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Research Article

Research on PAHs emission from small scale incinerators: A case study in Yen Lac District, Vinh Phuc Province

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Abstract: An evaluation of the PAHs emission from small scale incinerators (SSI) in Yen Lac district, Vinh Phuc province, Vietnam was assessed. Twenty-four representative dust samples from the SANKYO incinerators were taken. The concentration levels of PAHs in the samples were determined using gas chromatography coupled with mass spectrometry. The main applied research methods include field observation and sample analysis. The results of the analysis revealed the time trend variation of PAHs concentration in samples. In April, June, September, and November, Σ_{16}PAHs concentrations ranged from 97.83 to 113.0 µg/m^3, from 105.32 to 119.04 µg/m^3, from 107.25 to 118.73 µg/m^3 and from 101.56 to 139.48 µg/m^3, respectively. The mean percentages of L–PAHs, M–PAHs and H–PAHs in the analyzed dust samples are 55.7%, 33.8% and 10.5%, respectively. These values can be explained by the PAHs physical chemical properties as well as combustion technology of Sankyo incinerator. The emission factor of 16 PAHs is ranged from 0.0018 to 0.300mg/kg. The results of this study can be applied to estimate the amount of PAH generated when burning domestic waste in rural areas.

Keywords: PAHs; Emission factor; Small scale incinerators.

1. Introduction

In recent years, the problem of dust pollution in urban areas of Vietnam tends to increase [1–2]. Dust pollution in urban areas includes both internal and external sources, spreading from neighboring provinces. Dust exposure is statistically associated with a variety of dangerous diseases. The harm and danger of exposure to various types of dust depend on the characteristics of the emission source [1–2]. One of the sources of highly hazardous dust emissions is from small–scale domestic waste incinerators. Currently, to deal with pollution from domestic waste, many localities have chosen to invest in small scale domestic waste incinerators (SSI) as a solution. The above solution, although achieving short–term benefits, will have many consequences in the long run. Dust emitted from SSI contains many persistent toxic organic substances, which has caused significant pollution in the air, affecting the surrounding people. Therefore, assessing the harm, environmental risk level, toxic organic substances composition in dust from small scale incinerators is very necessary.

An aromatic compound with two or more fused arenes is called a polycyclic aromatic hydrocarbon (PAHs) [3]. They are primarily produced by the incomplete combustion of wood, grass, coal, fossil fuels, and municipal waste [4–5]. In most cases, PAHs are carcinogenic and hazardous to wildlife and humans [6]. PAHs have a low water solubility, hydrophobic nature and were often accumulated in various environmental systems including dust, soil, sediment and organisms [7–8].

In Vietnam, several studies have been conducted on the contamination of PAHs in air and street dust. Typically, the study about air PAHs samples at three surveyed locations in Hanoi in 2003 showed the PAHs concentration in the range of 144,93 to 295,63 ng/m^3 [9–10] determined the concentrations of PAHs in street dust samples range from 530 to 4700 µg kg^{-1} dry weight in Hanoi, Vietnam. However, to our knowledge, little data is available concerning PAHs emission from small scale domestic waste incinerators (SSI) in countryside's of Vietnam. International research often concentrated on 16 representative PAHs including: naphthalene (Nap), acenaphthylene (Acey), acenaphthene (Ace), fluorene (Flu), phenanthrene (Phe), anthracene (Ant), fluoranthene (Flt), pyrene (Pyr), chrysene (Chr), benzo[a]anthracene (BaA), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), benzo[a]pyrene (BaP), indeno [1,2,3–cd] pyrene (IcdP), dibenzo[a,h]anthracene (DahA), and benzo [g,h,i] pyrene (BghiP).

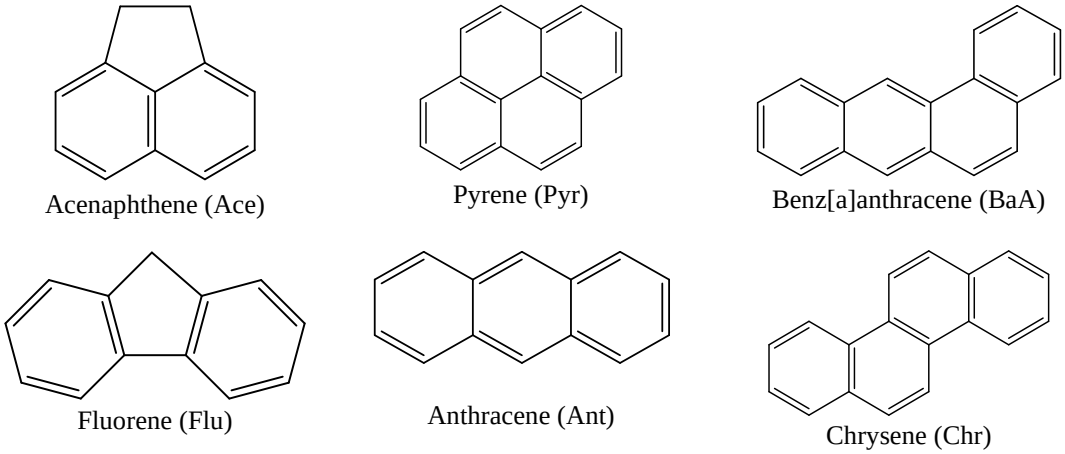

Figure 1. Some typical PAHs structures.

Rural areas in Vinh Phuc province emit about 600 tons of solid waste per day into the environment. The ability to collect and treat is about 70%, the rest is incinerated. In Vinh Phuc province, there are 33 SSI. The conventional incineration process consists of 3 main steps: classification, incineration, and treatment of dust and ash. When all three stages are combined synchronously, the basic pollution source will be solved. However, in Vinh Phuc province, only one stage has been completed, which is burning garbage, the remaining stages have not been thoroughly treated. The research area in Vinh Phuc was selected at the SSI in Yen Lac district. The SSI started operating in 2014, have a capacity of 500 kg/h and all use Sankyotechnology made in Thailand with a capacity of 500kg/h. However, in the process of using Sankyotechnology, the treatment of smoke and dust has not been thorough, and the lack of synchronous operation has also affected the environment. Therefore, the research of the PAHs emission in Yen Lac district, Vinh Phuc province is important. The research results can be applied to other rural areas with the same household waste composition and treatment technology as Vinh Phuc. The main objectives of the study include: i) Assessment of PAHs concentration in dust emitted from chimneys of SSI; ii) Assessment of ratio and composition of PAHs in dust samples; iii) Research on load and emission factor of PAHs from SSI.

2. Materials and methodology

2.1. Study area and sampling

2.1.1. Study area

The study area in Vinh Phuc was selected in Yen Lac district where has several SSI incinerators (Figure 2).

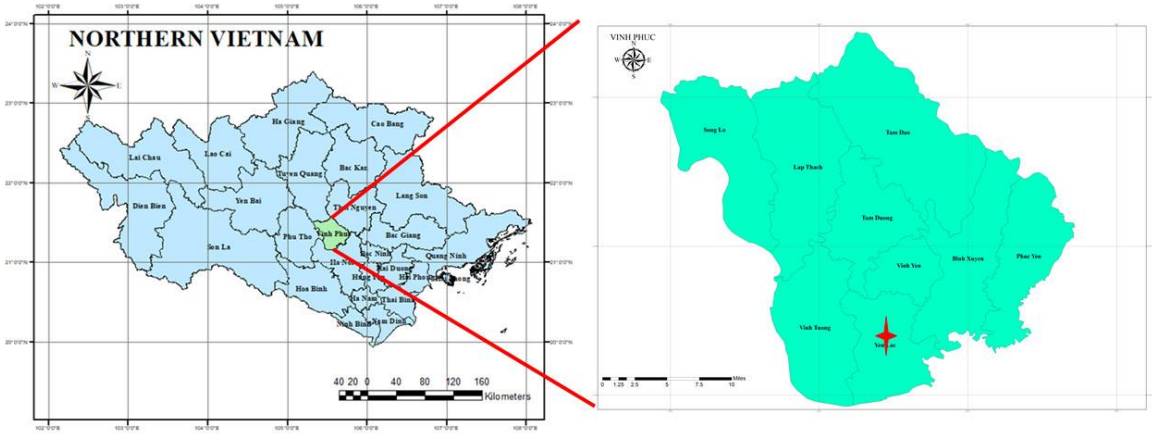

Figure 2. Location of the study area.

The composition of domestic solid waste in Yen Lac district has a combination of sources in purely agricultural areas and towns.

Table 1. Results of analysis of domestic solid wastecomposition in Yen Lac district.

No	Composition of domestic solid waste	Percentage (%)
1	Organic component	68.11
2	Waste paper, glass, metal	5.90
3	Plastic bags, plastic bottles	4.0
4	Toxic material (battery, paint…)	0.01
5	Porcelain, concrete, brick, coal slag, tires...	21.98

Sankyo incinerator uses natural gas fuel with the function of burning domestic solid waste for the entire population of Yen Lac district (Figure 2). The process consists of three steps: classification, burning, treatment of dust and ash.

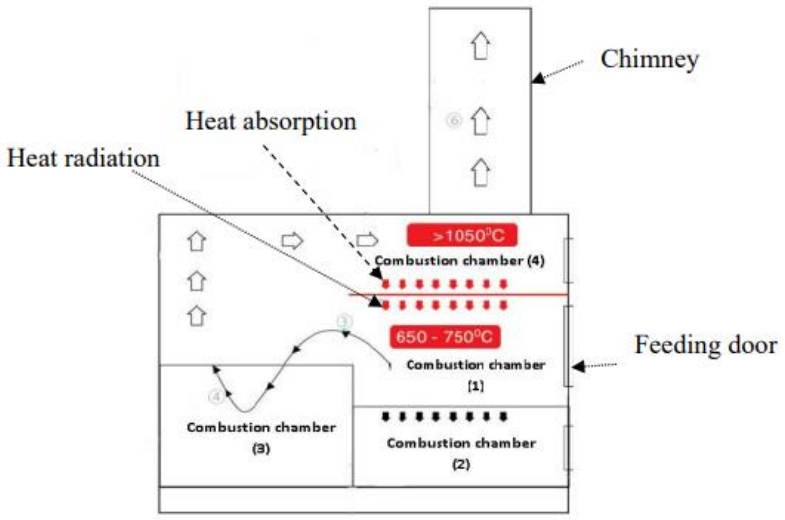

Figure 3. Simulation of Sankyo incinerator.

- Waste treatment process: The solid waste is collected and brought to the treatment area. Preliminary classification: bricks, glass, silt... non–combustible is removed for burial; nylon, plastic, metal... sold as scrap, the rest is burned. In the primary and secondary combustion chambers, the waste is burned at temperatures of 650^{o}C and 1050^{o}C, the retention time is about 2–3 seconds. Output waste includes smoke and ash (Figure 3).

- Exhaust gas treatment process: According to the design, the exhaust gas is cooled through the radiator ribs. Exhaust smoke is treated through dust traps staggered along the chimney to completely store dust before discharging.

- The composition of waste before being put into the incinerator: determined on average in 4 sampling periods.

2.1.2. Sampling

A total of 24 samples were collected from two SSI in Yen Lac district. Repeating sampling time is April, June, September, and December 2021 at each location of the waste incinerator. Samples were taken according to the instructions in Circular No. 40/2015/TT–BTNMT on technical process of emission monitoring. The samples were taken isokinetically using the train may be constructed by adaptation of an ARB Method 5 train. The train consists of a nozzle, probe, heated particulate filter, condenser, and sorbent module, followed by three impingers and a silica gel drying cartridge. An in–stack filter cannot be used because the filter material must be different than the Teflon required by the method at the in–stack temperatures. For sources emitting a large amount of particulate matter, a cyclone or similar device in the heated filter box may be used. Place 100 ml of the impinger solution in the first impinger and weigh. Record the total weight. Repeat the procedure for the second impinger. Leave the third impinger empty. Weigh the empty third impinger and record the weight. Just before assembling the sampling train, weigh 200 to 300 g of silica gel to the proximity 0.5 g directly into a tared impinger or silica gel cartridge. To adsorb gaseous PAH, a sorbent trap containing Amberlite resin (XAD–2) was used. Before use the resin (and the glass wool) was Soxhlet extracted by methylene chloride for 24 hours at approximately four cycles per hour and dried by pure nitrogen gas stream. The flue gas flow rate was measured by the integrated manometer in the train, and the isokinetic sampling gradient rate was maintained automatically by the device.

2.2. Study methods

Analysis of Polycyclic Aromatic Hydrocarbon in Airborne Particulate Matter Samples by Gas Chromatography in Combination with Mass Spectrometry (GC–MS). Quality assurance and quality control were conducted by performing laboratory blanks, sampling blanks, and recoveries of international sediment exchange for tests on organic contaminants samples.

Approximately l hour before HRGC/LRMS or HRGC/HRMS analysis, adjust the sample extract volume to approximately 500 µL. This is done by adding 50 µL of the recovery standard spike solution to the 450 µL final volume of the concentrated sample extract giving the sample extract concentration required. If the sample volume must be changed to achieve a desired detection limit, the recovery spike solution concentration must be adjusted accordingly to achieve the target concentrations. Inject a 2 µL aliquot of the sample extract onto the DB–5 column. Use the same volume when during calibration. Recommended GC/MS operating conditions. The presence of a given PAH has qualitatively confirmed the criteria are satisfied. The response for any quantitation or confirmation ion in the sample extract must not exceed the response of the highest concentration calibration standard. Collect, record, and store the data for the calculations required.

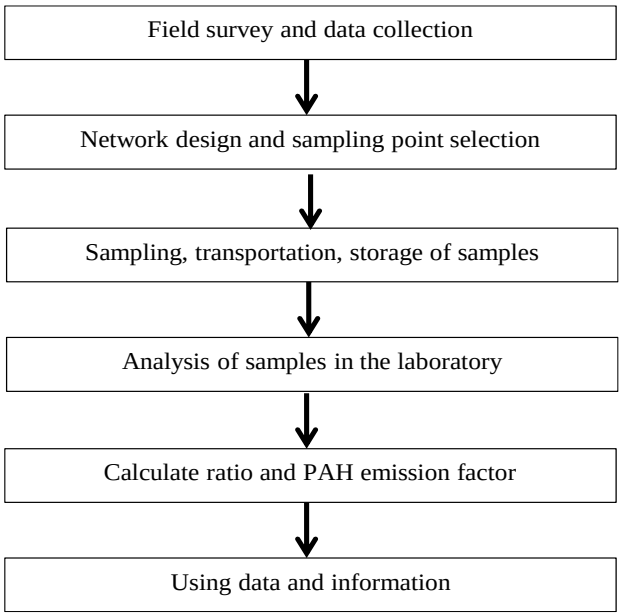

Figure 4. Research structure diagram.

Limit of detection (LOD) was calculated as 3 times signal–to–noise ratio obtained from lowest matrix–matched samples. Meanwhile, the method limit of quantification (LOQ) was calculated by 10 times signal to noise at the lowest concentration matrix–matched samples. The numbers of injection of blanks and QC samples in one analysis batch contained at least 20% of total numbers of injection. The method of determining the emission factor: Apply the direct observation method to calculate the emission factor of PAH from the dust sample in the chimney.

3. Results and discussion

3.1. PAHs concentration in dust emitted from chimneys of SSI

From April to November 2021, PAHs were found in all of the dust samples that demonstrated the occurrence of PAHs in SSI (Table 2). This is understandable because PAHs are mostly produced by incomplete combustion [4–5]. The total average of Σ_{16}PAHs concentration in dust samples was 114.24, ranging from 97.83 to 139.48 µg/m^3.

Table 2. The PAHs concentrations (µg/m^3) in dust samples from study area.

Compound	April	June	September	November
Nap	30.87–32.68 [(a)] (31.9 ±0.67)	31.65–34.84 (33.8 ±1.18)	32.17–34.29 (33.39 ±0.78)	30.51–35.24 (33.23 ±1.75)
Acy	0.22–0.28 (0.25 ±.022)	0.24–0.28 (0.26 ±0.015)	0.18–0.23 (0.2 ±0.02)	0.23–0.30 (0.27 ±0.03)
Ace	0.36–0.51 (0.44 ±0.05)	0.47–1.33 (0.96 ±0.32)	0.35–0.43 (0.39 ±0.03)	0.46–1.0 (0.77 ±0.2)
Flu	21.59–22.68 (22.21 ±0.4)	22.15–23.50 (22.9 ±0.5)	18.77–19.61 (19.25 ±0.03)	21.36–22.68 (22.12 ±0.49)
Phe	0.38–0.45 (0.42 ±0.026)	0.46–0.53 (0.5 ±0.026)	0.32–0.37 (0.35 ±0.02)	0.45–0.62 (0.55 ±0.06)
Ant	5.88–6.84 (6.43±0.35)	6.56–7.63 (7.17 ±0.04)	5.16–5.89 (5.58 ±0.27)	6.33–8.12 (7.36 ±0.66)
Py	6.27–12.57 (9.89 ±2.33)	13.13–15.14 (14.28 ±0.74)	15.57–16.56 (16.13 ±0.37)	12.66–14.07 (13.47 ±0.5)
Flt	6.33–6.60 (6.5 ±0.12)	6.66–7.08 (6.9 ±0.15)	6.77–7.02 (6.9 ±0.09)	6.42–9.35 (8.1 ±1.1)
BaA	0.30–0.44 (0.38 ±0.05)	0.50–0.62 (0.56 ±0.004)	0.38–0.55 (0.48 ±0.06)	0.48–0.96 (0.75 ±0.18)

Compound	April	June	September	November
Chr	0.15–0.20 (0.18 ±0.02)	0.17–0.22 (0.2 ±0.02)	0.09–0.18 (0.14 ±0.03)	0.16–0.21 (0.19 ±0.02)
BbF	2.07–2.38 (2.25 ±0.11)	2.29–2.72 (2.53 ±0.16)	1.77–1.99 (1.89 ±0.08)	2.21–3.27 (2.8 ±0.4)
BkF	0.12–0.14 (0.13 ±0.007)	0.24–0.25 (33.8 ±1.18)	0.11–0.13 (0.12 ±0.007)	0.22–0.45 (0.35 ±0.08)
BaP	0.17–0.19 (0.18 ±0.007)	0.20–0.22 (0.24 ±0.004)	0.12–0.14 (0.13 ±0.007)	0.19–0.34 (0.27 ±0.06)
Ind	14.32–18.13 (16.5 ±1.4)	14.42–17.99 (16.47 ±1.32))	18.54–24.03 (21.69 ±2.0)	13.90–34.54 (25.76 ±7.6)
BghiP	4.33–4.46 (4.4 ±0.048)	4.58–4.99 (4.8 ±0.15)	5.06–5.16 (5.12 ±0.04)	4.42–6.56 (5.6 ±0.8)
DahA	1.2–1.3 (1.26 ±0.04)	1.6–1.7 (0.65 ±0.04)	1.89–2.15 (2.01 ±0.09)	1.56–1.77 (9.12 ±16.6)
L–PAHs [b]	59.33–63.44 (61.8 ±1.53)	61.53–68.11 (65.31 ±2.44)	59.65–60.82 (59.17 ±1.43)	59.34–67.96 (64.30 ±3.20)
M–PAHs [c]	13.05–19.87 (16.97 ±2.53)	20.46–23.06 (21.95 ±0.96)	22.81–24.31 (23.67 ±0.56)	19.72–24.59 (22.52 ±1.81)
H–PAHs [d]	20.01–25.3 (23.48 ±1.59)	21.73–26.17 (24.28 ±1.64)	25.6–31.45 (28.96 ±2.17)	20.94–45.16 (34.87 ±8.99)
Σ_8PAHs [e]	22.66–27.24 (25.29 ±1.69)	24.0–28.71 (26.71 ±1.74)	48.5–58.36 (52.32 ±4.40)	23.14–48.10 (37.49 ±9.25)
Σ_{16} PAHs [f]	97.83–113.0 (106.55 ±5.63)	105.32–119.04 (113.21 ±5.1)	107.25–118.73 (113.85 ±4.26)	101.56–139.48 (123.36 ±14.06)

(a) min – max (mean ± standard deviation); (b) Low molecular weight PAHs with 2 and 3 aromatic rings (Nap, Acey, Ace, Flu, Phe, Ant); (c) Middle molecular weight PAHs with 4 aromatic rings (BaA, Chr, Pyr, Fla); (d) High molecular weight PAHs with 5 and 6 aromatic rings (BbF, BkF, BaP, IcdP, BghiP); (e) sum of 8 carcinogenic PAHs compounds (BaA, Chr, BbF, BkF, BaP, Ind, BghiP, DahA); (f) sum of all 16 selected PAHs.

In Vietnam, there has been no study on PAH in incinerators before, but when compared with other studies around the world, the value of total Σ_{16}PAHsconcentration was dramatically higher than the Σ_{16}PAHs in PM10 from outside residential apartments around two MSWIs in Shenzhen, China [11] and sampling sites located 1 km from the medical waste incinerator in Taiwan, China [12]. It was found that the concentration of PAHs around these incinerators in Shenzhen and Taiwan was affected by the outside environment, including wind, temperature, and sunlight, while that of PAHs in dust samples taken from the SSI was not affected by those environmental factors. Moreover, some PAHs cause cancer to people in contact, however, the National Technical Regulation on domestic solid waste incinerators in Vietnam does not have threshold parameters for the concentration of PAHs [13].

The highest levels of Σ_{16}PAHs were found in November, ranging from 101.56 to 139.48, with a mean of 123.36 ± 14.06 µg/m^3. In contrast with November, the concentration of the Σ_{16}PAHs Vinh Phuc was lowest in April (min–max: 97.83–113.0 µg/m^3; mean: 106.55 ± 5.63 µg/m^3). The concentration of PAHs in the sampling months is not significantly different; the possible explanation could be due to the amount or pattern of biomass in the incinerator, which requires further investigation. Furthermore, PAH concentrations tend to decrease in the following order: L–PAH (min–max: 59.28–65.28 µg/m^3; mean: 62.61 ± 2.15 µg/m^3) > H–PAH (22.32–32.02; 28.9 ± 3.6)> M–PAH (19.01–22.95; 21.28 ± 1.46). This is consistent with simple incineration conditions that are more beneficial to the further degradation and conversion of PAHs with lower molecular weight (LMW) [14].

The total amount of carcinogenic PAHs compounds among the BaA, Chr, BbF, BkF, BaP, Ind, BghiP, and DahA ranged from 22.66 to 58.36. Ind (13.90–34.54) has the highest concentration in eight carcinogenic PAHs, while BkP (0.22–0.45) has lowest.

3.2. PAHs composition in dust samples

In terms of composition analyses, all 16 PAHs congeners were found in the soil samples collected. The following were the mean percentages of PAHs congeners in all dust samples: Nap (29.64), Acy (0.22%), Ace (0.55%), Flu (19.1%), Phe (0.4%), Ant (5.81%), Pyr (11.75%), Flt (6.24%), BaA (0.5%), Chr (0.16%), BbF (2.1%), BkF (0.2%), BaP (0.17%), Ind (17.3%), BghiP (4.4%), DahA (1.46%) (Figure 5). Low molecular weight PAHs like Nap, Flu, Phe, and Ant was the most abundant in the dust sample. L–PAHs were typically produced by biomass (grass, wood) and coal burning (low or moderate–temperature combustion processes), while H–PAHs were produced by vehicular emissions and industrial fuel combustion (high–temperature from combustion processes). The analysis of the PAHs profile in incinerator dust samples revealed that M–PAH and H–PAHs predominated. In 16 PAHs, four–ring PAH homologs contribute the majority, with a progression of two–ring >three–ring > six–ring > four–ring > five–ring. There is a direct correlation between PAH abundance and combustion processes. Due to this, PAHs are produced in different ways in different types of combustion. In the analyzed dust, L–PAH compounds dominated (55.72%), which indicates that combustion is the primary source of PAHs along the incinerator.

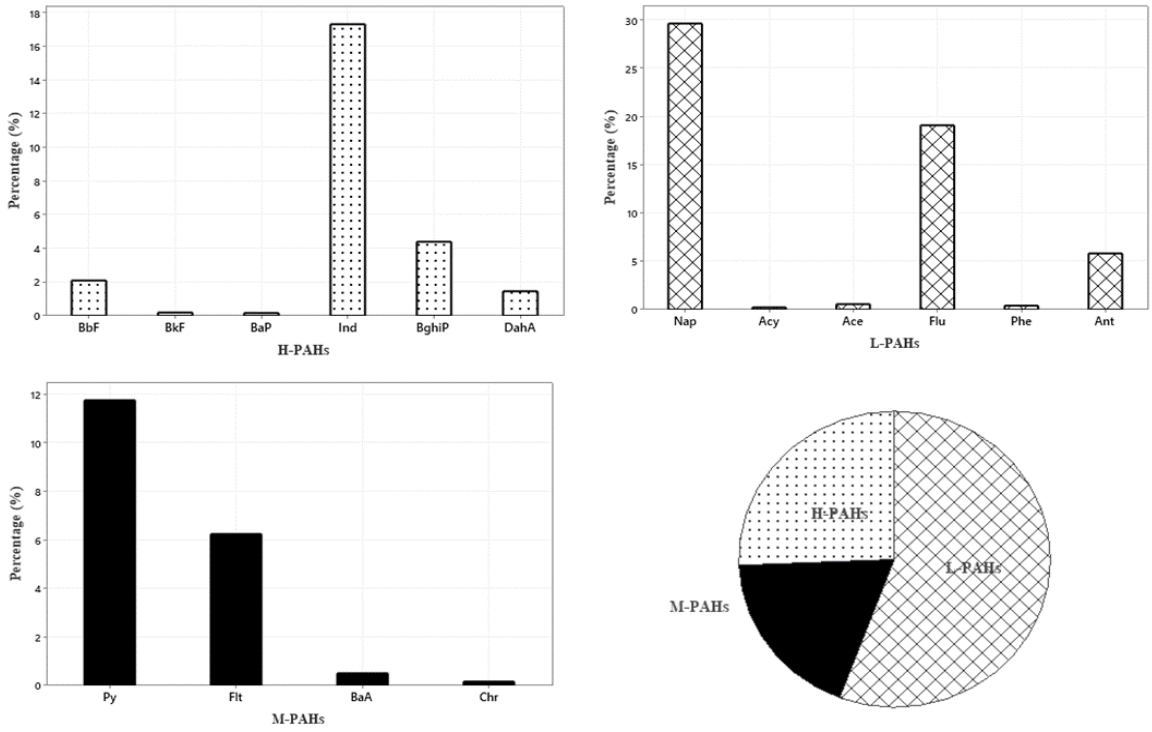

Figure 5. The percentage of PAHs concentration in dust samples from the chimneys of the SSI.

Table 3 contains isomeric ratios of selected individual PAHs compounds that can be used to discuss contaminant sources in greater detail.

Table 3. The isomeric ratio of PAHs and emission sources.

Isomeric ratio	**Ratio values**	**Emission sources** [(a)]
Ant/(Ant+Phe)	<0.1	Petroleum contamination
	>0.1	Combustion
Flt/(Flt+Pyr)	>0.5	Combustion of grass, wood, and coal
		Petroleum contamination
	<0.4	Burning of petroleum
	0.5 – 0.4	

Isomeric ratio	Ratio values	Emission sources [(a)]
BaA/(BaA+Chr)	>0.35	Combustion sources
	0.20 – 0.35	Mixed source
	<0.20	Petroleum sources
Ind/(Ind+BghiP)	<0.20	Petroleum contamination
	0.20 – 0.50	Fossil fuel combustion
	>0.50	Incomplete combustion of grass, wood, and coal

(a): [15–16]

At present, no study in Vietnam has published the ratio of PAHs in dust samples emitted from small–scale domestic waste incinerators. Therefore, the results on the ratio of PAH in dust samples from this study can be used to determine the source of PAH emissions caused by the burning of domestic waste (Figure 6).

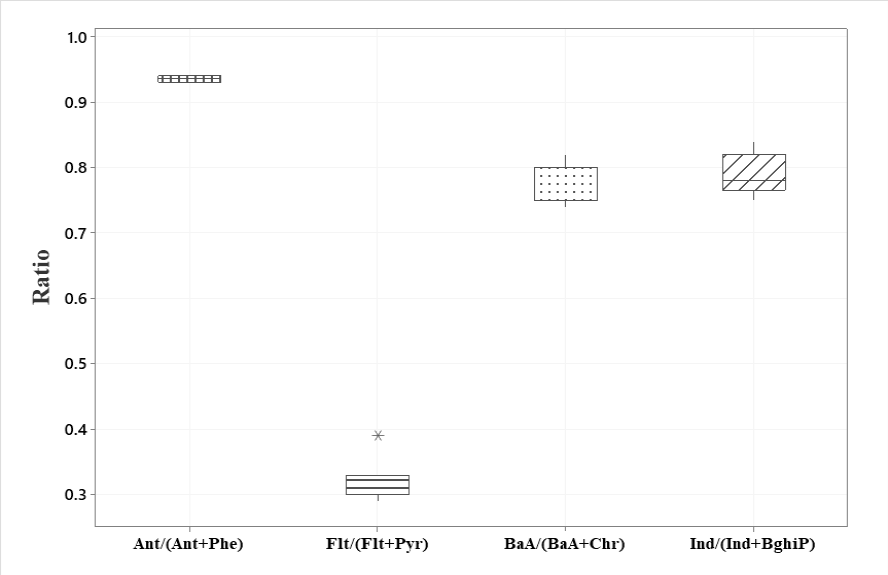

Figure 6. Range of ratio of some typical PAHs in the samples in this study.

3.3. Emission factor of PAHs

Studies on the emission factor of PAHs have been conducted from different components such as cellulose, hemicellulose, and lignin [17–18]; however, only previous studies have examined the emission factor of PAHs from rice straw in Vietnam [17, 19–20]. This is the first study in Vietnam to report on a system for detecting PAHs in the chimneys of small–scale incinerators. Table 4 displays the emission factors of individual PAHs in dust emitted from SSI chimneys. The total Σ_{16}PAHshad a mean emission factor of 10.17 ± 2.03 mg/kg. Overall, the EF of Σ_{16}PAHs levels determined during this study were similar to previous studies.

Table 4. The emission factor of PAHs (mg/kg) in this study and comparison with other studies.

Compound	The emission factor of PAHs (mg/kg–dry)					
	This study (burning biomass)	Burning rice straw, open experiment[(a)]	Burning rice straw, hood experiment[(b)]	Hood experiment[(c)]	Burning leaf litter[(d)]	Burning maize residue[(d)]
Nap	0.120	0.14	n.a.[(e)]	0.39	0.005	0.005
Acy	0.30	0.12	n.a.	n.a.	0.006	0.005
Ace	0.004	0.14	n.a.	0.002	0.000	0.000
Flu	0.0445	0.02	0.02	n.a.	0.011	0.005
Phe	0.198	0.16	n.a.	0.02	0.073	0.030
Ant	0.059	0.08	n.a.	0.01	0.037	0.034

Compound	The emission factor of PAHs (mg/kg–dry)					
	This study (burning biomass)	**Burning rice straw, open experiment[(a)]**	**Burning rice straw, hood experiment[(b)]**	**Hood experiment[(c)]**	**Burning leaf litter[(d)]**	**Burning maize residue[(d)]**
Py	0.064	1.12	0.01	0.26	0.100	0.037
Flt	0.173	6.58	n.a.	0.49	n.a.	n.a.
BaA	0.0023	0.07	0.03	0.11	0.076	0.040
Chr	0.0018	0.91	0.04	0.15	0.117	0.050
BbF	0.0016	1.26	0.08	0.12	0.115	0.055
BkF	0.0018	0.20	0.04	0.05	0.069	0.041
BaP	0.0047	0.85	0.12	0.11	0.045	0.032
Ind	0.0054	0.02	0.10	n.a.	0.055	0.041
BghiP	0.0212	0.07	0.14	0.02	n.a.	n.a.
DahA	0.0149	0.17	n.a.	0.08	0.047	0.022
Σ_{16}PAHs	10.17	12.53	15.12	1.8	0.910	0.469

(a): [17]; (b): [19]; (c): [20]; (d): [20]; (e) n.a.: not available.

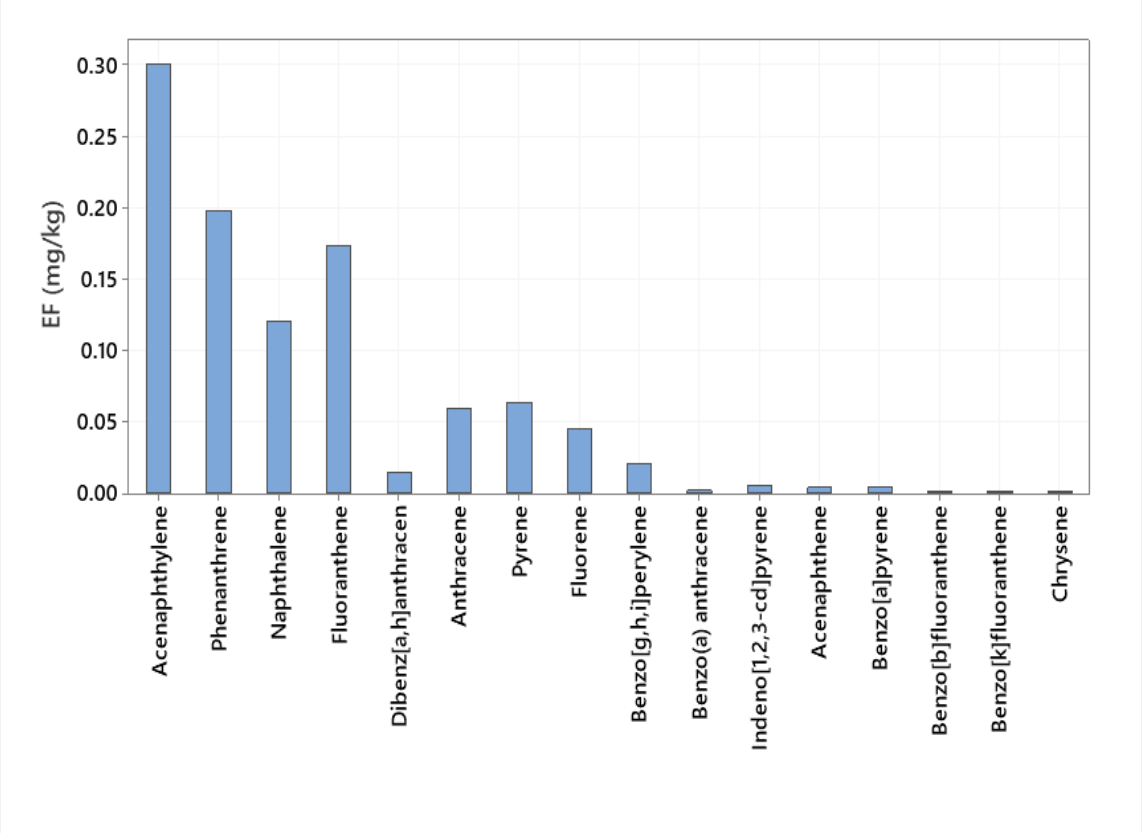

Figure 7. The mean of emission factor of PAHs of this study.

According to [21], the average Σ16PAHs emission factor from leaf litter burning and maize residue burning in Chamber was 0.910 and 0.469 mg/kg, respectively. According to [17], the total EF ofΣ_{16}PAHs of rice straw combustion in the Mekong Delta of Vietnam was 12.53 mg/kg. The EF ofΣ_{16}PAHs, on the other hand, showed a significant amount of variability due to differences in combustion conditions such as temperature, oxygen content, and biomass components. The composition of domestic waste includes organic matter, wastepaper, glass, metal, and plastic materials.

An average emission factor is shown for each PAHs (Figure 7). The EFs of each PAHs from the chimneys in descending order were Acy (0.3) > Phe (0.198) > Flt (0.173)> Nap (0.12) > Pyr (0.064) > Ant (0.059) > Flu (0.0445) > BghiP (0.0212) > DahA (0.015) > Ind (0.0054) >BaP (0.0047). PAHs such as Chr, BbP, BkP, and BaA have a relatively low emission factor average of approximately 0.002.

4. Conclusion

PAHs emission from SSI in Yen Lac district, Vinh Phuc province, Vietnam was investigated. Sixteen representative PAHs were revealed in dust samples taken from the Sankyo incinerator. PAHs levels in samples are in the medium range comparison with other incinerators in Vietnam. The PAHs composition shows that H–PAHs have a percentage higher than M–PAHs and L–PAHs. The PAHs emission factor are ranged from low to medium values which depend on each PAHs. Several substances in the group of PAHs are potentially carcinogenic and therefore require further environmental risk studies in the future. These are the initial results on the emission factor of PAH due to domestic waste incineration in rural areas. To confirm further and to be able to apply in the future inventory of PAH emissions, monitoring sessions and sample numbers must be expanded.

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