CHAPTER 4

CONCLUSIONS

Incense burning is a significant indoor source of $PM_{2.5}$, PAHs and NO_2. This study has brought important information on the emissions of $PM_{2.5}$ and PAHs from burning of incenses and their raw materials, including sawdust, wood powder (Chankao), plant-based glutinous powder, bamboo and dye powder, based on the burning experiments in the chamber. The data was used to estimate pollutant emissions for indoor air quality assessment. The average emission factors (EFs) of $PM_{2.5}$ emitted from incense burning ranged from 3.44±0.22 to 30.00±4.69 g/kg $_{incense}$. Furthermore, in this study it was found that the EFs of $PM_{2.5}$ emitted from incense burning 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 smoke-free incense stick burning (incense H) showed the lowest EFs of $PM_{2.5}$. EFs of total PAHs (t-PAHs) emitted from incense burning ranged from 1.14±0.035 to 4.04±0.09 mg/kg $_{incense}$. The carcinogenic PAHs (c-PAHs) were 36-83 %. The EFs of t-PAHs values 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). The emission rates (ERs) of $PM_{2.5}$ (mg/hr) and $PM_{2.5}$-bound PAHs (µg/hr) from incense burning in a descending order were aromatic incense cones (86.7±8.2 to 179±29 mg/hr and 10.5±1.7 to 30.7±1.5 µg/hr) > aromatic incense sticks (4.9±0.2 to 43.9±1.4 mg/hr and 2.03±0.04 to 9.32±2.72 µg/hr) > traditional incense sticks (14.6±0.5 to 25.4±0.8 mg/hr and 1.82±0.16 to 5.73±1.79 µg/hr). The ERs of both $PM_{2.5}$ and $PM_{2.5}$-bound PAHs from incense burning were the highest in aromatic incense cones (I) and the lowest in longan peel based incense (C). Burning of all types of incenses generated dominant species of PAHs such as FLA, PYR, BaP, BaA and CHR.

Toxicity equivalent (TEQ) and mutagenic equivalent (MEQ) concentrations were calculated to indicate human health risk from PAHs inhalation. Based on EFs values (mg/kg), TEQ and MEQ were calculated. It was found that dried-flower based incense (D and E) and aromatic incense cones (I and J) showed high values of TEQ (0.425±0.032 to 0.649±0.039 mg/kg) and MEQ (0.541±0.040 to 0.724±0.035 mg/kg), while incense A, longan peel based incense (C) and smoke-free incense (H) presented low concentrations of TEQ (0.138±0.037 to 0.319±0.041 mg/kg) and MEQ (0.162±0.044 to 0.364±0.033 mg/kg). Moreover, the concentrations of TEQ and MEQ based on ERs values (µg/hr) were low from longan peel based incense burning (0.374±0.053 and 0.392±0.055 µg/hr) and smoke-free incense burning (0.410±0.054 and 0.520±0.051 µg/hr) , while the values were high for aromatic incense cone burning (1.246±0.203 to 4.365±0.196 and 1.583±0.234 to 4.808±0.217 µg/hr). It can be concluded that longan peel based incense and smoke-free incense are suitable to be used indoors, while aromatic incense cone should be avoided because it induces high emission of c-PAHs, which adversely affects human health.

The EFs of $PM_{2.5}$ values emitted from the raw material burning in descending order were wood powder (44.7±3.2 g/kg) > sawdust (31.5±2.2 g/kg) > plant-based glutinous powder (24.7±0.9 g/kg) > bamboo (13.9±2.2 g/kg) > dye powder (2.0±0.5 g/kg). The sawdust and wood powder are important ingredients for production of incenses in Thailand and they were found to emit high concentrations of PAHs. The dominant PAHs emitted from raw material burning were ANT, FLA, CHR and PHE. Concentrations of individual PAHs (ANT, FLA and PYR) were well correlated with $PM_{2.5}$, but $PM_{2.5}$ was not correlated with t-PAHs, c-PAHs and nc-PAHs. However, a strong correlation was found between $PM_{2.5}$ and 4 and 5 rings of PAHs released from raw material burning. Furthermore, high correlations were found between individual PAHs including PHE & ANT, FLA & PYR and BaA & CHR. Therefore, they were used for calculation of isomeric ratios for identification of PAHs sources. The PAHs ratios of FLA/(FLA+PYR), IND/(IND+BPER), BaA/(BaA+CHR) and ANT/(ANT+PHE) were 0.52-0.68, 0.19-0.65, 0.39-0.59 and 0.27-1.00, respectively. Moreover, the total index values were 7.02-12.9. The obtained ratios were classified for grass, wood and coal combustion and high temperature combustion processes. The

highest EFs of gas released from all types of incense and raw material burning were found with CO, followed by NO, while SO_2 was only emitted from dye powder burning.

The concentrations of all pollutants (NO_2, $PM_{2.5}$ and total PAHs) found on several occasions at the selected shrines in descending order were the Chinese New Year > other special occasions > the normal period. The concentrations of indoor $PM_{2.5}$ were strongly correlated with t-PAHs, c-PAHs and NO_2. The concentrations of $PM_{2.5}$, NO_2, t-PAHs, c-PAHs and nc-PAHs were found to be positively correlated with the amounts of incense burned by visitors at the shrines. It was clearly seen that the levels of those pollutants were significantly higher during the special occasions than during the normal periods. Moreover, the $PM_{2.5}$ concentrations were higher than the standard values regulated by various organizations concerned with air quality and health. During special occasions, the emission of $PM_{2.5}$ and c-PAHs could be high and could cause a more potential risk to human health than normal periods.

The inhalation cancer risk assessment was calculated based on the toxicity equivalent concentrations. The results revealed that the equivalent values during the Chinese New Year were many times higher than the equivalent values obtained on other occasions, where the results were related with concentrations of PAHs. The exposure to PAHs could be implemented in relation to chronic effect on human health. To improve indoor air quality, where a lot of incenses are used, the ventilation systems should be good enough. In public places such as temples and shrines, the number of incense to be burned by individual visitor should be strictly controlled, while the outdoor air circulation and indoor ventilation system should be ensured to be adequate for such practice.