Techno-Science Research Journal 6 (2018) 44-51

Content list available at ITC

Techno-Science Research Journal

Journal Homepage : www.itc.edu.kh

Techno-Science Research Journal

Size distribution of particulate matters surrounding the burning zones of medical wastes in the remote area of Cambodia

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Abstract: *This study attempts to investigate size distribution of particulate matters emitted from medical waste burning and ambient air quality of a hopistal in a remote area of Cambodia. The particulate matters are mainly discussed in different size ranges of 0.1-10 µm, which was sampled by a nano-sampler on a single chamber incinerator (SCI) and a stella incinerator (SI). In addition, carbonaceous aerosols and gaseous pollutants were also included. The results show that SCI produced carbonaceous aerosols and gaseous pollutants significantly higher than SI while the pollutants in the surrounding areas were naturally diluted by the ambient air. The median mass aerodynamic diameters (MMAD) of the surrounding area are 0.8 µm for SI and 1.0 µm for SCI. Total suspended particle emission by SCI (714.4 µg/m^3) is 11.5 folds greater than that by SI (62.5 µg/m^3). Furthermore, the fine particles, $PM_{2.5}$, were as high as the nano particles $PM_{0.1}$ around 20-25% from both incinerators and the surrounding areas (approximately 80-180 m in distants). The high concentration of particulate matters released from both incinerators might influence the ambient air quality, which was very awful impact to the local people, patients, and staffs in the hospital.*

Keywords: Particulate matters; Emission; Medical waste; Burning; Remote area; Cambodia

1. INTRODUCTION

Cambodia is a developing country where the medical waste management is in a critical consideration. Cambodia has set the policy and framework related to the medical waste management to provide the safety health care. The methods and technical disposals are burning, sterile by chemical substance, dry and wet treatment, landfill, inertisation and encapsulation. The burning is a preferred option for the final medical waste disposal even though there is a few incinerators in the country. Somehow, the medical wastes are disposed in the landfill called the city dumpsite where informal waste recyclers living for their daily income. Medical wastes at landfill site cause danger to children who are working as the waste recyclers (Chandara, 2006; Miller, Cooke, & Sheehan, 2016). However, the burning is not supported by the residences because of smoke, odor, and particulate matters as they believe it leads to human health problems and uncomfortable living environments according to the ambient air quality standard (Table 1) and the limitation of emission from the incinerators (Table 2).

Emissions from medical waste incinerators are scientifically proofed that they are more dangerous than the emissions from municipal solid waste incinerators. The emissions are flue gases and particulate matters with its associated include elemental carbon (EC), organic carbon (OC), dioxin, and polycyclic aromatic hydrocarbon PAHs (Singh & Prakash, 2007). Particulate matters are one of significant sources of ambient air pollution. The particulate maters can contaminate the human health based on the size of the particles. The fine particles can penetrate deeper and take more damage to the

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respiratory system than the coarse particles. As known, the information of the air pollution in Cambodia is in the initial stage where they can be found in several documents related to a city only (Furuuchi et al., 2006, 2007; Furuuchi, Murase, Tsukawaki, Sieng, & Yamashita, 2005; Porsry, Sophal, Piseth Chan, Huyleang, & Siengheng, 2013). Disimmilar to Cambodia, the medical waste burning information in another countries have been moved to the implementation and improvement stage in which they were able to investigate the PAHs (Y. Chen, Zhao, Xue, & Li, 2013; Lee, Liow, Hsieh, Chen, & Tsai, 2003; Zhao, Zhang, Hao, & Wang, 2008) and dioxin in the flue gas, fly ash and bottom ash (T. Chen, Li, Yan, & Jin, 2009; Singh & Prakash, 2007; Wei, Liu, Zhang, Zhu, & Xu, 2016). However, the study of size distribution of the particulate matters in micron and submicron sizes in Cambodia is limited. Hence, the size distribution of particulate matters emitted from the medical waste burning related to the surrounding areas in remote areas in Cambodia is investigated in this research.

Table 1. Ambient air quality standard per 24 hours

Pollutants (µg/m^3)	Cambodia-AQS	WHO-AQG	US-EPA-NAAQS
TSP	100	120	-
PM_{10}	-	50	150
$PM_{2.5}$	-	25	35
CO	30000*	30000*	9000*
SO_2	-	20	75**
NO_2	100	200	100**

***** Limit per 8 hours; ** Limit per hour
Adapted from (2006)

Table 2. Limitation of pollutants emitted from medical waste incinerator

	US-EPA(1)				Cambodia (2)
Pollutants (mg/m^3)	Small rural (<907 kg/week)	Small (<91 kg/h)	Medium (91-227 kg/h)	Large (>227 kg/h)	Incinerators
TSP	87	66	46	25	400
CO	20	20	5.5	11	1000
SO_2	55	4.2	4.2	9	500
NO_2	130	190	190	140	1000

Adapted from (1) US-EPA (2013)
(2) Royal Government of Cambodia (2000)

In the present study, the medical waste burning in the remote area, Cambodia was investigate based on its emitted emission especially the particulate matters. Two different types of incinerators and three different sampling zone surrounding the incinerators were applied to characterize the particulate matters as well as carbonaceous aerosols and the other pollutants. The size distribution of particulate matters was also discussed. Results of this study will be useful to push the interest of air pollution emitted from the medical waste burning and effected areas to the government level and local citizen surrounding the burning zones.

2. METHODOLOGY

2.1 Medical Wastes

The medical wastes were burnt in two different incinerators. A single chamber incinerator was used to burn infectious wastes, pathological wastes and general health-care wastes. A stella incinerator was used to burn shape wastes such as syringes, blood vials, infectious glassware, culture dishes, scalpel blade, hypodermic needle, and medical laboratory trashes. According to US-EPA, the two incinerators were categorized in the small rural incinerators in which the single chamber incinerator and stella incinerator burn 6.7 and 1.3 T/year of medical wastes, respectively.

2.2 Sampling Location

The particles were sampled from two incinerators and three different areas in the hospital located in the northern part of Cambodia (Fig 1). A high volume sample model SHIBATA HV-500F and a nano-sampler model F1 were used to collect the particles while a gas sampler model Gastec GV100 was used to measure the concentration of CO, CO_2, NO_2, SO_2, NH_3, and VOCs (CH_3CHO). The sampling was conducted for 2 hours. By the different location, installations were conducted as following:

- Single chamber incinerator (L = 130 cm, W = 130 cm, and H = 395 cm, SCI): the particles and gas samplers were set on the top of incinerator (H = 395 cm) and 50 cm from the incinerator stack (Fig. 2.a).
- Stella incinerator (L = 100 cm, W = 100 cm, and H = 500 cm, SI): the particles and gas samplers were set on the top of incinerator (H = 500 cm) and 50 cm from the incinerator stack (Fig. 2.b).
- Blank zone (BZ) was located in the central of the hospital.
- Infectious disease department zone (IDZ) was located 65 m from SCI and 75 cm from the land.
- Obstetric department zone (ODZ) was located 74 m from SI. The samplers are placed from the land by 75 cm in order to prevent accidental contamination and activities and to check the inhalation air quality.

2.3 Analysis

2.3.1 Particle Sampling

The particles were collected by the nano-sampler and the high volume sampler for the size segregation and total suspended solid particle (TSP), respectively. The nano-sampler segregated the particle sizes: >10, 1-2.5, 0.5-1, 0.1-0.5, and <0.1 µm. The nano-sampler was operated at 40 L/min, and the higher volume sampler was operated at 500 L/min. Before and after sampling, quartz filters (Ø55 mm for the nano-sampler and Ø110 mm for the high volume sampler) were baked in a furnace at 350 °C for

2 hours and then treated in a dark desiccator for 48 hours at room temperature (25 ºC and 50% RH).

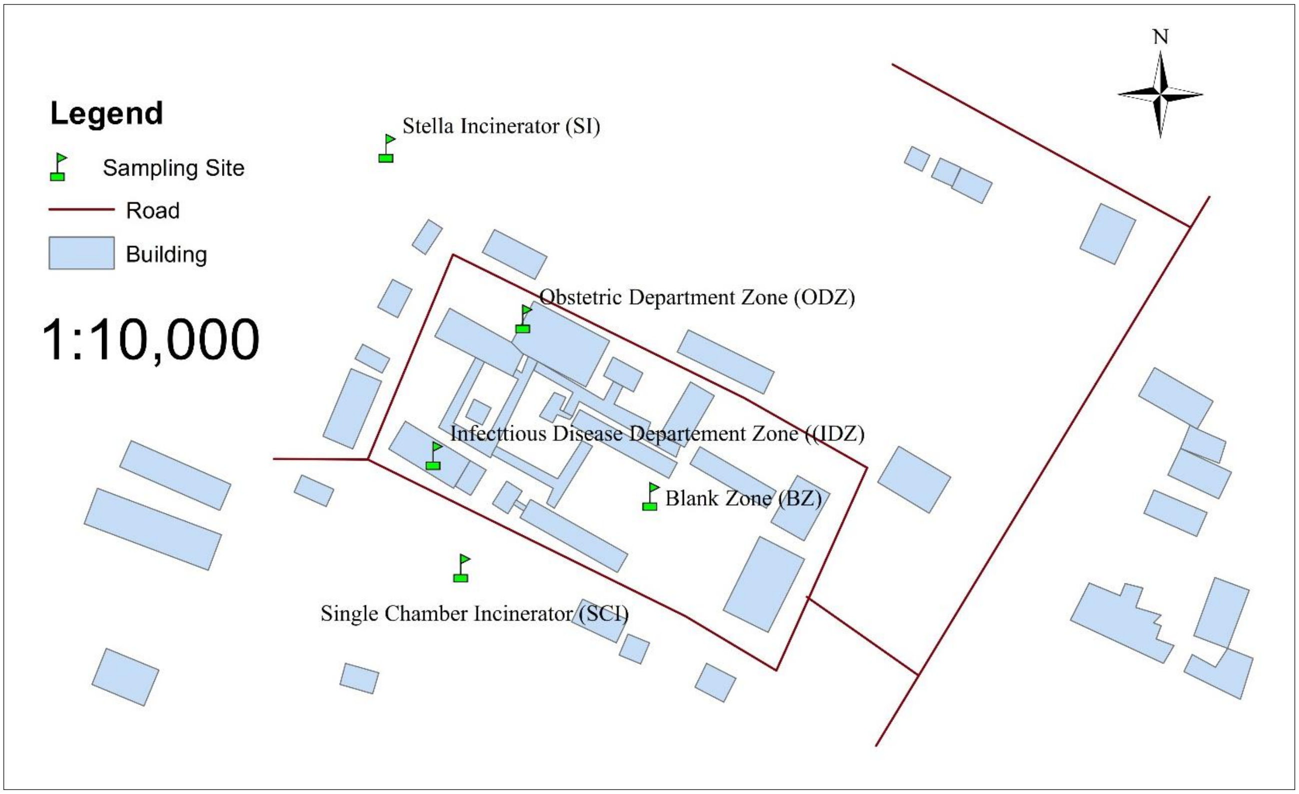

Fig. 1. Emission sampling map in a hospital, northern part of Cambodia

Fig. 2. (a) Single chamber incinerator and (b) Stella incinerator

2.3.2 Carbonaceous Aerosol Analysis

The OC and EC were analyzed by DRI Model 2001 Thermal/Optical Carbon Analyzer (Atmoslytic Inc., Calabasas, CA, USA) following Interagency Monitoring of PROtected Visual Environment (IMPROVE) Thermal/Optical Reflectance (TOR) Protocol (Chow et al., 2007; Porsry et al., 2013). Half a square meter of punch quartz filter was pyrolized and oxidized in vary temperatures and gases. The oxidation of carbonaceous particulate matters transformed into CO_2 and reduce to CH_4 once it passed MnO_2 at 912 ºC as an oxidizer and granulated firebrick impregnated with a nickel catalyst at 420 ºC as the carrier gas, respectively. The Flame Ionization detector (FID) was used to display the evolution of carbon in each fraction and to quantify CH_4. The He-Ne laser (633 nm) was bombarded to the filter on each stages of analysis in which provide the reflectance (R) and transmittance (T). The OC fraction could be noted in the condition of pure He at 120, 250, 450, and 550 ºC of the fraction OC_1, OC_2, OC_3, and OC_4, respectively. After that, the condition was switched to 2% O_2/98% He in order to analyze EC_1, EC_2 and EC_3 at 550, 700, and 800 ºC, respectively. The carbon fractions w determined following the equations below:

$$Char - EC = EC_1 + OP \quad \text{(Eq. 1)}$$

$$Soot - EC = EC_2 + EC_3 \quad \text{(Eq. 2)}$$

$$EC = EC_1 + EC_2 + EC_3 - OP \quad \text{(Eq. 3)}$$

$$OC = OC_1 + OC_2 + OC_3 + OC_4 + OP \quad \text{(Eq. 4)}$$

3. RESULTS AND DISCUSSION

3.1 Particle Size Distribution and Concentration of Particulate Matters

The TSP of five different sampling zones are show in Fig. 3. The results indicate that the sources of SCI incinerator emitted the particulate matters higher than the SI incinerator for 11.5 folds while the ambient particulate matters of BZ zone were higher that IDZ zone and ODZ zone for 2.2 and 1.5 folds, respectively. The BZ zone was placed outside and far from the building in which it was free flow of air. In addition, it was the main access zone where the residents, patients and staffs access to each buildings in the hospital. The three sampling zones met the requirement of the Cambodian Air Quality Standard (TSP < 100 µg/m^3). However, the sources of SCI incinerator was as high as twice of Cambodia Emission Standard (TSP < 400 µg/m^3) and 8.2 folds of US-EPA Emission Standard for small rural medical waste incinerator, except 62.46 µg/m^3 of SI incinerator met the requirement of both standards.

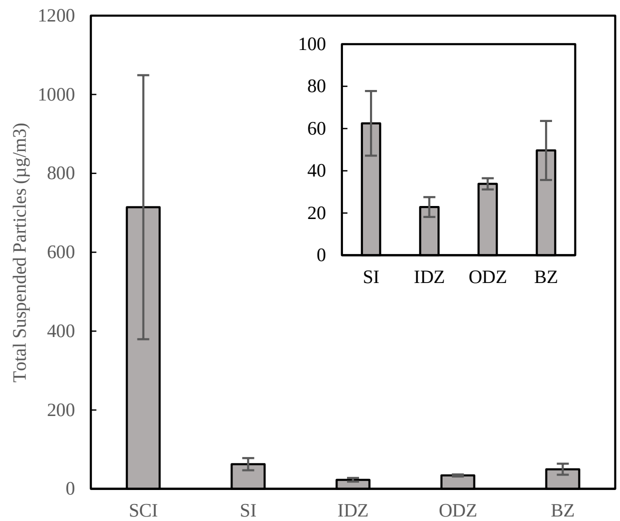

Fig. 3. Total Suspended Particles of different sampling sources and areas

The mass fractions of particulate matters in different size ranges from sources and in surrounding areas show that the boundary of particulate matters $PM_{2.5}$ were in range 20-25 % as well as the critical particulate matters $PM_{0.1}$ (Fig 4). The $PM_{0.1}$ was critically polluted to the respiratory system once it deposited at the end zone of lung, called alveoli. The finer particulate matters were, the more toxic was to the respiratory system. Fine particulate matter travel in long distance and associated with sunlight during this long range transport in the atmosphere form more toxic compounds before they come back to the environment as acid rain.In addition, the average mass median aerodynamic diameters (MMAD) of SI, IDZ, ODZ, and BZ were found on 1 µm of particulate matters, except SCI on 0.8 µm of particulate matters because of the different kinds of medical wastes in the two incinerator and atmospheric process. However, mass fraction of particulate matters have confirmed good agreement with th literatures (Kan, Kaosol, Tekasakul, & Tekasakul, 2017; Shen, 2014). Furthermore, the particulate matters in all sampling zone displayed in a single mode of the accumulation behavior (Fig. 5). The peak was found at 0.65 µm of particle sizes. The SI and SCI incinerators might be the sources of the surrounding areas of IDZ, ODZ, and BZ zone in the hospital due to the similar trend lines of peaks at 0.65 µm of particles and the location of the incinerators inside the hospital.

Table 3 shows the comparison of particulate matters emitted from cited documents of medical waste incinerators and the study incinerators. The SCI incinerator emitted a massive amount of particulate matters due to the uncontrolled design and emission as compared to the SI incinerator.

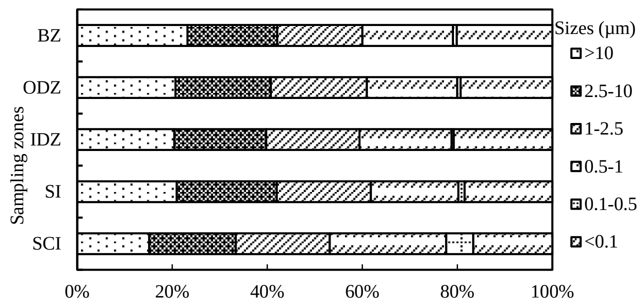

Fig. 4. Mass fraction of particulate matters in different size ranges from sources and in surrounding areas

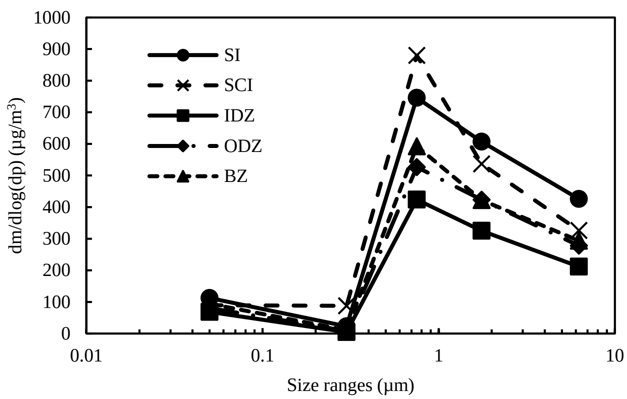

Fig. 5. Size distribution of particulate matters from sources and in surrounding areas

Table 3. Comparison of particulate matters emitted from medical waste incinerators

Type of Incinerators	Particulate matters	References
- SCI incinerator	379.5 – 1049.2 µg/m^3	This study
- SI incinerator	47.2 – 77.7 µg/m^3	This study
- Single-chamber incinerator	16.6 – 1170.6 mg/m^3	(Hoyos, Cobo, Aristizábal, Córdoba, & Montes de Correa, 2008)
- Double-chamber pyrolytic incinerator	27.5 – 156.8 mg/m^3	(Hoyos et al., 2008)
- Double-chamber excess air incinerator	162.4 – 468 mg/m^3	(Hoyos et al., 2008)
- Batch incinerator with two - burners and a scrubber (light oil as fuel)	25.4 – 1610 mg/m^3	(Zakaria, Labib, Mohamed, El-Shall, & Hussein, 2005)
- Batch incinerator with two burners and a scrubber (kerosene as auxiliary fuel)	790 – 2110 mg/m^3	Zakaria et al., 2005
- Primitive incinerator	161.1 – 1716.6 mg/m^3	Zakaria et al., 2005
- Batch incinerator with two burners and a scrubber (no measure controlled)	120 – 1055 mg/m^3	Zakaria et al., 2005

The SCI incinerator could be considered as the traditional incinerator, which was just constructed by the wall of bricks (Fig. 2.a). There was no emission control devices to treat the pollutants. Nevertheless, the result was much far better than the literatures (Hoyos et al., 2008; Zakaria et al., 2005) which were over the standard of medical waste incinerated emission as shown in Table 2. Another reason, it might cause from the loads and various kinds of infectious wastes, pathological wastes and general health-care wastes. It was also realized that these wastes contained high moisture content which remained from the flesh, blood and residue of patients. Hence, the design and materials could influence to the concentration of particulate matters.

3.2 Carbonaceous Aerosol and Gaseous Pollutants

Figure 6 shows the carbonaceous aerosols from the sources and surrounding areas. The SCI incinerator emitted the most carbonaceous aerosols to the environment. The consequence could cause by incomplete combustion in the traditional incinerator. The type and moisture of medical waste were also main factors affect the carbonaceous aerosol between the SCI and SI incinerators (Chomanee, Tekasakul, Tekasakul, Furuuchi, & Otani, 2009; Shen, Xue, et al., 2013). The highest concentration carbonaceous aerosols were in the SCI incinerator which presented OC, EC, Char-EC, and Soot-EC approximately 222.99, 278.46, 368.68 and 328.67 µg/m^3 whereas the OC, EC, Char-EC, and Soot-EC of SI were approximately 7.98, 22.02, 3.51, and 18.51 µg/m^3, respectively. The relatively high temperature in the flame phase would enrich the concentration of EC in the incinerators more than OC (Li, Wang, Duan, Hao, & Nie, 2009; Shen, 2014). As the results, EC in the surrounding areas was smaller than OC in IDZ, ODZ and BZ. The total carbon in the particulate matters from the SCI and SI incinerators were 70 and 48 %, respectively. The carbonaceous aerosol was likely to accumulate in the fine particulate matter according the literatures (Li et al., 2009; Viidanoja et al., 2002) as well as polycyclic aromatic hydrocarbons (Hata et al., 2014; Kan et al., 2017; Shen, Wei, et al., 2013). The OC/EC was 0.80 of SCI and 0.36 of SI, and Char-EC/Soot-EC ratios was 1.12 of SCI and 0.19 of SI. The orders of the surrounding areas were IDZ > BZ > ODZ of OC and IDZ > ODZ > BZ of EC, Char-EC, and Soot-EC.

The gaseous emission emitted from the incinerators and surrounding burning zones is shown in Table 4. Over limited CO_2 concentration were detected by gaz analyser from SCI and SI incinerators. However, the SCI incinerator detected 17.06 ppm of CO, 18.81 ppm of CH_3CHOH, and 1.88 ppm of SO_2 while the SI incinerator detected 19.69 ppm of CO, 17.06 ppm of CH_3CHOH, and 3.28 ppm of SO_2. The other three sites such as IDZ, ODZ, and BZ could not detect CO, SO_2,

CH_3CHOH, NO_2, and NH_3 in the ambient environment due to high dilution ratio of uncontrolled ambient air, except CO_2.

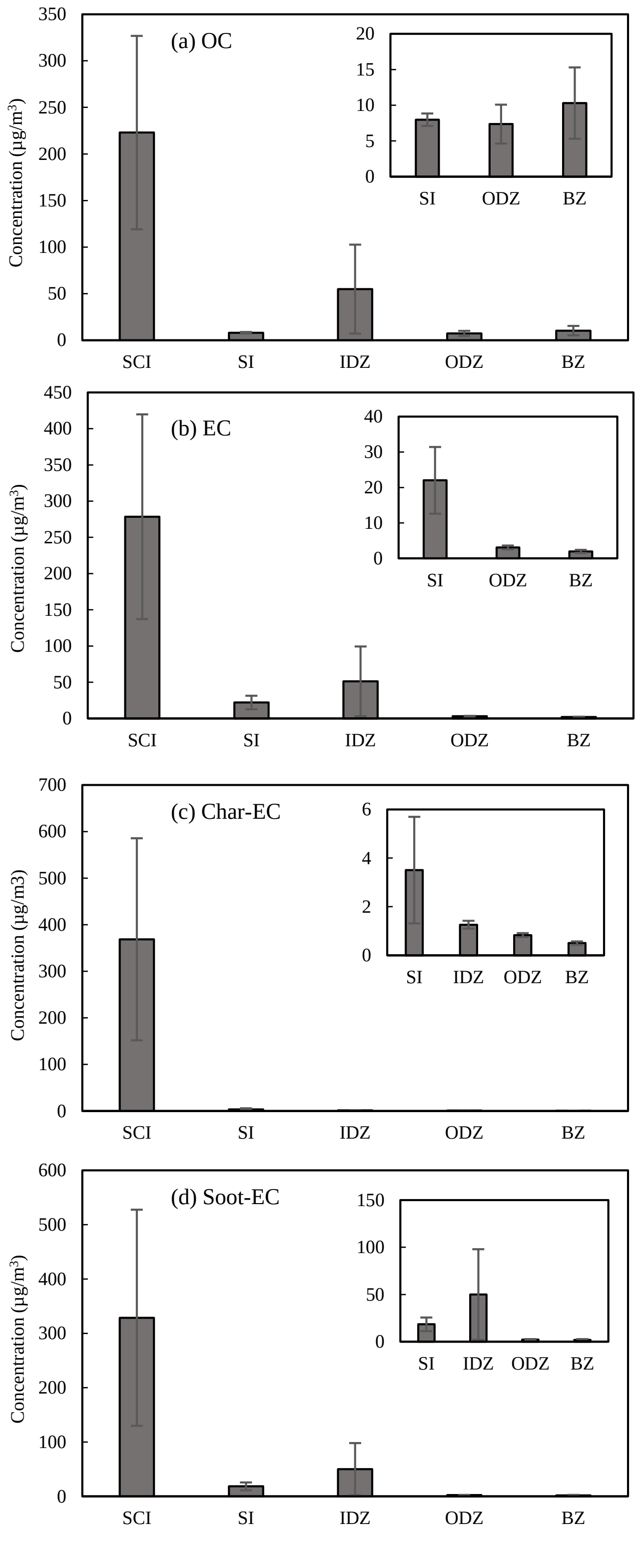

Fig. 6. Carbonaceous aerosol from sources and surrounding areas: (a) OC, (b) EC, (c) Char-EC, and (d) Soot-EC

The pollutants emitted from the medical waste burning could be exposed to the staffs, patients, and local people surrounding this area by inhalation directly. Moreover, they could also have the indirect problems because of the deposition of pollutants which contaminated in water, soil, vegetable and food. The type of incinerators and medical wastes affected the emitted pollutants. The expected pollutants included carbonaceous aerosols, dioxin, and polycyclic aromatic hydrocarbons in the particles of $PM_{2.5}$ and $PM_{0.1}$ might decrease when the modern design of SI incinerator are used. The traditional incinerator is not recommend for burning of medical waste. The standard requirement of medical waste incinerator should meet the agreement of destruction and removal efficiency (DRF) greater than or equal 99.99% (Singh & Prakash, 2007), which is very difficult to implement in the developing country especially in the remote area, Cambodia.

Table 4. Gaseous emission emitted from sources and in surrounding areas

Gasouse Emission (ppm)	SCI	SI	IDZ	ODZ	BZ
CO	17.06	19.69	-	-	-
CO_2	>2000	>2000	437.50	437.50	437.50
CH_3CHOH	18.81	17.06	-	-	-
SO_2	1.88	3.28	-	-	-
NO_2	-	-	-	-	-
NH_3	-	-	-	-	-

4. CONCLUSIONS

The emitted particulate matters from the medical waste burning demonstrates that the SCI incinerator produced the high amount of particulate matters and carbonaceous aerosols which significantly affected the ambient air quality and residence people, especially the patients and staffs in the hospital. The total carbons of SCI and SI incinerators were 48 and 70 % of particulate matters, respectively. The MMAD of particulate matters was 0.8-1.0 µm whereas the $PM_{2.5}$ and $PM_{0.1}$ were 20-25 % of the total particulate matters. The SCI incinerator as the traditional incinerator is not recommended to continue using, and the numbers of modern incinerator like SI incinerators are prone to increased and use in order to reduce the amount of pollutants. Once the modern incinerators are widely used in the country instead of open landfill, the affects from the medical waste in the open dumping to children and the volume of wastes will also be minimized.

ACKNOWLEDGMENTS

This work was supported by Kanazawa University and Faculty of Chemical and Food Engineering, Institute of Technology of Cambodia. The author would like to thank to Mr. Pidao Choon for mapping and Ms. Surapa Hongtieab for lab guidance.

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