THE OCCUPATIONAL INHALATION EXPOSURE OF FINE ($PM_{2.5}$) AND COARSE ($PM_{2.5-10}$) PARTICULATE MATTER EMITTED FROM E-WASTE BURNING ACTIVITY IN LOCAL E-WASTE DISMANTLING SITE, BURIRAM PROVINCE, THAILAND

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Abstract - The mass concentrations offine ($PM_{2.5}$) and Coarse ($PM_{2.5-10}$) particulate matter were collected from the primitive e-waste burning workers in the burning process directly, using Personal Modular Impactor and Personal Air Sampler. The concentrations of $PM_{2.5-10}$ ranged from 67.9186 to 2,285.1133 µg/m^3 with the average concentration 441.7375 µg/m^3. For $PM_{2.5}$, the concentrations ranged from 144.1645 to 17430.0303 µg/m^3 and the mean concentration was 2773.6267 µg/m^3 (N=33), which was much higher than the average $PM_{2.5}$ concentrations found in ambient air in e-waste dismantling area, e-waste industrial park, and e-waste mechanical dismantling site in China. The correlation between quantity of burnt e-waste and the concentrations of $PM_{2.5-10}$ and $PM_{2.5}$ indicated the positive correlation among the factors above. Moreover, the relationship between PM concentrations and activity patterns revealed that the different activity patternsare significantly influenced the concentration of $PM_{2.5-10}$ and $PM_{2.5}$.

Keywords - E-waste open burning, $PM_{2.5}$, $PM_{2.5-10}$, Inhalation exposure

I. INTRODUCTION

Nowadays, with the continuous worldwide development of information and communication technology, the global market of electrical and electronic equipment is expanded rapidly in accordance with the enormous economic demand [1]. According to the high consumption rate and the shorter lifespan of products, the waste of electrical and electronic equipment (WEEE or e-waste) becomes a type of waste that has fastest generation rate in the world [2], and the problem of increasing number of e-waste has received considerable critical attention in this recent year.

Compare with other types of waste, e-waste is chemically and physically prominent because it composed of both useful valuable materials and toxic substances. Therefore, special disposal and recycling methods to avoid the impact on environment and side effects on human health is needed [3]. Recycling is the best way to create an opportunity for bringing back reusable components. However, developed countries tend not to recycle e-waste in order to abstain from high cost and some limited environmental regulations. In contrast, they manage e-waste by sending to landfill or export to other developing countries, where primitive recycling techniques (e.g. dismantling, crushing, separating, and open burning) are used and contributes more severe environmental contamination and even detrimental health burdens on workers from lacking of technology and appropriate protection [4].

Currently, Thailand is also facing the problem of e-waste management due to the large quantity of e-waste generated continuously year by year. According to Thailand State of Pollution Report 2015, the estimated amount of household hazardous waste generated in 2015 was increase from 2014 by 2.57%, and the largest proportion was belonged to e-waste, which accounted for 65% from all [5]. Several district in Kalasin and Buriram province of Thailand are the main areas where the stream of e-waste are received for separation the valuable components by using primitive methods [6]. Open burning of electric wires and some other parts of e-waste components is one of the main process in the dismantling activities that used to separate copper and various types of valuable metal from the residues. This process can be found normally in the e-waste dismantling workplace [7].

Previous studies revealed that the significant amount of particulate matter emitted from e-waste open burning process. Zheng et al. [8] collected the daily samples of $PM_{2.5}$ in the community with e-waste dismantling, Guiyu, China. The study found that the geometric mean of $PM_{2.5}$ concentrations in Guiyu (49.9 µg/m^3) was significantly higher than that in the reference area; moreover, this level of concentration also exceeded the current World Health Organization 24h $PM_{2.5}$ ambient air quality guidelines and Chinese 2012 National Ambient Air Quality Standards Level I. The GM $PM_{2.5}$ concentrations in the site also exceeded WHO annual ambient air quality standard and Chinese NAAQS annual standards.

In addition, Puangprasert[9], which studied about inhalation exposure to heavy metals and health risk assessment of separating electronic waste workers in Buriram Province, Thailand, found that the concentration of PM_{10} obtained from the day that workers had open burning activities was 0.4608

mg/m^3, higher than average PM_{10} from other separation activities (0.0646 mg/m^3) about seven folds. This result revealed that workers who do burning activities may have higher opportunity to be exposed particulate matter and other toxic substance adsorbed on the surface of particles. Moreover, the result from questionnaire survey found that the workers had developed some unusual symptom from lacking of personal protective equipment, especially dermal allergy and skin irritation. However, there has not been studied about the concentration of $PM_{2.5}$ and $PM_{2.5-10}$ emitted into environment from the open burning of e-waste and expose to the workers via inhalation route directly. Therefore, this research aims to study about the emission of coarse and fine particulate matter from the open burning of e-waste in Buriram province, Thailand, which the measured results will also be used in the further step to quantify the concentrations of 16 US EPA Polycyclic aromatic hydrocarbons (PAHs) and assess the health risk from inhalation and dermal contact of the dismantling workers in this site. The research outcomes can be served as the warning guideline for workers and for further surveillance and management planning to protect both people and environmental health.

II. METHODOLOGY

A. Studied area and population

The samples in this study were collected from the volunteer workers who live among the households in the e-waste dismantling community at DaengYai sub district in Ban Mai Chaiyapot district, Burirum province, Thailand. The study was conducted in February to August, 2017 in accordance with the real working time, and the number of total samples for each type of particulate matter is 33 samples.

Preparation methods for inhalation exposure sampling

1. Sampling filter preparation

In this study, $PM_{2.5}$ and $PM_{2.5-10}$ samples were collected by using Polytetrafluoroethylene (PTFE) filters with 37 mm diameter and 2 µm pore size and PTFE filters with 25 mm diameter and 0.2 µm pore size, respectively. Both two size of filters were cleaned by being soaked with acetone in a beaker that is closed by aluminum foil to prevent the evaporation of solvent for 15 minutes. Then, the filters will be dried up on a watch glass in fume hood for 10 minutes.The cleaned filters were stored in opaque plastic cases and kept in a desiccator for at least 24 hours before weighing by the 7 decimal places analytical balance (Mettler-Toledo UMX2 Ultra Microbalance). After weighing, the filters were stored in opaque plastic cases until the sampling period.

2. Personal air sampler preparation

The personal air samplers (SKC Airchek Sampler Model 224-PCXR8) were calibrated by the primary gas flow calibrator (Defender 530, Drycal TECHNOLOGY) with sampling flow rate about 3 L/min and connected to The Personal Modular Impactor (PMI) that contained both two size of filters. The joints between all equipment were wrapped by parafilm to prevent the leakage of particulate matter. This whole set of equipment was ready for sampling in the next step.

B. Sampling method

The whole set of personal air sampler with personal modular impactor that contained two types of filters were installed at each worker who was going to burn e-waste. Personal modular Impactor was pinched at worker's collar in order to be the representative of breathing zone, the hemisphere in front of the shoulders within a radius of approximately six to nine inches [10]. The personal air sampler was turned on when the worker started burning activities, and would be stopped when the worker finished e-waste burning work. The real total sampling time, amount of e-waste for burning, composition of e-waste, and the activity of each worker were all recorded in each time of sampling.

After finish sampling, the flow rates of personal air sampler were measured to calculate the volume of air flow through pump. The sampled filters were kept in opaque plastic cases that would be covered all the joints with parafilm and stored in a desiccator for at least 48 hours before weighing when they were arrived the laboratory.

The sampled filters were weighed by the 7 decimal places analytical balance (Micro balance) again to obtain the weight after sampling, used for PM mass calculation.

C. Calculation

The concentrations of each type of particulate matter will be calculated by these following Equation.;

$$C_{PM} = M_{PM}/V_{air} \quad \text{(Eq. 1)}$$

$$M_{PM} = W_{filter,\ post} - W_{filter,\ pre} \quad \text{(Eq. 2)}$$

$$W_{filter,\ pre} = (W_{filter,\ pre,1} + W_{filter,\ pre,2} + W_{filter,\ pre,3})\ /3 \quad \text{(Eq. 3)}$$

$$W_{filter,\ post} = (W_{filter,\ post,1} + W_{filter,\ post,2} + W_{filter,\ post,3})/3 \quad \text{(Eq. 4)}$$

$$V_{air} = \text{flow rate } (m^3/min) \text{ x sampling time (min)} \quad \text{(Eq. 5)}$$

where:

C_{PM} = PM concentration ($\mu g/m^3$)
M_{PM} = Mass of PM (μg)
V_{air} = Air volume (m^3)
$W_{filter,\ post}$ = Weight of filter after sampling (μg)
$W_{filter,\ pre}$ = Weight of the filter before sampling (μg)

III. RESULTS AND DISCUSSION

A. Particulate matter concentrations

The mass concentrations of particulate matter were collected during February to August, 2017, which there was the rainy weather in Thailand at that time. The humidity ranged from 56 to 87 % with the mean percent of humidity at 79.03. Regarding to the obtained results, the concentrations of $PM_{2.5-10}$ ranged from 67.9186 to 2,285.1133 $\mu g/m^3$with the average concentration 441.7375 $\mu g/m^3$ (N=33). For $PM_{2.5}$, the concentrations ranged from 144.1645 to 17430.0303 $\mu g/m^3$ and the mean concentration was 2773.6267 $\mu g/m^3$

According to the Pearson's correlation statistical analysis, both two types of particulate matter had no significant relation with each other at 95% confidence interval ($p > 0.05$), which the concentration for each type of PM might be involved with the other specific factors that would be discuss in the next part.

Compare with other study, the average concentration of $PM_{2.5}$ was obviously higher than an average ambient $PM_{2.5}$ concentration that was measured from the air in an informal electronic waste recycling site of China (49.9 $\mu g/m^3$) for 55.58 times [8]. The concentration also higher than an average $PM_{2.5}$ concentration collected from ambient in the big e-waste industrial park in Fengjiang, China (49.61 $\mu g/m^3$ in summer and 153.88 $\mu g/m^3$ in winter, [11]) for 18.02 to 55.91 folds. The average concentration of $PM_{2.5}$ in this study was also significantly larger than the average concentration of $PM_{2.5}$ sampled from the e-waste mechanical workshop in China (271.7 $\mu g/m^3$, [12])for 10 times. The result revealed that the open burning of electronic waste emitted the significant amount of particulate matter, which was distinctively higher than the concentrations in ambient of e-waste recycling site and the concentration from other process of e-waste dismantling activity. Thus, the workers who carried the burning work might have the larger opportunity to expose the coarse and fine particulate matter that also included the other kinds of pollutants which are absorbed on the surface of the particles, and may lead to the more severe health consequence later on.

B. Influencing factors for PM concentrations

1. The quantity of burnt e-waste

The streams of e-waste that would be burnt each time were variety in terms of types and quantity, which depended on the waste that the workers received from the middleman. Types of burnt e-waste mostly were electric wire, small motors, and some other residue parts that contain valuable metals and cannot be separated by any mechanical processes. The quantity of burnt e-waste in this study ranged from 100 to 300 kg, and the average amount of waste was 201.52 kg.

The correlation between quantity of burnt e-waste and the concentrations of $PM_{2.5-10}$ analyzed by Pearson correlation suggested the positive correlation ($r=0.393$, $p<0.05$) between 2 factors above. The same correlation also showed in the $PM_{2.5}$ concentrations, the Pearson correlation between quantity of burnt e-waste and the concentrations of $PM_{2.5}$ had the positive relationship ($r=0.627$, $p<0.01$). Consequently, these results examined that the increasing of amount of burnt e-waste influenced the higher concentration of coarse and fine particles emitted through the ambient air.

2. Pattern of burning activities

Regarding to the record from observation, the procedure for e-waste burning could be separated into important activities, including Piling of waste, Fire mixing to the pile of waste, Sweeping the small residue metals after finishing, Compiling the metal after finishing, and Pounding the finished burnt waste to remove the no valuable leftover.

The burning activity among the workers in this study could be divided into thirteen obvious patterns as follows, 1) 60% Fire mixing 40% pounding, 2) 15% Fire mixing 85% Sweeping, 3) 70% Fire mixing 30% Sweeping, 4) 80% Fire mixing 10% Sweeping 10% Compiling, 5) 65% Fire mixing 35% Sweeping, 6) 55% Fire mixing 45% Sweeping, 7) 90% Fire mixing 10% Sweeping, 8) 5% Fire mixing 95% Compiling, 9) 80% Fire mixing 20% Sweeping, 10) 35% Fire mixing 50% Sweeping 15% Compiling, 11) 35% Fire mixing 50% Sweeping 15% Compiling, 12) 45% Fire mixing 35% Sweeping 20% Compiling, 13) 65% Fire mixing 15% Sweeping 20% Compiling, and 14) 75% Fire mixing 25% Sweeping.

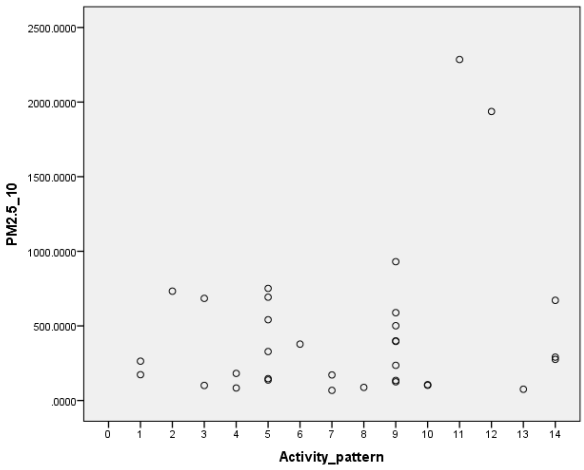


Figure 1.Scatter plot between $PM_{2.5-10}$concentrations and activity patterns

Scatter plot between PM concentrations and activity patterns to investigate the relationship between the two factors was created. The graph in Figure 1. Shows the dominant high concentration of $PM_{2.5-10}$ in the activity pattern number 11 and 12, which are 11) 35% Fire mixing 50% Sweeping 15% Compiling, 12) 45% Fire mixing 35% Sweeping 20% Compiling, respectively. In contrast, the Figure 2. shows the high concentration of $PM_{2.5}$ mostly found in activity

pattern number 9, which is 80% Fire mixing 20% Sweeping. These results indicated that the activities that influenced the concentration of $PM_{2.5-10}$ were the more mechanical activities, such as sweeping and compiling. Nevertheless, the activity that more affected to increase the concentration of $PM_{2.5}$ was fire mixing, which is the process that the worker had to be close or covered by the smoke of burning waste directly.

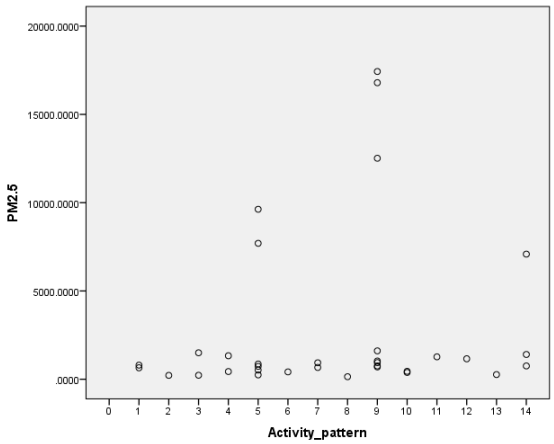


Figure 2.Scatter plot between $PM_{2.5}$concentrations and activity patterns

CONCLUSION

The mass concentrations of particulate matter were collected during February to August, 2017 from the e-waste burning workers directly using Personal Modular Impactor and Personal Air Sampler. According to the obtained results, the concentrations of $PM_{2.5-10}$ ranged from 67.9186 to 2,285.1133 µg/m^3 with the average concentration 441.7375 µg/m^3. For $PM_{2.5}$, the concentrations ranged from 144.1645 to 17430.0303 µg/m^3 and the mean concentration was 2773.6267 µg/m^3 (N=33), which was much higher than the average $PM_{2.5}$ concentrations found in China ambient air in e-waste dismantling area. The correlation between quantity of burnt e-waste and the concentrations of $PM_{2.5-10}$ and $PM_{2.5}$ analyzed by Pearson correlation suggested the positive correlation between the factors above, which meant that the higher of amount of burnt e-waste, higher concentration of coarse and fine particles emitted from the burning process. At last, the scatter plot between PM concentrations and activity patterns revealed that the activities that influenced the concentration of $PM_{2.5-10}$ were the more mechanical activities, such as sweeping and compiling, while the activity that more affected to increase the concentration of $PM_{2.5}$ was fire mixing, which is the process that the worker had to be close to the source of the burning smoke directly.

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