0.10	0.72±0.07	1.38±0.38	0.04±0.02	4.42±0.12	1.09±0.31
BaA	0.41±0.12	0.48±0.03	0.24±0.02	0.22±0.13	0.22±0.03	0.66±0.04	1.12±0.45	0.24±0.01	3.59±0.26	0.94±0.14
CHR	0.42±0.11	0.53±0.04	0.28±0.04	0.15±0.04	0.15±0.05	0.63±0.05	1.31±0.49	0.38±0.08	3.44±0.32	0.92±0.12
BbF	0.25±0.13	0.43±0.07	0.17±0.02	0.12±0.06	0.10±0.03	0.33±0.03	0.68±0.23	0.41±0.05	1.70±0.13	0.35±0.04
BkF	0.16±0.08	0.34±0.02	0.18±0.01	0.13±0.02	0.21±0.05	0.29±0.03	0.48±0.17	0.21±0.03	1.49±0.03	0.33±0.03
BaP	0.38±0.13	0.49±0.07	0.23±0.04	0.23±0.04	0.29±0.07	0.41±0.02	0.67±0.21	0.27±0.05	3.18±0.15	0.66±0.12
IND	0.26±0.08	0.39±0.03	0.11±0.02	0.76±0.08	0.81±0.06	0.19±0.01	0.27±0.06	0.22±0.01	1.29±0.13	0.25±0.04
DbA	0.08±0.01	0.18±0.01	0.06±0.01	0.18±0.04	0.20±0.02	0.05±0.00	0.07±0.02	0.02±0.00	0.19±0.04	0.06±0.03
BPER	1.10±0.08	0.28±0.00	0.12±0.02	0.41±0.09	0.54±0.10	0.12±0.01	0.56±0.14	0.14±0.02	1.22±0.20	3.23±0.58
t-PAHs	**5.73±1.79^{a}**	**4.46±0.21^{ac}**	**1.82±0.16^{b}**	**3.84±0.06^{c}**	**4.16±0.62^{c}**	**4.88±0.09^{ac}**	**9.32±2.72^{d}**	**2.03±0.04^{b}**	**30.7±1.5^{e}**	**10.5±1.7^{d}**
c-PAHs	**1.96±0.63 ^{a}**	**2.84±0.16 ^{b}**	**1.27±0.13^{c}**	**1.78±0.04 ^{a}**	**1.98±0.17^{ab}**	**2.56±0.16^{ab}**	**4.60±1.62^{d}**	**1.74±0.03^{a}**	**14.9±0.7^{e}**	**3.51±0.51^{d}**
nc-PAHs	**3.76±1.16**	**1.62±0.05**	**0.55±0.04**	**2.06±0.10**	**2.18±0.45**	**2.30±0.24**	**4.72±1.11**	**0.29±0.02**	**15.8±1.3**	**6.98±1.38**

a, b, c, d, and e = Significant differences ($p < 0.05$) among group incense types and x and y = Statistically significant for grouping of incense (*p*<0.05) based on t-PAHs; ND = Not detected

Table 3.8 Emission rates of gas species emitted from incense burning

Type of incense	Code (n=3)	Burning duration (min)	Mean±SD			
			mg		Emission rates (mg/hr)	
			CO	NO	CO	NO
Traditional incense sticks	A	120	925±26	102±5	462±13	6.7±0.5
	B	35	118±7	3.5±0.6	202±13	6.0±1.1
	C	43	119±9	1.7±0.2	166±13	2.4±0.2
	D	38	102±5	1.2±0.6	161±8	1.8±0.9
	E	42	117±12	0.9±0.5	167±17	1.3±0.7
Aromatic incense sticks	F	65	266±11	3.1±0.3	245±10	2.9±0.2
	G	65	703±23	10.1±0.7	649±21	9.4±0.6
	H	30	96.8±5.8	ND	194±10	ND
Aromatic incense cones	I	17	273±15	5.6±0.1	962±54	19.7±0.4
	J	15	93.8±9.2	1.4±0.2	375±35	5.6±1.0

ERs of NO in a descending order were aromatic incense cones (5.6±1.0 to 19.7±0.4 mg/hr) > aromatic incense sticks (ND to 9.4±0.6 mg/hr) > traditional incense sticks (1.3±0.7 to 6.7±0.5 mg/h). The values of traditional incense sticks burning were lower than those in Hong Kong (1.5 to 7.8 mg/hr) (Lee and Wang, 2004). Moreover, the values of aromatic incense sticks burning were lower than those reported in the previous study (0.3 to 1.9 mg/hr) (Lee and Wang, 2004). The ERs of NO of aromatic incense cone burning in this study were higher than those in USA (0.16 to 4.39 mg/hr) (Jetter et al., 2002).

The highest ERs of CO and NO was obtained from incense I (962±54 mg/hr for CO and 19.7±0.4 mg/hr for NO), while the lowest values were from dried flower/fruit peel based incenses (161±8 mg/hr (D) and 1.3±0.7 mg/hr (E), respectively) and even lower than the smoke-free incense (H). ERs of CO (608 to 643 mg/hr) and NO (4.3 to 7.8 mg/hr) emitted from environmental- friendly incense burning (Lee and Wang, 2004) were ~4 times higher than those of dried flower/fruit peel based incense in this study. The component of incense stick was made from sawdust in this study (D, E, F and G) found that ERs of CO (161±8 to 649±21 mg/hr) were lower than those of Ongwandee and Pipithakul (2010) (378±12 to 790±47 mg/hr). There was no NO emission from smoke-free incense (H).

3.3.3 Emission of pollutants from burning of raw materials used for incense production

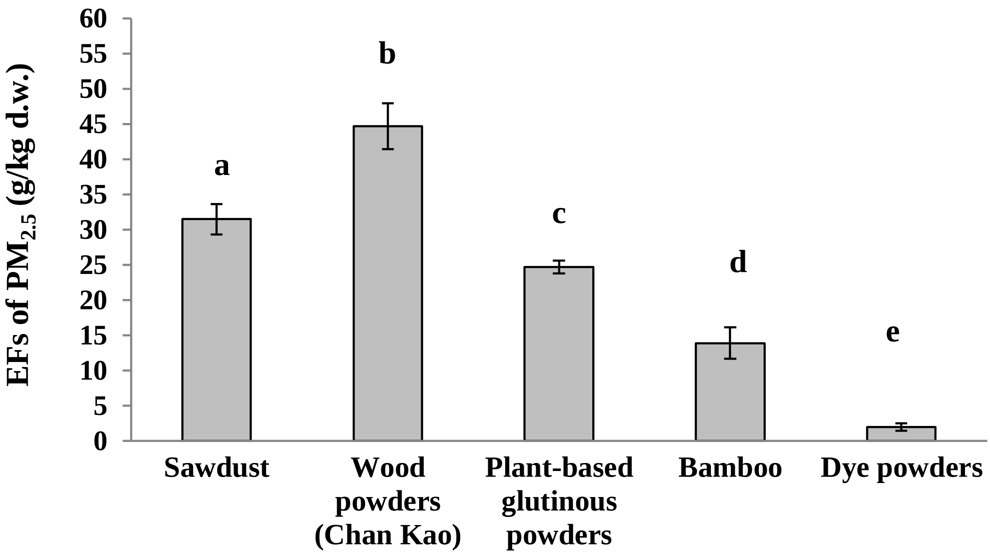
1) $PM_{2.5}$ emitted from raw material burning

Approximately one gram of each raw material was burned in the chamber until the burning process was completed (~30 mines). The experiment was repeated 3 times for each type. $PM_{2.5}$ was collected as mentioned in topic 2.8 (Chapter 2). Weight of $PM_{2.5}$ emitted was calculated into concentrations (mg/m^3) and EFs ($gPM_{2.5}/kg_{\ d.w.}$) as shown in Table 3.9, Figure 3.11 and Table D-2 (Appendix D). Emission factors (EFs) of $PM_{2.5}$ (g/kg) from raw materials burning in descending order were 44.7±3.2 (wood powders) > 31.5±2.2 (sawdust) > 24.7±0.9 (plant-based glutinous powders) > 13.9±2.2 (bamboo stick) > 2.00±0.5 (dye powders). One-Way ANOVA was used to differentiate $PM_{2.5}$ emitted from different of raw materials. Concentrations of $PM_{2.5}$ were log–transformed to achieve normal distribution. The EFs of $PM_{2.5}$ emitted from raw materials were found to be significantly different ($p<0.05$). In comparison with the study of Schauer et al. (2001), their $PM_{2.5}$ emission factors from pine (9.5±1.0 g/kg), oak (5.1±0.5 g/kg) and eucalyptus (8.5±0.8 g/kg) burning in a fireplace were lower than those of raw material burning found in this study except for dye powders burning. Iinuma et al. (2007) found that the EFs of $PM_{2.5}$ released from burning of softwood (pine wood, pine wood with green needles and spruce with green needles) in a laboratory were 5.5 to 7.9 g/kg, while the EFs of the burning of hardwood (musasa) and Indonesian peat were 5.6 g/kg and 33.0 g/kg, respectively. However, it was found that $PM_{2.5}$ emission factors from softwood and hardwood burning were lower than those found in this study.

Table 3.9 Emission factors of $PM_{2.5}$ from raw material burning

Raw materials (n = 3)	**$PM_{2.5}$ (Mean±SD)**		
	mg	**mg/m^3**	**EFs (g/kg $_{d.w.}$)**
Sawdust	31.6±2.2	97.8±6.7	31.5±2.2
Wood powders (Chankao)	44.9±3.2	139.0±10.1	44.7±3.2
Plant-based glutinous powders (tree bark)	24.7±0.9	76.5±2.7	24.7±0.9
Bamboo stick	14.0±2.2	43.1±6.9	13.9±2.2
Dye powders	2.0±0.5	6.18±1.7	2.0±0.5

Note: volume of air = 0.32 m^3



a, b, c, d, and e = Significant differences ($p < 0.05$) among groups of raw materials

Figure 3.11 Emission factors of $PM_{2.5}$ from burning of raw materials used for incense production

2) $PM_{2.5}$–bound PAHs emitted from raw material burning

$PM_{2.5}$ samples collected from various types of raw materials burning were extracted as described in section 2.10, Chapter 2 and analyzed by GC-MS for PAHs content. The EFs of PAHs are shown in Table 3.10. The EFs of PAHs (mg/kg) from raw material burning in descending order were 1.44±0.09 (saw dust) ~ 1.46±0.19 (wood powders) > 0.74±0.07 (plant-based glutinous powders) > 0.60±0.07 (bamboo stick) > 0.38±0.07 (dye powders). One-Way ANOVA was used to differentiate the t-PAHs concentrations between raw materials. The EFs of t-PAHs from sawdust and wood powders (Chankao) were not significantly different ($p>0.05$), but they were significantly higher ($p>0.05$) than that from plant-based glutinous powders. There was no significant difference ($p>0.05$) between plant-based glutinous powders and bamboo, while dye powder was significantly lower than those values of all types materials. Lu et al., (2009) reported that EFs of t-PAHs on TSP from rice straw and bean straw burning were 9.29-23.6 mg/kg and 3.13-49.9 mg/kg, respectively. Jenkins et al., (1996) and Oanh et al., (1999) found that TSP–bound t-PAHs emitted from biomass burning were 43-192 mg/kg (wood), 14.23 mg/kg (almond), 25.05 mg/kg (walnut), 30.58 mg/kg (fir) and 28.96 mg/kg (pine). The EFs of t-PAHs were highest from sawdust and lowest from dye powders. The EF of PM_{10}-bound biomass emitted from burning of rice straw, leaf litter and maize residue in the chamber were 0.465±0.213 mg/kg, 0.910±0.277 mg/kg and 0.469±0.106 mg/kg, respectively (Wiriya et al., 2015).

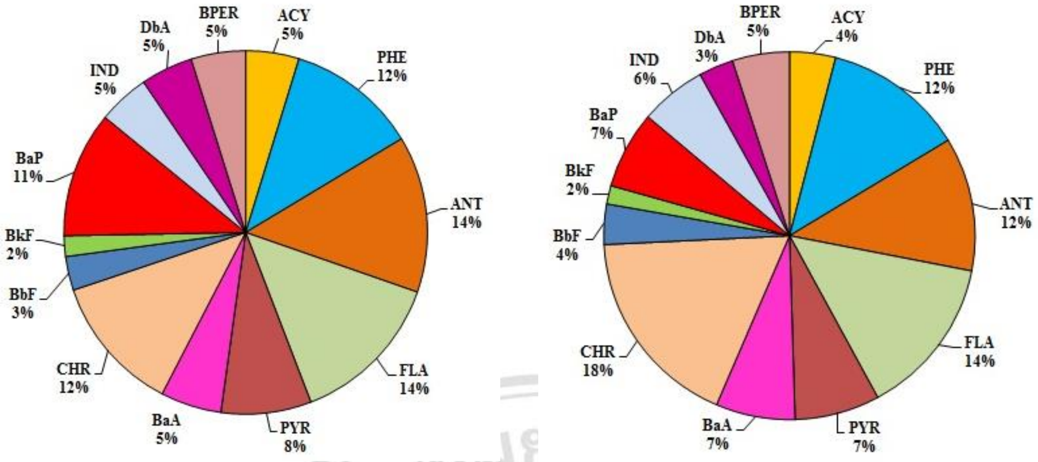
The dominant PAHs emitted from raw material burning were ANT (12-20%), FLA (9-19%), CHR (12-30%) and PHE (8-13%) as shown in Figure 3.12. The study of Jenkins et al. (1996) found that the dominant 19-PAHs emitted from almond wood burning were NAP, ACY, PHE and FLA. The burning of walnut wood emitted NAP, ACE, PHE, while pine burning emitted NAP, PHE, 2-mNAP and ACE. Moreover, Hedbery et al. (2002) reported that FLU, PHE, ANT, FLA and PYR contributed to more than 70% of mass PAHs from birch wood burning. Oanh et al., (1999) reported that DbA, BPER and COR (Coronene) were the dominant PAHs of particle phase from wood burning. A study from Shauer et al. (2001) showed that PHE and ANT were major $PM_{2.5}$-bound PAHs emitted from wood burning. Iinuma et al. (2007) reported that FLU, PHE, BaP and BbF were the dominant of the $PM_{2.5}$-bound PAHs emitted from burning of peat, soft wood and savanna grass. According to the previous studies PHE was the major from the PAHs released from wood burning (Jenkins et al., 1996; Shauer et al., 2001; Iinuma et al., 2007). Ratios of EFs of c-PAHs and nc-PAHs from burning all selected raw materials for incense production were 38-63 % and 37-62 %, respectively (Fig. 3.13).

Figure 3.14 shows ratios of EFs of PAHs containing different number of rings. The PAHs EFs in descending order were 4 rings (47-68 %) > 3 rings (18-32 %) > 5 rings (13-24 %) > 6 rings (ND-10 %). The 2 rings were not found in this study. The major component of $PM_{2.5}$-bound PAHs released from raw material burning was 3 and 4 rings. Hedderg et al. (2002) revealed mass of PAHs emitted from birch wood was 70% of 3 and 4 rings PAHs (FLU, PHE, ANT, FLA and PYR). Wiriya et al. (2015) reported that 4 and 5 rings were the major PM_{10}-bound PAHs collected from biomass burning in a chamber. The 5 rings (40% and 60%) and 6 rings (19-32%) were the dominant PAHs released from biomass pellets in biomass boiler (Atkins et al., 2010). Unlike the other, Hall et al. (2012) found high ratio of 2 rings (66%), while 3 rings (27%) and 4 rings (8%) were less in the $PM_{2.5}$-bound PAHs released from Florida sugarcane burning. Moreover, they mentioned that PAHs formation is sensitive to temperature because they were well formed at high temperature (excess of 500 °C) (Conde et al., 2005). However, high moisture content in fuels might decrease temperature and efficiency in combustion which it possibly inhibited PAHs formation (Korenaga et al., 2001).

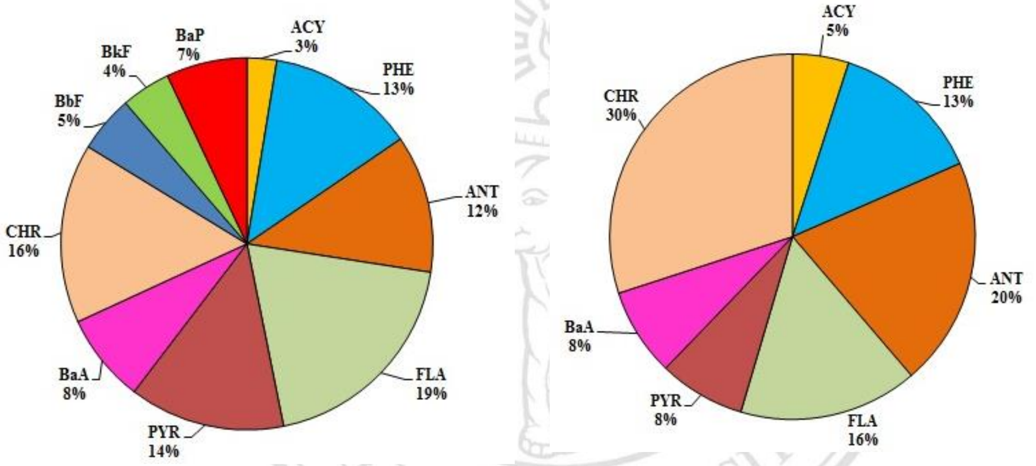
Table 3.10 Emission factors of PAHs (mean±SD.) from raw material burning in a chamber.

PAHs (n=3)	**EFs of PAHs (µg/kg $_{d.w}$)**				
	Sawdust	**Wood powders (Chan Kao)**	**Plant-based glutinous powders**	**Bamboo**	**Dye powders**
NAP	ND	ND	ND	ND	ND
ACY	68.5±5.9	58.4±29.0	19.2±2.1	30.1±8.0	ND
ACE	ND	ND	ND	ND	ND
FLU	ND	ND	ND	ND	ND
PHE	168±12	180±36	95.5±13.8	81.3±16.9	29.3±3.7
ANT	201±14	172±14	88.8±4.0	123±17	44.9±3.0
FLA	200±16	205±27	144±15	95.6±24.6	30.1±7.5
PYR	116±9	108±17	100±13	46.2±8.0	32.4±6.4
BaA	78.3±6.0	101±10	57.5±8.6	47.0±7.0	28.8±3.3
CHR	177±22	260±32	116±12	181±28	98.4±44.7
BbF	43.6±3.5	52.8±9.3	36.7±6.6	ND	17.3±1.5
BkF	26.5±2.7	23.6±1.6	52.1±4.5	ND	48.1±5.5
BaP	162±24	99.2±21.7	28.4±2.2	ND	46.9±2.2
IND	66.1±14	84.7±13.2	ND	ND	ND
DbA	67.2±32	44.2±10.8	ND	ND	ND
BPER	70.0±14	72.5±11.4	ND	ND	ND
t-PAHs (mg/kg)	**1.44±0.09** ^{a}	**1.46±0.19** ^{a}	**0.74±0.07** ^{b}	**0.60±0.07** ^{b}	**0.38±0.07** ^{c}
c-PAHs (mg/kg)	**0.62±0.05**	**0.66±0.09**	**0.29±0.03**	**0.23±0.04**	**0.24±0.05**
nc-PAHs (mg/kg)	**0.82±0.04**	**0.79±0.10**	**0.45±0.04**	**0.38±0.04**	**0.14±0.02**

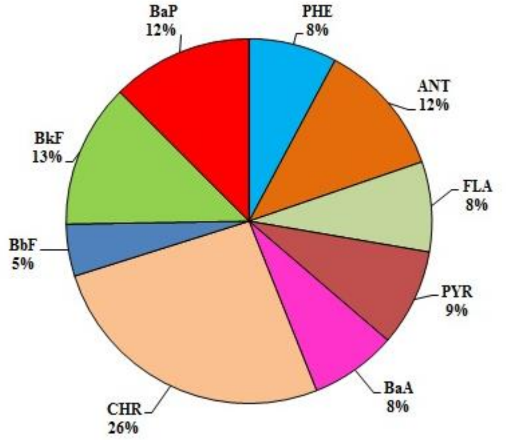
a, b and c = Significant differences ($p < 0.05$) among groups of raw material
ND = Not detected



Sawdust **Wood powders (Chankao)**



Plant-based glutinous powders **Bamboo sticks**



Dye powders

Figure 3.12 Variation of $PM_{2.5}$-bound PAHs $_5$ from raw materials burning

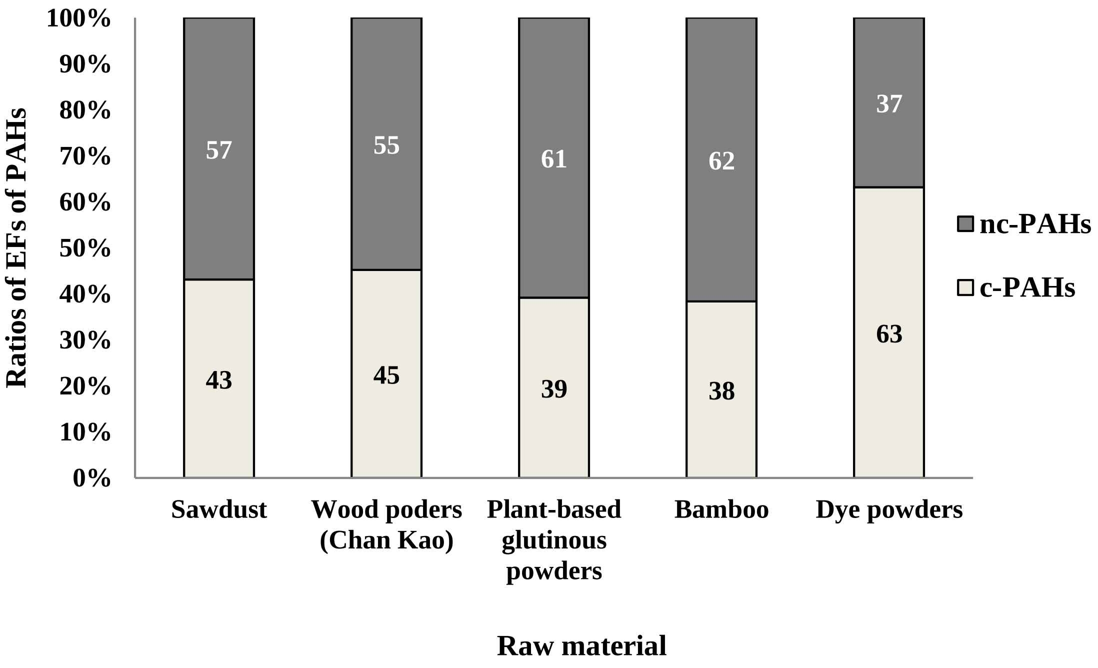


Figure 3.13 Ratios of c-PAHs and nc-PAH from burning of raw materials used for incense production

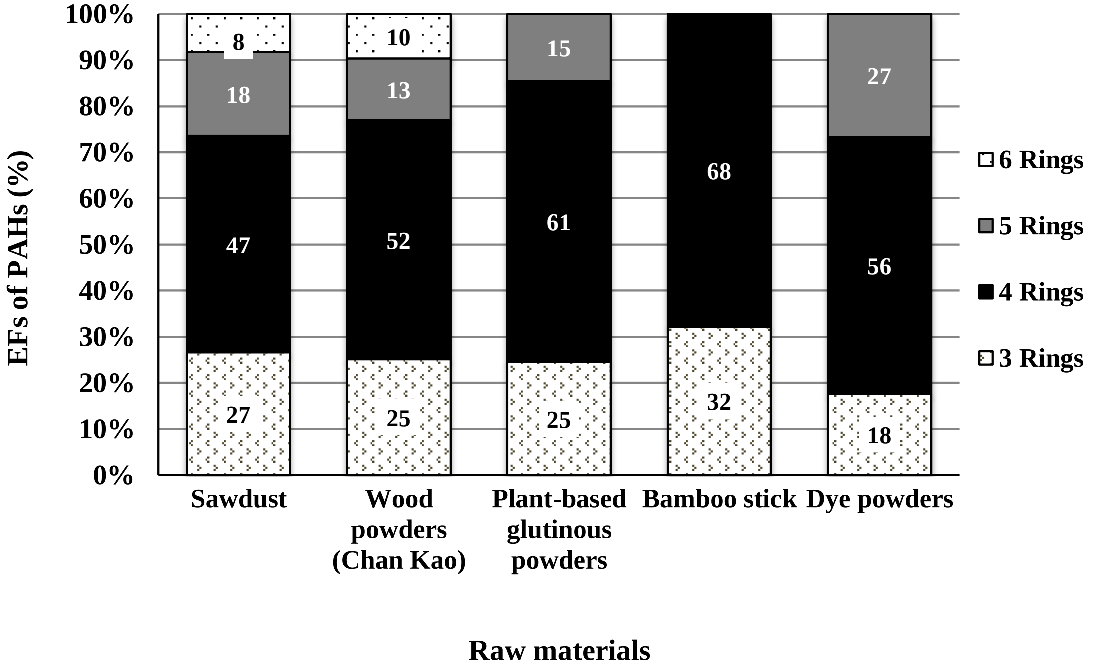


Figure 3.14 Ratios of PAHs containing 3-6 rings in $PM_{2.5}$ emitted from burning of raw materials used for incense production

4) Toxic Gases emitted from raw material burning

Toxic gases including CO, NO and SO_2 emitted from burning of raw material were monitored using a gas analyzer throughout the experiment. Their EFs are shown in Table 3.11. The EFs of CO emitted from raw material burning ranged 3.1±0.2 to 177±4 g/kg, while those of NO were 0.28±0.07 to 1.02±0.17 g/kg. SO_2 was only found in burning of dye powders (15.96±0.96 g/kg). The trend of gases emitted from burning of all types of incense and raw materials were the same. CO was the dominant gas emitted. Saw dust burning emitted the highest CO (177±4 g/kg), whereas dye powders burning emitted only small amount of CO per weight of fuel (3.1±0.2 g/kg). The highest EFs of NO was found from plant-based glutinous powders (0.49±0.09 g/kg). Comparing with the previous studies, it was found that CO emission factors from raw material burning in this study were higher than those released from wood burning (31.65±0.08 to 64.96±0.05 g/kg) measured from a chamber (Bruns et al., 2015). Moreover, the EFs of CO and SO_2 were higher than the values released from rice straw (34.70 and 2.00 g/kg) and crop residues (92.00 and 0.40 g/kg) in India, Thailand and Philippines (Satyendra et al., 2013). Sillapapiromsuk et al. (2013) studied the EFs values of CO, NO and SO_2 released from burning of biomass in a chamber (rice straw, maize residue and leaf litter), which were 40.8±9.5 to 54.0±15.7 g/kg (CO), 0.8±0.2 to 1.8±0.7 g/kg (NO) and 0.2±0.3 to 0.4±0.6 g/kg (SO_2). However, it was found that the EFs values were lower than the value of raw material burning in study.

Table 3.11 Concentrations of gas species emitted from raw materials burning

Gases (n=3)	**EFs weight**	**Raw materials (Mean±SD)**				
		Sawdust	**Wood powders (Chan Kao)**	**Plant-based glutinous powders**	**Bamboo**	**Dye powders**
CO	ppm	1,032±24	970±30	493±20	754±104	18±1
	g/kg	177±4	166±5	84±3	129±18	3.1±0.2
NO	ppm	1.55±0.39	2.65±0.48	5.58±0.94	4.94±1.13	ND
	g/kg	0.28±0.07	0.49±0.09	1.02±0.17	0.91±0.21	ND
SO_2	ppm	ND	ND	ND	ND	40.7±2.4
	g/kg	ND	ND	ND	ND	16.0±1.0

3.3.4 Correlations of $PM_{2.5}$ and $PM_{2.5}$-bound PAHs emitted from the burning of incense and its raw material in the chamber

1) Correlation of $PM_{2.5}$ and individual PAHs

Correlations of $PM_{2.5}$ and individual PAHs were tested using the Spearman's correlations as shown in Tables 3.9 and 3.10. The Spearman's correlations can be classified into strong (*r*=1.000-0.500), moderate (*r*=0.499-0.300) and weak (*r*=0.299-0.000) (Xie et al., 2015).

1.1) Incense burning

The correlations of $PM_{2.5}$ and PAHs species are shown in Table 3.12. It was found that the correlation between PHE, ANT, FLA, BaA, BPER and $PM_{2.5}$ concentrations was strong (*r*=0.5-0.7). Moreover, the correlations between $PM_{2.5}$ and BaP were strong (*r*=0.611) ($p < 0.05$). Strong correlations among individual PAHs in the same group of molecular structure such as 4 rings PAHs; FLA and PYR (*r*=0.965) and BaA and CHR (*r*=0.794). Similar degree of correlation was also found between 5 rings PAHs. BaP was also moderately significantly correlated with 5 rings PAHs.

Strong correlation was observed for individual PAHs including FLA & PYR (r=0.965) and BaA & CHR (r=0.794). The correlations between ANT and PHE (r=0.796) was relatively strong (p<0.01).

1.2) Raw material burning

Significantly strong correlations were found between concentrations of $PM_{2.5}$ and 4 and 5 rings PAHs (p<0.01) as shown in Table 3.13. The 3 rings PAHs (PHE and ANT) were highly correlated with 4 rings (FLA, PYR, BaA and CHR) (p<0.01). There was a strong correlations among individual PAHs in the same group of the 4 ring PAHs such as FLA & PYR (r=0.915), FLA & BaA (r=0.946), PYR & BaA (r=0.810) and BaA & CHR (r=0.798) (p<0.01). The correlations of 4-rings PAHs were strongly significantly correlated with 5 rings PAHs such as PYR & BbF (r=0.754), PYR & BaP (r=0.797), BaA & BbF (r=0.815) and BaA & BaP (r=0.733). The correlations between BbF & BaP (r=0.821) and BaP & DbA (r=0.861) was relatively strong (p<0.01).

However, high correlations were found between PHE & ANT, FLA & PYR and BaA & CHR. They were used for calculation of isomeric ratios for identification of sources of incense and biomass burning (Hischenhuder and Stijve, 1987; Yunker et al., 2002; Orecchio, 2010; Orecchio, 2011; Yang et al., 2013)

Table 3.12 Correlation coefficients of $PM_{2.5}$ and $PM_{2.5}$-bound PAHs obtained from incense burning

N = 30	**$PM_{2.5}$**	**NAP**	**ACY**	**ACE**	**FLU**	**PHE**	**ANT**	**FLA**	**PYR**	**BaA**	**CHR**	**BbF**	**BkF**	**BaP**	**IND**	**DbA**	**BPER**
$PM_{2.5}$	1.000																
NAP	**0.645****	1.000															
ACY	**0.635****	0.864**	1.000														
ACE	ND	ND	ND	ND													
FLU	ND	ND	ND	ND	ND												
PHE	**0.646****	0.283	0.153	ND	ND	1.000											
ANT	**0.792****	**0.637****	**0.545****	ND	ND	**0.796****	1.000										
FLA	**0.505****	0.013	0.087	ND	ND	**0.605****	0.355	1.000									
PYR	**0.501****	-0.039	0.071	ND	ND	**0.562****	0.311	**0.965****	1.000								
BaA	**0.608****	0.304	0.282	ND	ND	**0.506****	0.438*	**0.745****	**0.716****	1.000							
CHR	0.289	-0.077	0.072	ND	ND	0.125	-0.007	**0.661****	**0.645****	**0.794****	1.000						
BbF	-0.243	-0.363*	-0.162	ND	ND	-0.236	-0.273	0.047	0.023	0.270	**0.651****	1.000					
BkF	0.240	0.114	0.214	ND	ND	0.149	0.265	0.157	0.150	0.347	0.342	0.462*	1.000				
BaP	**0.611****	0.354	0.335	ND	ND	**0.534****	**0.648****	0.405*	0.371*	**0.677****	0.399*	0.215	**0.679****	1.000			
IND	0.220	0.252	0.206	ND	ND	0.351	**0.569****	-0.196	-0.228	0.106	-0.098	0.280	**0.602****	**0.596****	1.000		
DbA	0.389*	**0.659****	**0.596****	ND	ND	0.423*	**0.699****	-0.064	-0.080	0.124	-0.223	-0.149	0.458*	**0.478****	**0.694****	1.000	
BPER	**0.537****	0.350	0.243	ND	ND	**0.464****	**0.630****	0.089	0.097	-0.028	-0.316	**-0.512****	-0.199	0.207	0.216	0.294	1.000

**Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

ND = not detected

The strong correlations were marked with bold values.

Table 3.13 Correlation coefficients of $PM_{2.5}$ and $PM_{2.5}$-bound PAHs obtained from raw materials burning

N = 15	$PM_{2.5}$	NAP	ACY	ACE	FLU	PHE	ANT	FLA	PYR	BaA	CHR	BbF	BkF	BaP	IND	DbA	BPER
$PM_{2.5}$	1.000																
NAP	ND	ND															
ACY	0.763**	ND	1.000														
ACE	ND	ND	ND	ND	ND												
FLU	ND	ND	ND	ND	ND												
PHE	0.939**	ND	0.867**	ND	ND	1.000											
ANT	0.779**	ND	0.946**	ND	ND	0.854**	1.000										
FLA	0.946**	ND	0.821**	ND	ND	0.964**	0.836**	1.000									
PYR	0.884**	ND	0.683**	ND	ND	0.904**	0.747**	0.915**	1.000								
BaA	0.962**	ND	0.815**	ND	ND	0.948**	0.816**	0.946**	0.810**	1.000							
CHR	0.704**	ND	0.792**	ND	ND	0.746**	0.757**	0.686**	0.483	0.798**	1.000						
BbF	0.836**	ND	0.518*	ND	ND	0.802**	0.491	0.832**	0.754**	0.815**	0.542	1.000					
BkF	-0.388	ND	-0.628	ND	ND	-0.444	-0.600*	-0.363	-0.227	-0.423	-0.706**	0.055	1.000				
BaP	0.768**	ND	0.617*	ND	ND	0.766**	0.682**	0.811**	0.797**	0.733**	0.325	0.821**	0.083	1.000			
IND	0.858**	ND	0.866**	ND	ND	0.866**	0.798**	0.874**	0.718**	0.868**	0.741**	0.769**	-0.304	0.793**	1.000		
DbA	0.795**	ND	0.839**	ND	ND	0.839**	0.861**	0.843**	0.749**	0.790**	0.619*	0.679**	-0.264	0.861**	0.947**	1.000	
BPER	0.807**	ND	0.766**	ND	ND	0.766**	0.719**	0.772**	0.635	0.822**	0.686**	0.735**	-0.250	0.788**	0.883**	0.861**	1.000

**Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

ND = not detected

2) Correlations between $PM_{2.5}$ and PAHs concentrations (t-PAHs, c-PAHs and nc-PAHs)

Correlations of $PM_{2.5}$ and PAHs released from the incense and raw materials burning in a chamber were analyzed by Spearman correlation (Table 3.14).

Table 3.14 Correlations between PAHs and $PM_{2.5}$ from burning of incense and their raw materials in the chamber

	$PM_{2.5}$	**t-PAHs**	**c-PAHs**	**nc-PAHs**
Incense burning (n=30)				
$PM_{2.5}$	1.000			
t-PAHs	0.818**	1.000		
c-PAHs	0.452*	0.799**	1.000	
nc-PAHs	0.818**	0.931**	0.604**	1.000
Raw material burning (n=15)				
$PM_{2.5}$	1.000			
t-PAHs	0.925**	1.000		
c-PAHs	0.857**	0.946**	1.000	
nc-PAHs	0.914**	0.996**	0.943**	1.000

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

For incense burning, there was strong correlation between $PM_{2.5}$ and PAHs (t-PAHs and nc-PAHs). A significantly moderate correlation ($p < 0.05$) was found between $PM_{2.5}$ and c-PAHs (r=0.452). Moreover, t-PAHs was strongly correlated with c-PAH (r=0.799) and nc-PAH (r=0.931).

For raw material burning, correlations between $PM_{2.5}$ and PAHs (t-PAHs, c-PAHs and nc-PAHs) were strong (r=0.8-0.9). Furthermore, t-PAHs was strongly correlated with c-PAH (r=0.946) and nc-PAH (r=0.996). In addition, c-PAHs was strongly correlate with nc-PAHs (r=0.943).

3.3.5 Toxicity equivalent (TEQ) and mutagenic equivalent (MEQ) concentration of incense and raw material burning

Estimation of carcinogenic health risks associated with the exposure of $PM_{2.5}$-bound PAHs can be calculated for toxicity equivalent (TEQ) and mutagenic equivalent (MEQ) concentrations (Nisbet and Lagoy, 1992; Jung et al., 2010). TEQs calculation is based on the toxic equivalent factor (TEFs) proposed by Nisbet and Lagoy (1992), while mutagenic equivalent factor (MEFs) is calculated based on Durant et al. (1999).

1) TEQ and MEQ based on EFs (mg/kg)

The mean TEQ and MEQ values calculated for each type of incense and raw material are shown in Table 3.15 to 3.17. The TEQ and MEQ values (mg/kg) from incense burning in descending order were traditional incense sticks (0.138 to 0.649 and 0.162 to 0.724) > aromatic incense cone (0.306 to 0.425 and 0.541 to 0.558) > aromatic incense sticks (0.235 to 0.354 and 0.266 to 0.384).

In case of incense burning, the highest values of TEQ (0.649±0.030 mg/kg) and MEQ (0.724±0.035 mg/kg) were found in incense E, which is made from dried flower. However, the mean MEQ values were approximately 2-3 times higher than TEQ values for all types of incense burning. The main reason was that the MEF value of individual PAHs was calculated from Eq. 2.6 (page 58), in which the BbF and BPER emitted from incense burning were set in MEF calculation for almost 1-2 times higher than that in the TEF equation (see page 57 and Table 2.5).

Comparing the TEQ values with the previous study in Taiwan, in which particles-phase samples in the sampling chamber were collected. The values of TEQ in this study (0.138±0.037 to 0.649±0.30 mg/kg) were lower than their work (0.890 to 1.270 mg/kg) (Yang et al., 2007a). Yang et al. (2012a) collected particle-bound PAHs sample from incense burning in a sampling chamber and their TEQ (0.152±0.003 to 0.727±0.114 mg/kg) was almost the same with this study. Furthermore, TEQ values from mosquito coil burning reported by Yang et al. (2015b) found that they were 1-3 times (0.204±0.042 to 0.788±0.009 mg/kg) higher than the values of mosquito incense stick (incense G) (0.235±0.073 mg/kg) in this study.

The TEQ and MEQ values of t-PAHs emitted from burning of different group of incenses were compared. Both of TEQ (0.138±0.037 to 0.649±0.030 mg/kg) and MEQ (0.162±0.044 to 0.724±0.035 mg/kg) values of traditional incense (A, B, C, D and E) were higher than those of aromatic incense (F, G and H), which were 0.235±0.073 to 0.354±0.020 mg/kg and 0.266±0.083 to 0.384±0.022 mg/kg, respectively. The TEQ and MEQ values from machine based incense (incense A, F and G) were lower than those from hand-made incense (B, C, D, E and H). When compared with a study of smoke-free incenses burning in Taiwan (Yang et al., 2012a), it was found that the TEQ values (0.168±0.006 and 0.375±0.059 mg/kg) were higher than the smoke-free incense burning (H) in this study (0.287±0.035 mg/kg). Furthermore, the TEQ values for sandalwood incense sticks in the previous study (0.612±0.037 and 0.538±0.099 mg/kg) were higher than those of sandalwood odor incense sticks (F) in this study (0.354±0.020 mg/kg). However, The TEQ values of t-PAHs emitted from incense burning illustrated that TEQ of particulate phase PAHs were 6 times higher than gas phase PAHs. However, the TEQ values depend very much on the relative humidity in air (Yang et al.2013).

Table 3.15 Mean concentrations of TEQ and MEQ of $PM_{2.5}$-bound PAHs emission factors emitted from incense burning in a chamber

Types of incense	**Code (n=3)**	**Mean±SD (mg/kg $_{\text{incense}}$)**	
		TEQ concentrations	**MEQ concentrations**
Traditional incense sticks	**A**	0.138±0.037	0.162±0.044
	B	0.424±0.035	0.444±0.039
	C	0.319±0.041	0.334±0.043
	D	0.609±0.039	0.693±0.033
	E	0.649±0.030	0.724±0.035
Aromatic incense sticks	**F**	0.354±0.020	0.384±0.022
	G	0.235±0.073	0.266±0.083
	H	0.287±0.035	0.364±0.033
Aromatic incense cones	**I**	0.506±0.028	0.558±0.032
	J	0.425±0.032	0.541±0.040

Table 3.16 Mean concentrations of TEQ and MEQ of $PM_{2.5}$-bound PAHs emission rate emitted from incense burning in a chamber

Types of incense	**Code (n=3)**	**Mean±SD (µg/hr)**	
		TEQ concentrations	**MEQ concentrations**
Traditional incense sticks	**A**	0.693±0.189	0.817±0.220
	B	0.864±0.067	0.905±0.076
	C	0.374±0.053	0.392±0.055
	D	0.580±0.035	0.659±0.027
	E	0.691±0.072	0.771±0.082
Aromatic incense sticks	**F**	0.635±0.031	0.690±0.033
	G	1.070±0.336	1.216±0.379
	H	0.410±0.054	0.520±0.051
Aromatic incense cones	**I**	4.365±0.190	4.808±0.217
	J	1.246±0.203	1.583±0.234

2) TEQ and MEQ based on ERs (µg/hr)

Table 3.16 showed that the mean TEQ and MEQ emission rates (ERs) calculated for each type of incense and raw material. The TEQ and MEQ values (µg/hr) from incense burning in descending order were aromatic incense cones (1.246 to 4.365 and 1.583 to 4.808 µg/hr) > aromatic incense sticks (0.410 to 1.070 and 0.520 to 1.216) > traditional incense sticks (0.374 to 0.864 and 0.392 to 0.905). The highest values of TEQ (4.365 µg/hr) and MEQ (4.808 µg/hr) were found in incense I (aromatic incense cone), while the lowest values of TEQ and MEQ were found in longan peel incense (C) and followed by smoke-free incense (H).

Comparing the TEQ values with the previous study in Taiwan, in which particles-phase samples in the sampling chamber were collected. The values of TEQ in this study (0.374 to 1.070 µg/hr) were higher than their work (0.121 to 0.669 µg/hr) (Yang et al., 2012a). Moreover, Yang et al. (2012a) reported that TEQ value from smoke-free incense burning (0.337 to 0.562 µg/hr) was almost the same with this study (0.410 µg/hr), while TEQ values from sandalwood burning (0.327 to 0.669 µg/hr) in their study were higher than the values of sandalwood odor incense stick (incense F) in this study (0.635 µg/hr).

3) TEQ and MEQ of raw material burning

The TEQ and MEQ values of t-PAHs from raw material burning are shown in Table 3.17. Their descending order were found in sawdust (0.262 and 0.238 mg/kg) > wood powders (0.182 and 0.180 mg/kg) > plant-based glutinous powders (0.067 and 0.071 mg/kg) > dye powders (0.058 and 0.061 mg/kg) > bamboo (0.008 and 0.007 mg/kg). The mean values of MEQ were lower than those of TEQ for all types of raw material burning because the factor of DbA, which was almost 3 times higher in the TEF equation than that in the MEF equation (Eq. 2.6 and Table 2.5). Comparing with the study of Wiriya et al. (2015), where PM_{10} samples were collected from leaf litter, maize residue and rice straw burning, the average TEQ values were 0.160±0.035 mg/kg, 0.105±0.031 mg/kg and 0.091±0.034 mg/kg, respectively. It can be concluded that TEQ values calculated from leaf litter maize residue and rice straw burning were higher than the values of plant-based glutinous powder, bamboo and dye powder burning reported in this study. However, the TEQ values of sawdust and wood powder burning were higher than leaf litter maize residue and rice straw burning reported by the previous study.

Table 3.17 Mean concentrations of TEQ and MEQ of $PM_{2.5}$-bound PAHs emitted from raw material burning in a chamber

Raw materials	**Mean±SD (mg/kg $_{dry}$)**	
	TEQ concentration	**MEQ concentration**
Sawdust	0.262±0.053	0.238±0.031
Wood powders (Chankao)	0.182±0.033	0.180±0.029
Plant-based glutinous powders	0.067±0.006	0.071±0.006
Bamboo	0.008±0.001	0.007±0.001
Dye powders	0.058±0.003	0.061±0.003

3.3.6 Isomeric ratios of PAHs emitted from burning of incense and its raw material

PAHs isomeric ratios have been used worldwide to determine their source (Yunker et al., 2002; Ohura et al., 2004; Tobiszewski and Namiesnik, 2012; Yang et al., 2012a; Wiriya et al., 2013). The isomeric ratios have been used to separate biomass burning and petroleum (Hischenhuber and Stijve, 1987, Yanker et al.,2002), non-traffic emissions and traffic emission (Katsoyiannis et al., 2007). Isomeric ratios of PAHs including FLA/(FLA+PYR), IND/(IND+BPER), BaA/(BaA+CHR) and ANT/(ANT+PHE) obtained from incense and candle burning were classified as grass, wood and coal combustion (Orecchio, 2011; Yang et al., 2012a; Derudi et al., 2014). Therefore in this work their ratios were considered and proposed with a narrower range in order to specify as markers for incense burning. However, the proposed values were compared with previous studies.

The FLA/(FLA+PYR) and IND/(IND+BPER) ratios have been used to specify sources of PAHs. Value of FLA/(FLA+PYR) and IND/(IND+BPER) higher than 0.5 indicated grass, wood and coal combustion, while a value lower than 0.5 indicated fossil fuel combustion or petroleum input (Hischenhuber and Stijve, 1987; Yunker et al., 2002). Ratio of BaA/(BaA+CHR) implied petroleum (contamination from petroleum products or pyrolytic pollution emission source) (<0.20), petroleum or combustion (0.20 to 0.35) and combustion (>0.35) (Hischenhuber and Stijve, 1987). The ratio value of ANT/(ANT+PHE) > 0.10 indicated a high temperature source (combustion), while a ratio < 0.10 was referred to petroleum (Yunker et al., 2002). Moreover, a total index was used to confirm emission of PAHs (Mannino and Orecchio, 2008). The total index higher than 4 indicated PAHs from high temperature processes (combustion), while the value less than 4 indicated low temperature (petroleum products).

Isomeric ratios of incense and raw material burning are shown in Tables 3.18 and 3.19. The FLA/ FLA/(FLA+PYR) ratios with the values of 0.50-0.68 were found from incense burning, while the values of 0.48-0.67 were found from raw material burning. The BaA/(BaA+CHR) ratio values were 0.39-0.59 (incense burning) and 0.21-0.33 (raw material burning). The values of IND/(IND+BPER) ratios of incense and raw material burning were ND-0.65 and ND-0.54, respectively. Ratio values of ANT/(ANT+PHE) were 0.27-0.70 (incense burning) and 0.48-0.60 (raw material burning). Furthermore, the total index identified the products resulting from high temperature process sources (combustion). It was found that the ranges of total index of were 4.73-12.87 (incense burning) and 7.43-9.53 (raw material burning).

Table 3.20 shows comparison of the isomeric ratio values of PAHs emitted from incense burning to different literature studies. The FLA/(FLA+PYR) ratio >0.5 indicated grass, wood and coal combustion. In the previous study (Yang et al., 2012a; Yang et al., 2013; Yang et al., 2015b; Derudi et al., 2012; Orecchio, 2011), the ranges of ratio values from burning of incense, mosquito coil and candles were 0.41-0.60, while in this study they were 0.50-0.68, which were well agreed with the ratios of FLA/(FLA+PYR) indicating grass, wood and coal combustion. Yang et al., (2012a) and Yang et al., (2013) investigated the values of IND/(IND+BPER) ratios from incense burning in chamber (0.52-0.67), while Yang et al., (2015b) and Orecchio, (2011) revealed IND/(IND+BPER) ratios emitted from mosquito coil and candles (0.56-0.79). The values of ratio indicated grass, wood and coal combustion. However, the ratios of IND/(IND+BPER) for incense burning in this study were ND-0.65, which were lower than the previous studies. The IND/(IND+BPER) ratios of most incense burning in this study were lower than 0.5.

The BaA/(BaA+CHR) ratio values were 0.39-0.59, which were almost the same with the values from incense burning reported by Yang et al. (2012a) and Yang et al. (2013) (0.38-0.51). Moreover, the values of BaA/(BaA+CHR) released from candles burning were 0.01-0.76 (Derudi et al., 2012 and Orecchio, 2011). In this study, the value of BaA/(BaA+CHR) ratio was higher than 0.35 indicating combustion. The ratio values of ANT/(ANT+PHE) were 0.27-0.76, indicating a high temperature source (combustion) (>0.10). The values were also higher than those emitted from incense and mosquito coil and candles burning in the previous studies (0.07-0.87) (Yang et al., 2012a; Yang et al., 2013; Yang et al., 2015b; Derudi et al., 2012; Orecchio, 2011). Moreover, the total index of incense burning in this study (4.73-12.87) was higher than 4, which classified high temperature sources (combustion). Thus, PAHs concentrations were confirmed to be emitted by high temperature process. The range of total index value was higher than the result from previous work (3.86-8.26) (Yang et al., 2012a;

Yang et al., 2013; Yang et al., 2015b; Derudi et al., 2012) as shown in Table 3.16. Therefore, all results of isomeric ratios and total index from incense burning can be classified as grass, wood and coal combustion with high temperature processes.

Table 3.18 Isomeric ratios from incense burning

Isomeric ratios	Incense types									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
FLA/(FLA+PYR)	0.54	0.53	0.55	0.68	0.52	0.52	0.54	0.63	0.51	0.50
IND/(IND+BPER)	0.19	0.59	0.47	0.65	0.60	0.62	0.33	0.60	0.51	ND
BaA/(BaA+CHR)	0.49	0.48	0.46	0.59	0.59	0.51	0.46	0.39	0.51	0.50
ANT/(ANT+PHE)	0.38	0.47	0.76	0.69	0.70	0.43	0.27	ND	0.31	0.56
Total index	**7.95**	**9.55**	**12.19**	**12.87**	**12.51**	**9.40**	**7.02**	**4.92**	**7.93**	**9.35**

ND = Not detected

Table 3.19 Isomeric ratios from raw materials burning

Isomeric ratios	**Sawdust**	**Wood powders (Chan Kao)**	**Plant-based glutinous powders**	**Bamboo stick**	**Dye powders**
FLA/(FLA+PYR)	0.63	0.65	0.59	0.67	0.48
IND/(IND+BPER)	0.49	0.54	ND	ND	ND
BaA/(BaA+CHR)	0.31	0.28	0.33	0.21	0.23
ANT/(ANT+PHE)	0.54	0.49	0.48	0.60	0.60
Total index	**9.53**	**9.00**	**7.95**	**8.73**	**8.38**

ND = Not detected

Table 3.20 Comparison of isomeric ratios of incense burning from various studies.

Isomeric ratios	**Range of values**	**Materials burning**	**References**	**Reference values**	**sources**	**References**
FLA/(FLA+PYR)	**0.50-0.68**	incense burning	this study	< 0.40	Petroleum input	
	0.41-0.59	incense burning	Yang et al., (2012a)	0.4-0.5	Fossil fuel combustion	
	0.47	incense burning	Yang et al., (2013)	**>0.50**	**Grass,wood,coal combustion**	Yunker et al. (2002)
	0.47-0.51	mosquito coil burning	Yang et al., (2015b)			
	0.40-0.60	candle burning	Derudi et al., (2012)			
	0.49	candle burning	Orecchio (2011)			
IND/(IND+BPER)	**ND-0.65**	incense burning	this study	0.20	Petroleum	
	0.53-0.67	incense burning	Yang et al., (2012a)	0.20-0.50	Liquid fossil fuel combustion	Hischenhuber and Stijve (1987)
	0.56-0.65	mosquito coil burning	Yang et al., (2015b)	**> 0.50**	**Grass, wood and coal combustion**	
	0.52-0.53	incense burning	Yang et al., (2013)			
	0.79	candle burning	Orecchio (2011)			
BaA/(BaA+CHR)	**0.39-0.59**	incense burning	this study	< 0.2	Petroleum	
	0.38-0.51	incense burning	Yang et al., (2012a)	0.20-0.35	Petroleum or combustion	Hichenhuber and stijve (1987)
	0.49	incense burning	Yang et al., (2013)	**> 0.35**	**Combustion**	
	0.40-0.45	mosquito coil burning	Yang et al., (2015b)			
	0.01-0.76	candle burning	Derudi et al., (2012)			
	0.35	candle burning	Orecchio (2011)			

Table 3.20 Comparison of isomeric ratios from various materials burning and incense burning (continued)

Isomeric ratios	Range of values	material burning	References	Reference values	sources	References
ANT/(ANT+PHE)	**0.27-0.76**	incense burning	this study	< 0.10	Low temperature source (Petroleum)	Yunker et al. (2002)
	0.17-0.87	incense burning	Yang et al., (2012a)	**> 0.10**	**High temperature source (Combustion)**	
	0.21-0.22	incense burning	Yang et al., (2013)			
	0.25-0.26	mosquito coil burning	Yang et al., (2015b)			
	0.07-0.33	candle burning	Derudi et al., (2012)			
	0.28	candle burning	Orecchio (2011)			
Total index	**4.73-12.87**	incense burning	this study	< 4.00	Low temperature source (Petroleum)	
	6.30-6.48	incense burning	Yang et al., (2012a)	**> 4.00**	**High temperature source (Combustion)**	Mannino and Orecchio (2008)
	6.82-6.91	incense burning	Yang et al., (2013)			
	7.64-8.26	mosquito coil burning	Yang et al., (2015b)			
	3.86-7.92	candle burning	Derudi et al., (2012)			

3.4 Determination of NO$_2$, PM$_{2.5}$ and PM$_{2.5}$-bound PAHs from incense burning at selected shrines

3.4.1 NO$_2$ concentrations at the selected shrines

Concentrations of NO$_2$ were analyzed both indoors and outdoors at the 2 selected shrines in the city of Chiang Mai during the Chinese New Year, also on other special occasions and normal periods. The results are shown in Table 3.21. The 8 and 24 hrs average concentrations indoor NO$_2$ (ppbv) at the shrine 1 in descending order were 55.3 ± 0.0 and 40.4 ± 8.9 (Chinese New Year) > 41.6 ± 11 and 34.1 ± 7.3 (other special occasions) > 32.2 ± 5.8 and 23.9 ± 5.7 (normal periods), while those at the shrine 2 were 50.1 ± 12 and 41.4 ± 8.6 (Chinese New Year), 41.0 ± 8.0 and 34.0 ± 6.8 (other special occasions) and 33.8 ± 7.2 and 22.9 ± 5.9 (normal periods).

For statistical analysis, the measured NO$_2$ concentrations were log-transformed to achieve normal distribution. T-test was used to differentiate the average NO$_2$ concentrations between indoors and outdoors, while One-Way ANOVA was used to differentiate the average NO$_2$ concentrations between occasions. It was found that the concentrations of NO$_2$ measured indoors were slightly higher than outdoors, but without any significant difference ($p>0.05$). The indoor NO$_2$ concentrations measured in Chinese New Year were higher than those in the special occasions for all cases (8 and 24 hours at shrines), but they were not significantly different ($p>0.05$). Those average concentrations measured at both shrines were significantly higher than the normal period. The outdoor NO$_2$ concentrations measured in other special occasions and in normal period were not significantly different, but they were significantly lower than those measured in Chinese New Year ($p<0.05$), which were 55.3±0.0 (8 hrs) and 40.0±8.9 ppbv (24 hrs) at shrine 1and 50.1±12.0 (8 hrs) and 41.1±8.6 ppbv (24 hrs) at shrine 2. The result was related to the number of visitors and consequently the amount of incensed burned. Moreover, the 24 hrs NO$_2$ concentrations monitored indoor were 23.9±5.7 to 40.4±8.9 ppbv (shrine 1) and 22.9±5.9 to 41.4±8.6 ppbv (shrine 2). They were almost the same with the mean values (52±48 ppbv or 97±91 μg/m^3) emitted from the burning of biomass fuel (firewood), crop residue and animal dung in an Ethiopian home (Kumie et al, 2009). In Turkey, Bozkurt et al. (2015) 24 hrs NO$_2$ concentrations were measured in households and building found in a kitchen (27.6±7.8 to 41.9±16.1 ppbv), living room (19.8±4.3 to 30.5±10.9 ppbv), bedroom (16.8±5.4 to 27.4±11.1 ppbv), office (23.1±13.1 to 30.0±7.4 ppbv) and school (11.8±9.0 to 34.6±19.9 ppbv). All values were slightly lower than what have been found in this study. A major source of NO_2 was released from natural gas and liquefied petroleum gas (LPG) usage as a heating source. Moreover, the 24 hrs NO_2 concentrations collected at a living room and kitchen of an apartment in Lebanon were 8.3 ppbv and 11.8 ppbv, respectively (Ghosn et al., 2005), which were much lower than those found in this study. However, all the indoor NO_2 level did not exceed the standard level of NO_2 concentration (< 80 ppbv) for 8hrs, which was created by Indoor Quality objectives for Office Building and Public Places in Hong Kong (HK-IAQO) and Environmental Sanitation Division of Bangkok Metropolitan administration (BMA) Bangkok, Thailand.

The indoor/outdoor (I/O) ratio of NO_2 concentrations is generally found to be greater than 1, which shows that the exposure of NO_2 can be higher indoors than outdoor area (Monn et al., 1997). The average I/O ratio for NO_2 concentrations (Table 3.21) illustrated that the I/O ratio in shrine 1 was greater than that of shrine 2, due to a greater amount of incense being burned and poor ventilation system. The I/O ratio of NO_2, at shrine 1 was higher than 1 (indoors > outdoors), while that at shrine 2 was less than 1. The reason for this might be due to high traffic density at the roads nearby the shrine 2 (Salem et al., 2009; Ahmad et al., 2011). The highest I/O ratio over 8 hrs was found during Chinese New Year, due to the large amount of incense being burned. The mean I/O ratio of NO_2 was 1.2 ±0.4, which was lower than the mean ratio from medieval churches in Cyprus (1.97) (Loupa and Chao, 2008). This was probably related to the amount of incense being burned indoors. Moreover, Levy (1998) reported the I/O ratio of NO_2 emitted from a gas stove in homes of many countries (0.7-1.2) was almost the same with the value in this study.

Table 3.21 Concentrations of indoor (I) and outdoor (O) nitrogen dioxide in the selected shrines

Sampling periods		**NO$_2$ concentrations (ppbv)**					
		8 hrs			**24 hrs**		
		Indoor^{A}	**Outdoor^{A}**	**I/O ratio**	**Indoor^{A}**	**Outdoor^{A}**	**I/O ratio**
Shrine 1							
Chinese New Year	Range	55.2-55.3	47.3-54.6		32.9-54.3	24.1-67.9	
(n=2* and n=6**)	Mean ±SD	55.3 ± 0.0^{a}	50.9 ± 5.2^{a}	1.1	40.4 ± 8.9^{a}	38.6 ± 17.0^{a}	1.0
Other Special occasions	Range	31.1-58.9	15.8-39.5		28.9-51.0	26.1-33.8	
(n=5* and n=8**)	Mean ±SD	41.6 ± 11.0^{ab}	27.7 ± 11.0^{a}	1.5	34.1 ± 7.3^{a}	29.5 ± 2.7^{ab}	1.2
Normal period	Range	23.4-39.5	13.2-49.1		14.4-29.9	11.1-27.8	
(n=7* and n=8**)	Mean ±SD	32.2 ± 5.8^{b}	27.4 ± 11.0^{a}	1.2	23.9 ± 5.7^{b}	21.3 ± 5.4^{b}	1.1
Shrine 2							
Chinese New Year	Range	41.6-63.6	15.6-32.9		31.6-54.6	27.2-43.4	
(n=3* and n=6**)	Mean (±SD)	50.1 ± 12.0^{a}	24.3 ± 8.7^{a}	2.1	41.4 ± 8.6^{a}	32.8 ± 5.9^{a}	1.3
Other Special occasions	Range	29.6-54.0	34.5-57.1		27.0-45.2	32.9-51.7	
(n=9* and n=8**)	Mean (±SD)	41.0 ± 8.0^{ab}	42.0 ± 6.8^{b}	1.0	34.0 ± 6.8^{a}	41.8 ± 7.4^{b}	0.8
Normal period	Range	25.4-45.7	21.4-63.7		15.5-33.3	23.0-43.4	
(n=9* and n=13**)	Mean (±SD)	33.8 ± 7.2^{b}	39.0 ± 12.0^{b}	0.9	22.9 ± 5.9^{b}	31.5 ± 6.5^{a}	0.7

$^{a,\,b}$ = Significant differences ($p < 0.05$) among groups of sampling periods (vertical direction)

$^{A,\,B}$ = Significant differences ($p < 0.05$) among groups of sampling places (in/outdoor) within the same period

* the amount of samples over 8 hrs and ** the amount of samples over 24 hrs

3.4.2 PM$_{2.5}$ concentrations

Table 3.22 shows the concentrations of PM$_{2.5}$ and the number of visitors at both shrines in special occasions, Chinese New Year and normal period (background value). The background values of 8 hrs of indoor PM$_{2.5}$ ranged from 82±25 µg/m^3 (shrine 1) to 100±35 µg/m^3 (shrine 2), while those of the 24 hrs period were 50±20 µg/m^3 (shrine 2) to 52±24 µg/m^3 (shrine 1). One-Way ANOVA was used to differentiate the average PM$_{2.5}$ concentrations between occasions. The concentrations of PM$_{2.5}$ were 1/square root–transformed to achieve normal distribution. Concentrations of PM$_{2.5}$ at shrine 1 were slightly lower than those at shrine 2, but no significant difference ($p>0.05$). Based on the results, the different architecture of the two shrines might not play a significant role for PM concentrations. Otherwise, if the number of visitors is almost equal, the PM$_{2.5}$ concentrations in the shrine 1 should be higher than the shrine 2 due to its poorer ventilation system. In general at both shrines, the mean PM$_{2.5}$ concentrations in normal period were significantly less than those of the Chinese New Year and other special occasions in all cases (8 and 24 hrs), but there was no difference among 8 hrs PM$_{2.5}$ collected in other special occasions and normal period ($p>0.05$). The main reason was that shrine 1 was more popular than shrine 2, therefore number of visitors during occasions, was not so high at shrine2. PM$_{2.5}$ concentrations in descending order were Chinese New Year > other special occasions > the normal period. This pattern was the same for both 8 and 24 hrs periods at the two shrines. The main reason for high level of pollutants found indoors was clearly from number of visitors, which was related with the amount of incense being burned.

During the Chinese New Year and on other special occasions, the 24 hrs average values of PM$_{2.5}$ (35 µg/m^3) collected from both shrines were 3-11 times higher than standard value of the National Ambient Air Quality Standard (NAAQS), USA (US-EPA, 2006). Moreover, the values were 2-8 times higher than the value of Ambient Air Standard of Thailand (50 µg/m^3). Apart from that, The 24 hrs PM$_{2.5}$ concentrations (50±20 to 178±81 µg/m^3) found in this study (excluded values from Chinese New Year) were lower than those found in several indoor quality studies such as in XI'an museum, China in winter (242.3 ± 189.0 µg/m^3) (Cao et al., 2011), in rural site in Central Indian region, which has influence from incense and candle burning (143±56 to 198±81 µg/m^3)

(Massey et al., 2009) and in North-Central India (80±32 to 146±39 μg/m^3 (urban) and 119±34 to 207±54 μg/m^3 (roadside)) (Massey et al., 2012). Moreover, the 24 hrs PM$_{2.5}$ concentrations (50±20 to 406±159 μg/m^3) in this study were higher than the 24 hrs values reported by Wu et al. (2015), which were measured from 3 temples and 1 village at Mount Wutai Buddhism with emissions from incense, candle and coal burning in ambient air (1.43 to 59.20 μg/m^3). The 24 hrs PM$_{2.5}$ concentration measured in a normal period at both shrines was lower than that found in the residential home in Hong Kong (46.3-69.7 μg/m^3), which released from incense burning and cooking by liquefied petroleum gas and natural gas (Cao et al., 2005). The values were also lower than public housing (55.7±35 μg/m^3) and slum housing (77.8±36 μg/m^3) in Chile, which were emitted from heating bathing water and smoking cigarettes (Burgos et al., 2013). However, the PM$_{2.5}$ concentration found during Chinese New Year in this study was approximately 2-5 times higher than those in all above mentioned cases. The 8 hrs PM$_{2.5}$ concentration measured during Chinese New Year (524±110 μg/m^3 to 625±147 μg/m^3) was higher than that found in a temple in Hong Kong (360±23 μg/m^3) during Chinese lunar calendar (Wang et al., 2007). The 8 hrs indoor PM$_{2.5}$ concentrations collected at temples in Bangkok, Thailand, using personal modular impactors (PMI) were 47.00±5.99 to 174.00±39.15 μg/m^3 for guard, 54.64±6.16 to 982.20±196.54 μg/m^3 for janitor and 51.79±6.82 to 139.18±23.82 μg/m^3 for vendor (Nonthakanok, 2013). The values were slightly higher than those found in this study.

Table 3.22 Average indoor $PM_{2.5}$ concentrations and the number of visitors at two shrines measured on special occasions and over normal periods

Sampling periods		$PM_{2.5}$		Number of visitor	
		8 hrs	**24 hrs**	**8 hrs**	**24 hrs**
Shrine 1					
Chinese New Year	Range	448-603	136-450	474-547	117-961
(n=2* and n=6**)	Mean (±SD)	524±110 ^{a}	317±109 ^{a}	510±52 ^{a}	454±294 ^{a}
Other special occasions	Range	159-327	84-310	19-85	78-457
(n=5* and n=8**)	Mean (±SD)	228± 81 ^{a}	178±81 ^{a}	54±31 ^{a}	175±123 ^{a}
Normal period	Range	44-118	34-110	5-12	8-42
(n=7* and n=8**)	Mean (±SD)	82±25 ^{b}	52±24 ^{b}	11±4 ^{b}	18±13 ^{b}
Shrine 2					
Chinese New Year	Range	471-764	194-678	126-702	161-1,040
(n=3* and n=6**)	Mean (±SD)	625±147^{a}	406±159 ^{a}	390±291 ^{a}	631±319 ^{a}
Other special occasions	Range	99-309	73-276	10-55	17-82
(n=9* and n=8**)	Mean (±SD)	184±85^{b}	133±71 ^{b}	24±14 ^{b}	42±23 ^{b}
Normal period	Range	52-158	17-75	5-13	5-26
(n=9* and n=13**)	Mean (±SD)	100±35 ^{b}	50±20 ^{c}	8±3 ^{c}	12±6 ^{c}

$^{a, b, c}$ = Significant differences ($p < 0.05$) among groups of sampling periods (vertical direction)

* the amount of samples over 8 hrs and ** the amount of samples over 24 hrs

3.4.3 $PM_{2.5}$-bound PAHs concentrations

$PM_{2.5}$ samples at both selected shrines in Chiang Mai City were collected and analyzed in 3 periods; Chinese New Year, other special occasions and normal periods. $PM_{2.5}$ samples were analyzed for PAHs by using GC-MS. The results are shown in Table 3.22. Average concentrations of 8 hrs total PAHs (t-PAHs) at shrine 1 were 168±60 ng/m^{3} (Chinese New Year), 107±45 ng/m^{3} (other special occasions) and 62±30 ng/m^{3} (normal period), while the 24 hrs of t-PAHs in Chinese New Year, other special occasions and normal periods were 102±26 ng/m^{3}, 47±7 ng/m^{3} and 32±19 ng/m^{3}, respectively. At shrine 2, the 8 hrs mean concentrations of total $PM_{2.5}$-bound PAHs were 90±41 ng/m^{3} (Chinese New Year), 71±30 ng/m^{3} (Other special occasions) and 25±15 ng/m^3 (Normal period). The 24 hrs mean PAHs concentrations in all periods at both shrines were lower than those of 8 hrs (46±29 ng/m^3, 30±12 ng/m^3 and 14±9 ng/m^3, respectively). However, the trend of PAHs concentrations found in each occasion was the same.

The t-PAHs concentrations were square root-transformed to get normal distribution. Concentrations of t-PAHs at shrine 1 were significantly higher than those at shrine 2 (p<0.05). The main reasons could be because the use of big incense sticks and the poor ventilation system at shrine 1. One-Way ANOVA was used to test the difference of the mean of t-PAHs concentrations between occasions. At shrine 1, the t-PAHs concentrations in Chinese New Year were significantly higher than those in other special occasions and normal period. Moreover, it was found that 8 and 24 hrs of t-PAHs concentrations at shrine 2 during the normal period were significantly (p<0.05) less than those during the Chinese New Year and the other special occasions. The concentration levels were not significantly different in both the other special occasions and normal periods at shrine 1 (p>0.05). Because burned incense sticks were not allowed to be kept inside the shrine. The values of t-PAHs concentrations at both of the selected shrines were highest in Chinese New Year. The 24 hrs of t-PAHs concentrations extracted from $PM_{2.5}$ in shrines were 14±9 to 168±60 ng/m^3. The values were lower than those reported in a previous study in New Delhi, India (Masih et al., 2012), in which TSP-bound PAHs (ng/m^3) from roadside homes ranged from 159 in summer to 487 in winter, while those found in urban residential homes were 217 in summer to 234 in winter. The 24 hrs total PAHs in indoor TSP emitted from incense burning in a Taiwanese temples were 478 ng/m^3 (Liao and Chiang, 2006) and 6,258 ng/m^3 (Lin et al., 2002). Li and Ro (2000) investigated 24 hrs of t-PAHs concentrations at indoors, which have incense burning in the house in Taiwan, and found concentrations of 348±2.6 ng/m^3, which were higher than those found in this study. Moreover, the 8 hrs $PM_{2.5}$-bound PAHs concentrations emitted from incense burning at a Thai temple in Bangkok (1.01±0.98 to 47.7±72.8 ng/m^3) (Nonthakanok, 2013) were lower than in this study (25±15 to 90±41 ng/m^3).

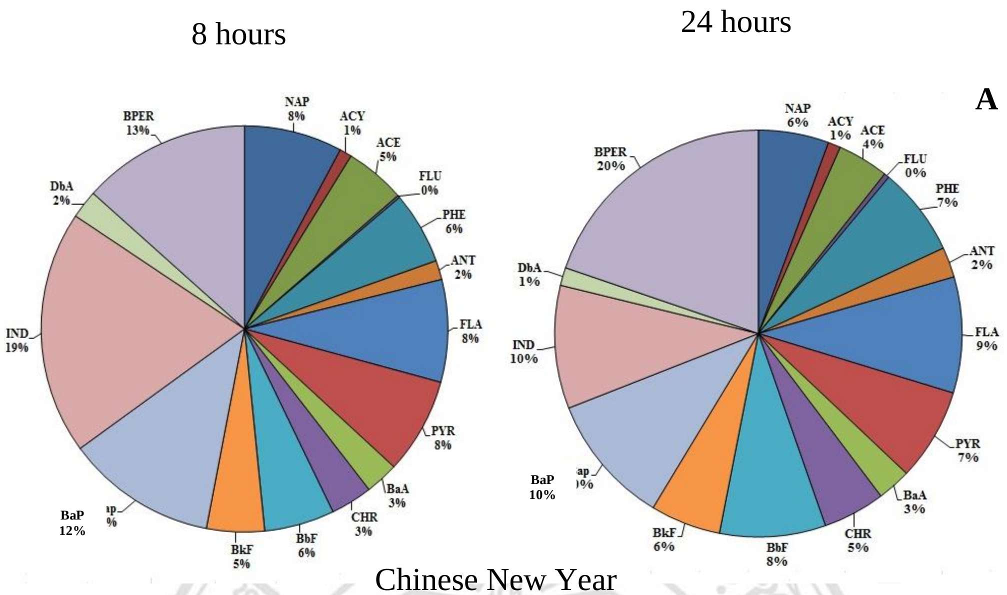
The average concentrations of c-PAHs) and nc-PAHs are shown in Table 3.23. The concentrations of c-PAHs and nc-PAHs were found to have the same trend as $PM_{2.5}$ concentrations. The 8 and 24 hrs average c-PAHs concentrations at shrine 1 in descending order were Chinese New Year (83.1 ± 35 ng/m^3 and 49.0 ± 16 ng/m^3) > other special occasions (55.0 ± 31 ng/m^3 and 26.2 ± 2.6 ng/m^3) > normal period (23.5 ± 15 ng/m^3 and 17.5 ± 16 ng/m^3). The average c-PAHs concentrations of 8 and 24 hrs at shrine 2 were 63.8±34 and 27.4±14 ng/m^3, 48.5±24 and 20.5±10 ng/m^3 and 15.4±12 and 9.55±7.5 ng/m^3 in Chinese New Year, other special occasions and normal periods, respectively. The 8 and 24 hrs of average nc-PAHs at shrines were found to have the same trend as c-PAHs concentrations. However, their c-PAHs concentrations at shrine 2 were 1-2 times higher than those nc-PAHs. The average concentrations (ng/m^3) of c-PAHs and nc-PAHs for 8 and 24 hr sampling were highest in Chinese New Year following with other special occasions and normal period. However, Chinese New Year and other special occasions were not significantly different (p>0.05), while the values of Chinese New Year were significantly higher than normal period. The exception was the 8 hr average of c-PAHs and nc-PAHs concentrations at shrine 2, which was significantly lower than those in Chinese New Year than the other special occasion (p<0.05). Moreover, the c-PAHs concentrations of both 8 and 24 hr samplings were about 1-2 times higher than those nc-PAHs on every occasion including normal period. The c-PAHs were found in high concentrations because high molecular weight PAHs (>200) could be more easily adsorbed to particulate phase (Orecchio, 2011).

Table 3.23 Average of total-PAHs (t-PAHs), carcinogenic-PAHs (c-PAHs) and non-carcinogenic PAHs (nc-PAHs) concentrations (ng/m^3) at shrines in various occasions

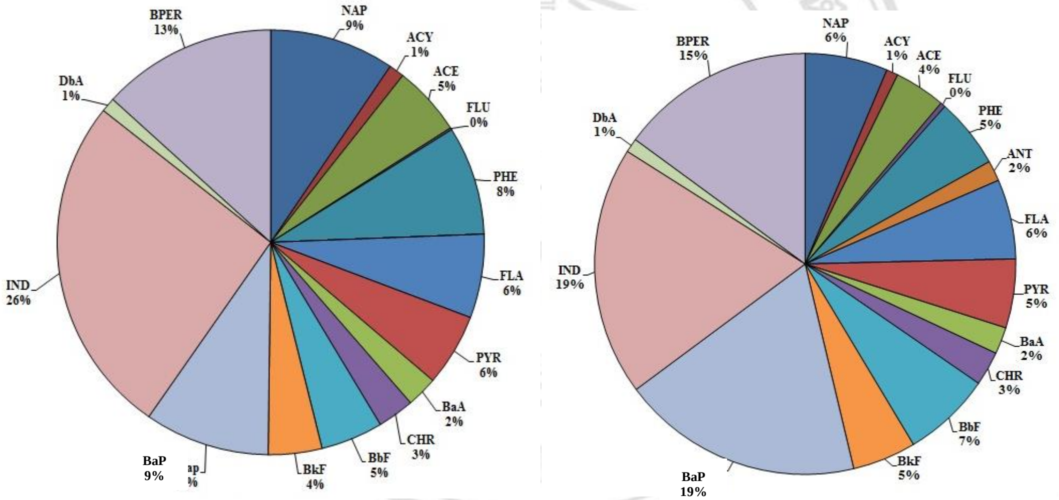
Sampling sites	**Sampling periods**	**Concentrations (Mean±SD)**					
		8 hrs			**24 hrs**		
		t-PAHs	**c-PAHs**	**nc-PAHs**	**t-PAHs**	**c-PAHs**	**nc-PAHs**
Shrine 1	**Chinese New Year**	168±60^{a} (n=2)	83±35^{a}	85±25 ^{a}	102±26^{a} (n=6)	49±16^{a}	52±18^{a}
	Other special occasions	107±45 ^{ab} (n=5)	55±31^{ab}	52±16^{ab}	47±7.3^{b} (n=8)	26±2.6^{b}	20±6^{b}
	Normal periods	62±30 ^{b} (n=7)	24 ±15^{a}	38±15^{a}	32±19^{b} (n=8)	18±16^{b}	15±5^{b}
Shrine 2	**Chinese New Year**	90±41^{a} (n=3)	64±34^{a}	26±9^{a}	45±29^{a} (n=6)	27±14^{a}	18±16^{a}
	Other special occasions	71±30^{a} (n=9)	48±24^{a}	22±8^{a}	30±12^{a} (n=8)	20±10^{ab}	10±4^{ab}
	Normal periods	25±15^{b} (n=10)	15±12^{b}	10±7^{b}	14±9^{b} (n=13)	10±8^{b}	5±3^{b}

$^{a, b}$ = Significant differences ($p < 0.05$) among groups of sampling periods (vertical direction)

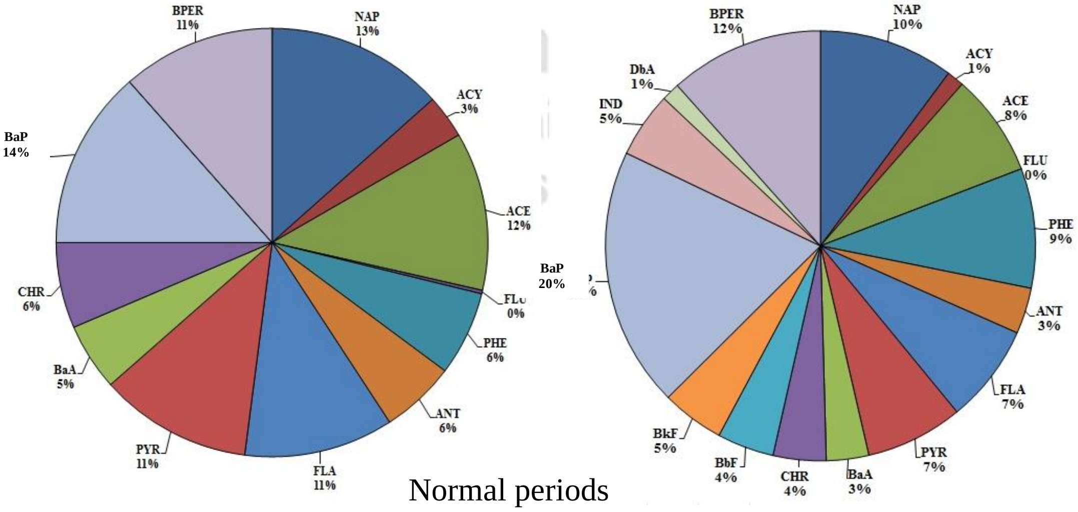
Figure 3.15-3.16 illustrates the median values of 8 and 24 hrs $PM_{2.5}$-bound PAHs concentrations in the selected shrines and percentage of individual PAHs on each occasion. The total PAHs concentrations were quite high in the Chinese New Year and getting lower in the normal periods. In Chinese New Year, PAHs concentrations at both shrines in descending order were BbF (8-21%) > BPER (9-15%) > BaP (10-15%) > IND (10-19%), while the concentrations of 16-PAHs on other special occasions in descending order were BbF (5-41 %) > IND (8-26%) > BaP (7- 19%) > BPER (7-15%). In normal periods, the concentrations of 16-PAHs in descending order were BbF (4-52%) > BaP (9-20%) > NAP (10-14%). The dominant PAHs were BbF, BaP, IND and BPER, while the highest dominant PAHs in both shrines were IND (shrine 1) and BbF (shrine 2) (Fig. 3.18). The result was same as Nonthakanok (2013), the dominant PAHs coolected at a Thai temple in Bangkok were found to be BaP, BbF and BPER, while Navasumrit et al. (2008) indicated that BaA, BbF, BaP and DbA were the dominant carcinogenic PAHs. In Taiwan, Lin et al. (2002) reported that the dominant PAHs in a Taiwanese temple were BaP, BPER, DbA and BbF. A study from Li and Ro (2000) reported that FLA, PYR, BaP and BPER were the dominant particulate-bound PAHs collected indoors from houses with incense burning. Moreover, Orecchio (2011) revealed that the highest mean of carcinogenic BbF (0.62 µg/kg) was observed from candle burning in a chamber. Heavy slack wax candle emitted BbF, BkF and BaP, which were 3.46 ± 3.45 ng/g, 3.50 ± 3.49 ng/g and 3.44 ± 3.40 ng/g, respectively (Derudi et al., 2014). Furthermore, Ciecierska and Obiedziriski (2013) investigated that 13 samples of vegetable unconventional oils were contaminated with 4 heavy PAHs including BaP (1.02±0.09 to 15.74±0.66 µg/kg), CHR (0.89±0.08 to 9.05±0.85 µg/kg), BaA (0.32±0.01 to 8.60±0.53 µg/kg) and BbF (0.64±0.07 to 4.99±0.19 µg/kg). Chiang et al., (2003) investigated that vegetable oil fumes released carcinogenic BaP (21.6±1.3 $\mu g/m^3$), DBA (3.2±0.1 $\mu g/m^3$), BbF (2.6±0.2 $\mu g/m^3$) and BaA (2.1±0.4 $\mu g/m^3$). Those findings supported the result of high concentration of BbF being emitted because burning of candles and incense were a common behavior of the visitors during praying. However, the 8 hrs indoor BaP concentrations measured from Chinese New Year and other special occasions (1.61 – 10.0 ng/m^3) were lower than the values found in Taiwanese temple (57.6-98.2 ng/m^3) (Lin et al., 2001). This is probably due to the amount of incense being burnt during the sampling period.



Chinese New Year



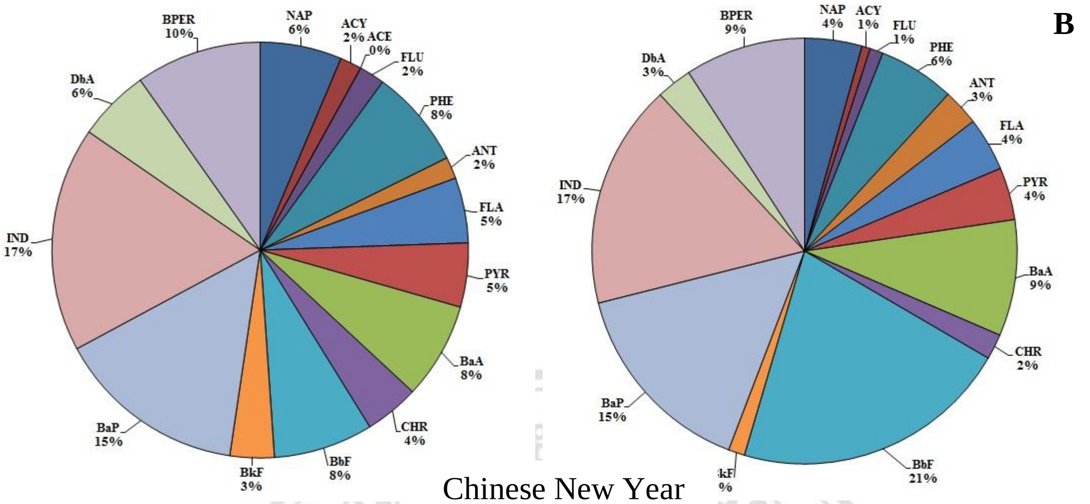
Other special occasions



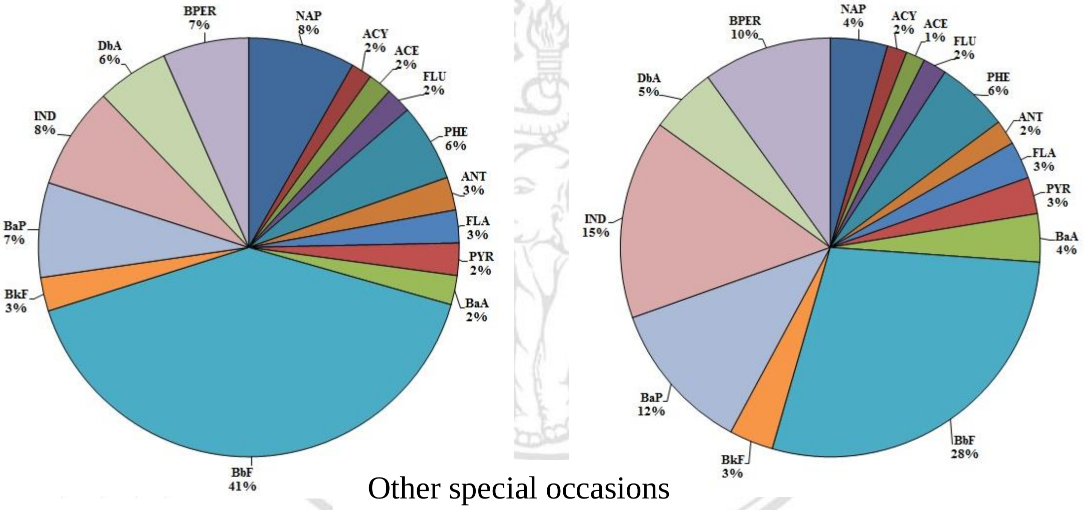
Normal periods

Figure 3.15 The relative percentages of PAHs at shrine 1

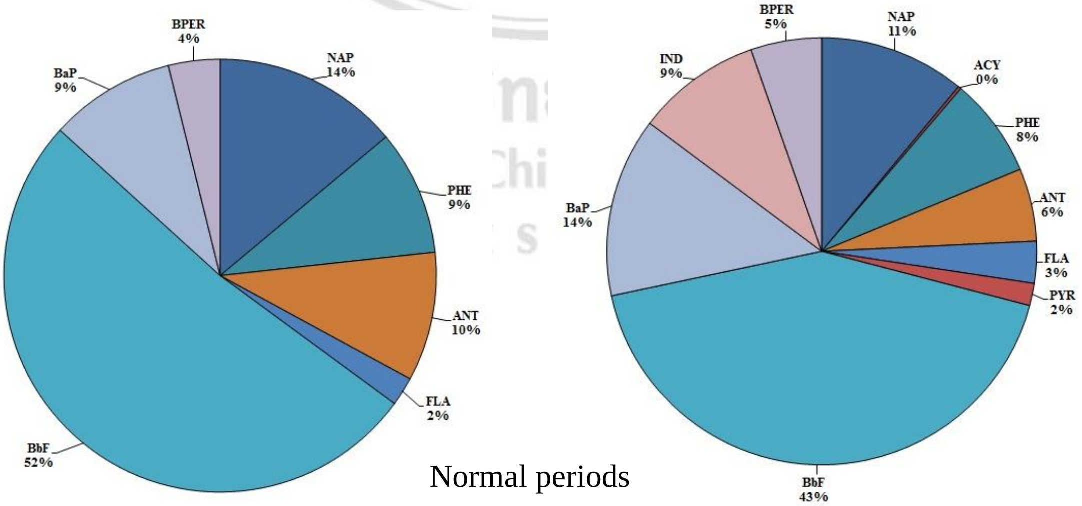
8 hours 24 hours



Chinese New Year



Other special occasions



Normal periods

Figure 3.16 The relative percentages of PAHs at shrine 2

The 16 PAHs were clustered based on the number of aromatic rings in their structures (2, 3, 4, 5 and 6 rings) from incense burning at shrines (Figure 3.17). It was found that the predominant PAHs in all occasions were 5-6 rings. The component of indoor $PM_{2.5}$ – bound PAHs emitted from incense burning were 5 rings (14-61 %) > 6 rings (4-39%) > 4 rings (2-24 %) > 3 rings (4-21 %) > 2 rings (4-14 %). Wu et al (2006) explained that the high molecular weight of PAHs (MW: 202-278) were mainly related to diameter of PM lower than 2µm. The study about particle - bound PAHs emitted from incense burning in a Muslim Holy shrine and a Buddhist temple in Central India revealed that the smoldering conditions of incense burning are dominant for the formation of 4-5 rings (35-37 % for 4 ring and 31-35 % for 5 ring) particulate phase PAHs (Dewangan et al., 2014).

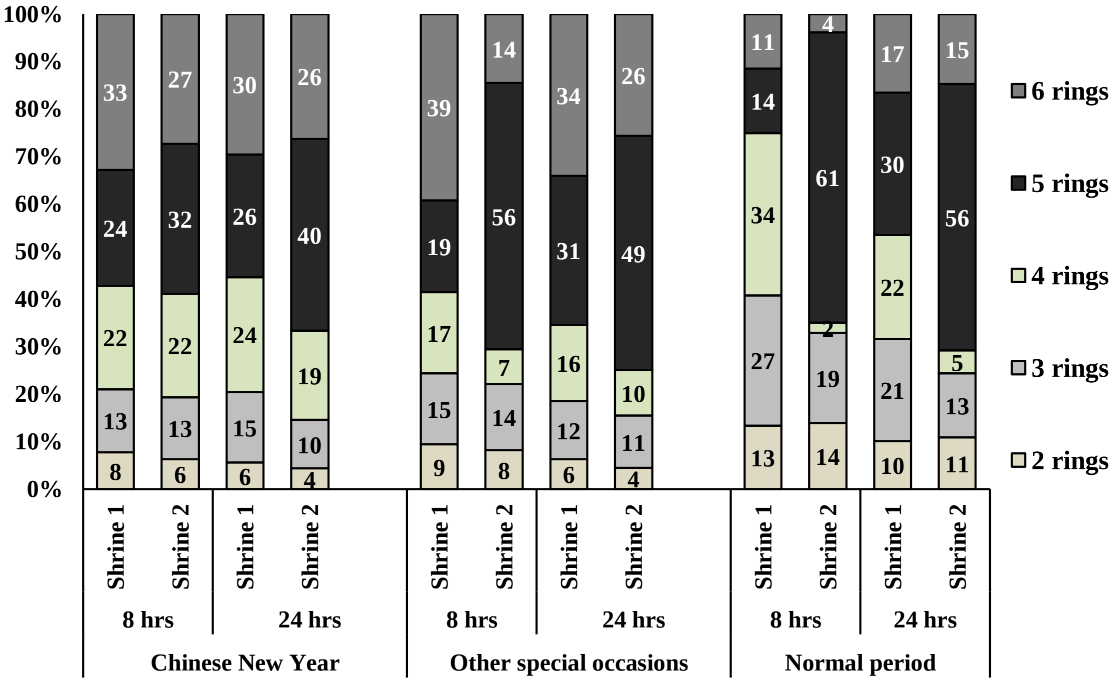


Figure 3.17 Percentage of the number of aromatic rings

3.4.4 Correlations between $PM_{2.5}$, number of visitors, PAHs and NO_2

The Spearman's rank-correlation of $PM_{2.5}$, number of visitors, t-PAHs, c-PAHs, nc-PAHs and NO_2 concentrations are shown in Table 3.24. $PM_{2.5}$ concentrations were significantly correlated (*p<0.01*) with concentrations of t-PAHs (*r* = 0.674-0.822), c-PAHs (*r* = 0.618-0.802) and nc-PAHs (*r* =0.612-0.914). Moreover, the strong positive correlations between $PM_{2.5}$ and all type of PAHs were found in 24 hr sampling (*r* = 0.674-0.822 (t-PAHs), 0.618-0.700 (c-PAHs) and 0.738-0.914 (nc-PAHs)). The correlation between t-PAHs and c-PAHs (*r* = 0.934-0.982) was higher than that between t-PAHs and nc-PAHs (*r* = 0.795-0.956). The 24 hrs of NO_2 concentration was significantly correlated (*p<0.01*) with concentrations of t-PAHs (*r* = 0.565-0.686), c-PAHs (*r* = 0.548-0.572), and nc-PAHs (*r* =548-0.789). The correlations between $PM_{2.5}$ and NO_2 concentrations were relatively strong (*r* = 0.680-0.843, *p<0.01*). The correlations between $PM_{2.5}$ level and the number of visitors (*r* = 0.854-0.930) were significantly higher (*p<0.01*) than those between the NO_2 and the number of visitors (*r* = 0.645-0.806). Moreover, the high correlations (*p<0.01*) between PAHs and the number of visitors were also found. The results obtained also indicated that the higher number of visitors was associated with the greater amount of incense being burned, resulting in higher pollutant concentrations indoors.

Table 3.24 Spearman correlations of $PM_{2.5}$, number of visitor, PAHs and NO_2 concentrations in 8 and 24 hrs

	8-hrs (n = 14)						**24-hrs (n = 22)**					
	$PM_{2.5}$	Visitors	t-PAHs	c-PAHs	nc-PAHs	NO_2	$PM_{2.5}$	Visitors	t-PAHs	c-PAHs	nc-PAHs	NO_2
Shrine 1												
$PM_{2.5}$	1.000						1.000					
Visitors	0.878**	1.000					0.930**	1.000				
t-PAHs	0.688**	0.645*	1.000				0.822**	0.801**	1.000			
c-PAHs	0.802**	0.805**	0.934**	1.000			0.700**	0.747**	0.942**	1.000		
nc-PAHs	0.612*	0.592*	0.956**	0.851**	1.000		0.914**	0.847**	0.921**	0.791**	1.000	
NO_2	0.723**	0.704**	0.495	0.587*	0.477	1.000	0.833**	0.806**	0.686**	0.572**	0.789**	1.000
	8-hrs (n = 21)						**24-hrs (n = 27)**					
Shrine 2												
$PM_{2.5}$	1.000						1.000					
Visitors	0.840**	1.000					0.858**	1.000				
t-PAHs	0.475*	0.618**	1.000				0.674**	0.592**	1.000			
c-PAHs	0.451*	0.599**	0.982**	1.000			0.618**	0.561**	0.980**	1.000		
nc-PAHs	0.448*	0.584**	0.795**	0.700**	1.000		0.738**	0.667**	0.850**	0.757**	1.000	
NO_2	0.658**	0.645**	0.287	0.335	0.175	1.000	0.843**	0.748**	0.565**	0.548**	0.548**	1.000

Note: ** Correlation is significant at the 0.01 level (2- tailed)

* Correlation is significant at the 0.05 level (2- tailed)

3.4.5 Isomeric ratios

Besides incense burning in the selected shrines, traffic might be another important source of the pollutants, i.e. $PM_{2.5}$, PAHs and NO_2. In order to confirm that the PAHs detected in this study were mainly from incense burning, sources of the PAHs were investigated and estimated by using isomeric ratios. PAHs isomer pair ratios have extensively been used to explain the characteristics of the specific source. Concentrations of some PAHs being considered as fingerprint of an emission sources were calculated (Orecchio, 2011; Tobiszewski and Namienik, 2012; Wiriya et al., 2013). Table 3.21 shows isomeric ratios from various studies. The FLA/(FLA+PYR) and IND/(IND+BPER) ratios have been used to specify source of PAHs. A ratio value higher than 0.5 indicated grass, wood and coal combustion, while a value lower than 0.5 indicated fossil fuel combustion or petroleum input (Hischenhuber and Stijve, 1987; Yunker et al., 2002). Ratio of BaA/(BaA+CHR) implied petroleum (<0.20), petroleum or combustion (0.20 to 0.35) and combustion (>0.35) (Hischenhuber and Stijve, 1987). The ratio value of ANT/(ANT+PHE) < 0.10 is referred to petroleum, while a ratio > 0.10 indicated high temperature source (combustion) (Yunker et al., 2002). According to previous reports, the investigated sample was evidenced by isomeric ratios, which are not in agreement with each other. Thus, a total index was proposed to confirm that mainly individual PAHs were emitted by combustion (Mannino and Orecchio, 2008). Total index represents a normalized the sum of previously discussed indices and can be calculated using Equation 2.5 (Yunker et al, 2002). The total index higher than 4 indicated PAHs from high temperature processes (combustion), while the value less than 4 indicated low temperature (petroleum products).

The obtained median values of isomeric ratios in 8 and 24 hrs sampling at both shrines were applied to identify sources of PAHs. It can be revealed that the FLA/(FLA+PYA) and IND/(IND+BPER) ratios were higher than 0.50, which indicated grass, wood and coal combustion. However, it was found that 24 hrs of IND/(IND+BPER) ratios at shrine 1 were lower than 0.50 in the Chinese New Year (0.33) and normal periods (0.30). The values of BaA/(BaA+CHR) ratios were 0.35-1.00, it implied combustion, while the ratio values of ANT/(ANT+PHE) were higher than 0.10 indicating high temperature source (combustion). All results of the isomeric ratios were in good agreement with the reference values for emission from grass, wood and coal combustion as shown in Table 3.25. Furthermore, the values of total index were ranked from 5 to 11 (>4.0) indicating high temperature processes (combustion). Therefore, PAHs concentration measured at indoor shrines were clearly a significant source from incense burning.

Table 3.25 Isomeric ratios of some PAHs considered as fingerprint of emission sources

Isomeric ratios	**Sites**	**sampling hours**	**Ratio values**			**Measuring**		
			Chinese New Year	**Other special occasions**	**Normal periods**	**Value**	**Source**	**Reference**
FLA/(FLA+PYR)	Shrine 1	8	0.52	0.54	0.49	< 0.40	Petroleum input	Yunker et al. (2002)
		24	0.56	0.54	0.50	0.40-0.50	Fossil fuel combustion	
	Shrine 2	8	0.51	0.50	1.00	**>0.50**	**Grass,wood,coal combustion**	
		24	0.51	0.51	0.65			
IND/(IND+BPER)	Shrine 1	8	0.59	0.66	ND	0.20	Petroleum	Hischenhuber and Stijve (1987)
		24	0.33	0.56	0.30	0.20-0.50	Liquid fossil fuel combustion	
	Shrine 2	8	0.64	0.54	ND	**> 0.50**	**Grass, wood and coal combustion**	
		24	0.65	0.61	0.64			
BaA/(BaA+CHR)	Shrine 1	8	0.44	0.46	0.44	< 0.20	Petroleum	Hichenhuber and stijve (1987)
		24	0.35	0.44	0.44	0.20-0.35	Petroleum or combustion	
	Shrine 2	8	0.64	1.00	ND	**> 0.35**	**Combustion**	
		24	1.00	1.00	ND			

ND = Not detected

Table 3.25 Isomeric ratios of some PAHs considered as fingerprint of emission sources (continued)

Isomeric ratios	Sites	sampling hours	Ratio values			Measuring		
			Chinese New Year	**Other special occasions**	**Normal periods**	**Value**	**Source**	**Reference**
ANT/(ANT+PHE)	Shrine 1	8	0.21	ND	0.47	< 0.10	Low temperature source (Petroleum)	Yunker et al. (2002)
		24	0.25	0.23	0.28	> **0.10**	**High temperature source (Combustion)**	
	Shrine 2	8	0.18	0.30	ND			
		24	0.32	0.25	ND			
Total index	Shrine 1	8	6.8	5.0	8.1	< 4.0	Low temperature source (Petroleum)	Mannino and Orecchio (2008)
		24	6.3	6.9	6.9	> **4.0**	**High temperature source (Combustion)**	
	Shrine 2	8	7.5	10.3	7.6			
		24	10.8	10.0	7.1			

ND = Not detected

3.5 Assessment of possible health effects based on PAHs concentrations

3.5.1 Toxicity equivalent (TEQ) and mutagenic equivalent (MEQ) concentration

The toxicity equivalent concentration (TEQ) is used for estimation of a human health risk from PAHs. It can be calculated using Equation 2.6. The mutagenic equivalent concentration (MEQ) was calculated by multiplying the concentration of each PAH compound with the mutagenic equivalent factor (MEF) relative to the mutagenic potency of BaP (Nisbet and LaGoy, 1992; Durant et al., 1999 and Jung et al., 2010) (Eq. 2.7).

Table 3.26 shows the values of TEQ and MEQ of each sampling period. Both TEQ and MEQ values obtained from both shrines in descending order were Chinese New Year > other special occasions > normal periods**.** The highest TEQ and MEQ values were found during Chinese New Year. The mean TEQ and MEQ values obtained in during Chinese New Year were 2-3 times higher than the normal periods, and 1-2 times higher than other special occasions. Comparing the 8 hrs TEQ value of this study with the previous study conducted in a temple by collecting 8 hrs of particle samples using personal samplers, it was found that the values of TEQ in our study (3.2±1.8 to 31.8±27.4 ng/m^3) were obviously higher than the previous work (0.29 ± 0.12 to 4.60 ± 1.35 ng/m^3) (Navasumrit et al., 2008). In comparison with the study in Taiwan (Kuo et al., 2008), where PM_{10} samples were collected for 8 hrs in a shrine, the TEQ value (36.6 ng/m^3) was almost the same with the value obtained during the Chinese New Year in this study. The TEQ values found in this study were much higher than the European guideline (1 ng/m^3).

The TEQ and MEQ values of 8 hrs sampling were higher than those of 24 hrs sampling. Both values presented similar trends. Moreover, the TEQ and MEQ values (8 and 24 hrs) at shrine 2 were lower than shrine 1. In overall, values of MEQ were higher than TEQ. The results agreed well with TEQ and MEQ values for 8 hrs $PM_{2.5}$ sampling from indoor and outdoor residents of young children in New York City (Jung et al., 2014). They found that the average TEQ values (0.478±0.709 ng/m^3) were lower than MEQ values (0.590±1.32 ng/m^3) from indoor sampling due to the dominant BbF, IND and BPER. Krugly et al. (2014) reported that MEQ values (0.81- 14.56

ng/m^3) of 8 hrs $PM_{2.5}$ collected from an indoor of a primary school in Lithuania were similar to the results found in this study during special occasions and normal period. However, the obtained TEQ and MEQ values emitted from motor vehicles and fuel burning for heating found in studied by Jung et al. (2010) and Krugly et al. (2014), were lower than those values Chinese New Year of this study. The main factors should be the ventilation system and the amount of incense being burned. Comparing with a study in ambient air of Chiang Mai (Peangchai et al., 2008; Chantara and Sangchan, 2009; Wiriya et al., 2013), where 24 hrs PM_{10} samples were collected, it was found that the ranges of TEQ values were 0.92-1.76 ng/m^3 and 0.75-1.60 ng/m^3 in the urban area and 0.25-3.70 ng/m^3 in the sub-urban area. It can be concluded that TEQ values calculated from ambient samples were much lower than the values reported in this study on every occasion and in every situation.

Table 3.26 Average concentrations of TEQ and MEQ values of PAHs in indoor air at selected shrines.

Sampling periods	TEQ concentration (ng/m^3)				MEQ concentration (ng/m^3)			
	Shrine 1		Shrine 2		Shrine 1		Shrine 2	
	8 hrs	24 hrs	8 hrs	24 hrs	8 hrs	24 hrs	8 hrs	24 hrs
Chinese New Year	31.5 ± 11.6 (n=2)	20.4 ± 6.7 (n=6)	31.8 ± 27.4 (n=3)	9.8 ± 4.3 (n=6)	39.0 ± 16.2 (n=2)	25.9 ± 8.0 (n=6)	25.3 ± 12.2 (n=3)	11.9 ± 5.4 (n=6)
Other special occasions	20.3± 14.0 (n=5)	11.8 ± 3.2 (n=8)	15.1 ± 7.6 (n=9)	6.8 ± 2.6 (n=8)	26.8 ± 17.7 (n=5)	14.3 ± 2.9 (n=8)	18.0 ± 8.0 (n=9)	8.0 ± 3.1 (n=8)
Normal periods	13.6 ± 11.7 (n=7)	6.9 ± 5.4 (n=8)	3.2 ± 1.8 (n=10)	2.6 ± 1.5 (n=13)	13.9 ± 11.5 (n=7)	7.9 ± 7.1 (n=8)	5.2 ± 3.3 (n=10)	3.6 ± 2.2 (n=13)

3.5.2 The inhalation cancer risk (ICR) assessment

The inhalation cancer risk (ICR) was used to estimate the value of cancer risk from PAHs exposure during different periods and can be calculated using Equations 2.8-2.9 (Sarkar and Khillare, 2012; Wiriya et al., 2013; Jung et al., 2010; Jia et al, 2011)

$$ICR = TEQ \times IUR_{BaP} \qquad (\textit{Eq 2.9})$$

Where, IUR_{BaP} is the inhalation unit risk.

Two different IUR_{BaP} values for lifetime (70 years) PAHs exposure were used in this study to estimate the inhalation cancer risk. The recommended IUR_{BaP} of the World Health Organization (WHO) is 8.7×10^{-5} $m^3/\mu g$ (WHO, 2000), while the IUR_{BaP} proposed by the Office of Environmental Health Hazard Assessment (OEHHA) of California Environmental Protection Agency (CalEPA) is 1.1×10^{-6} $m^3/\mu g$ (Collins et al., 1998; OEHHA, 2003). The mean TEQ value was obtained from the calculation of each period (Eq. 2.6). The inhalation cancer risk was calculated and compared among different periods as shown in Table 3.27.

The 8 and 24 hrs of lifetime inhalation cancer risks (ICR) calculated based on WHO and CalEPA guideline obtained from both shrines in descending order were Chinese New Year > other special occasions > normal periods. Moreover, it was found that the ICR values calculated based on WHO were higher than values of CalEPA. Hence, if a million people were exposed to PAHs at the level of 10 ng/m^3 TEQ (Chinese New Year) for 70 years, 850 persons may have a risk of cancer development. Following the same calculation, 11 persons based on CalEPA may develop cancer. The ICR values between 10^{-6} to10^{-4} are potential risk and ICR of 10^{-6} represents a lower-bound zero risk, while the upper 10^{-4} of ICR indicates high potential health risk (Chiang and Liao, 2006; Sarkar and Khillare, 2012). The calculated ICR values were found to have a high potential health risk based on WHO, while those based on CalEPA were in a lower-bound zero risk. The societal inhalation cancer risk was obtained by multiplication of ICR values with a million people (Jung et al., 2010). The societal inhalation cancer risk was obtained by multiplying the ICR by one million people. The societal ICR (cases/million people) for 8 hrs calculation based on WHO in descending order were Chinese New Year (2,700 (shrine 1) and 2,800 (shrine 2)), other special occasions

(1,800 (shrine 1) and 1,300 (shrine 2)) and the normal periods (1,200 and 280), while those based on CalEPA were 35 for both shrines in Chinese New Year, 22 (shrine1) and 17 (shrine 2) in other special occasions and 15 (shrine1) and 4 (shrine 2) in normal period. The societal ICR for 24 hrs calculation based on WHO in descending order were Chinese New Year (1,800 (shrine 1) and 850 (shrine 2)), other special occasions (1,000 (shrine 1) and 600 (shrine 2)) and the normal periods (600 and 230), while those based on CalEPA were 22 (shrine1) and 11 (shrine 2) in Chinese New Year, 13 (shrine1) and 8 (shrine 2) in other special occasions and 8 (shrine1) and 3 (shrine 2) in normal periods. The 24 hrs average value for the normal periods of this study based on WHO was 600 or 8.6 cases/year (shrine 1) and 230 or 3.3 cases/year (shrine 2), while those based on CalEPA was 8 or 0.11 cases/year (shrine 1) and 3 or 0.043 cases/year (shrine 2). In general, the values of societal ICR in all cases were found to be higher at shrine 1 than shrine 2. The main reason might be the poor ventilation system in the shrine 1. The societal ICR values of 8 hrs sampling calculated based on WHO and CalEPA were higher than the 24 hr sampling due to the service period of the shrine. Generally, the shrines are ordinarily opened in the daytime (8 am – 5 pm) except only during Chinese New Year, when the shrines are opened all day. Moreover, it was found that the number of cases proposed based on WHO in this study was higher than the previous study performed in ambient air of Chiang Mai in 2005 - 2006 (2 cases per year) (Pengchai et al. 2008), but it was much higher than the study in 2010-2011 (1.3 cases per year) (Wiriya et al., 2013). However, it should be noted that the values are only a rough estimation of cancer risk from the $PM_{2.5}$-bound PAHs inhalation.

Table 3.27 The inhalation cancer risk of $PM_{2.5}$-bound PAHs at shrines in various occasions

Index	Organizations	Sites	sampling hours	Chinese New Year	Other special occasions	Normal periods
ICR	**WHO (8.7 × 10^{-5} m^3/ng)**	Shrine 1	8	27×10^{-4}	18×10^{-4}	12×10^{-4}
			24	18×10^{-4}	10×10^{-4}	60×10^{-5}
		Shrine 2	8	28×10^{-4}	13×10^{-4}	28×10^{-5}
			24	85×10^{-5}	60×10^{-5}	23×10^{-5}
	CalEPA (1.1 × 10^{-6} m^3/ng)	Shrine 1	8	35×10^{-6}	22×10^{-6}	15×10^{-6}
			24	22×10^{-6}	13×10^{-6}	76×10^{-7}
		Shrine 2	8	35×10^{-6}	17×10^{-6}	35×10^{-5}
			24	11×10^{-6}	75×10^{-7}	29×10^{-7}
Risk (1×10^{6})	**WHO**	Shrine 1	8	2,700	1,800	1,200
			24	1,800	1,000	600
		Shrine 2	8	2,800	1,300	280
			24	850	600	230
	CalEPA	Shrine 1	8	35	22	15
			24	22	13	8
		Shrine 2	8	35	17	4
			24	11	8	3