PM2.5 AND ITS ION COMPOSITION EMITTED FORM BIOMASS BURNING IN OPEN-SYSTEM COMBUSTION CHAMBER

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Abstract- Open burning is the main contributor of air pollution in South East Asia. This work aims to determine $PM_{2.5}$ (particulate matter with a diameter ≤ 2.5 μm) and its ion composition emitted from biomass burning. Biomass samples (rice straw, maize residue and leaf litter) were burned in the open-system combustion chamber. $PM_{2.5}$ samples were collected and analyzed for its ion composition. Result can be used to estimate emission of air pollutants from open burning.

Keywords- Biomass Burning; $PM_{2.5}$; Ion Composition; Air Pollution; Combustion Chamber

I. INTRODUCTION

Open biomass burning is the main contributor to air pollution in South East Asia (SEA) region during hot dry season. Level of air pollutants has been increased, resulting in deterioration of air quality. It causes serious degradation of economic, environment and health. Air pollutants found in this region come from various sources such as traffic activities, industries, and biomass open burning [1]. The major source is biomass burning including forest fires and agricultural residues burning [2]. Particulate matters with an aerodynamic diameter ≤ 2.5 μm or $PM_{2.5}$ is one of the significant air pollutants in this area and $PM_{2.5}$ are deposited primarily in the pulmonary region [3] Concentration of $PM_{2.5}$ in dry season is frequently exceeded Thailand National Ambient Air Quality Standard for the average 24-hr $PM_{2.5}$ (50 μg m^{-3}) [4]. Forest fires and the burning of crop residues are the major sources of air pollutants in Chiang Mai, Thailand [5]. Emissions from open burning concentrated in the harvest season, a large amount of pollution that enters the atmosphere in this period resulted in a rapid increase of concentration of pollutants in the atmosphere. Therefore, emissions from open burning still play a significant role in the air pollution [6]. Ions bounded with PM_{10} emitted from biomass burning such as K^+ and Cl^-, especially NO_3^- SO_4^- and NH_4^+ generally account for one-third of particulate matter mass in the urban atmosphere [5]. The K^+ was found mainly in the fine mode during agricultural burning [7], while ions dominated emitted from flaming smoke were Cl^- and K^+ which contributed 3.4% and 2.4% of the PM mass for rice straw [8]. Therefore, the main objective of this study to determine the $PM_{2.5}$ concentration and its water-soluble ion component emitted from biomass burning of different biomass types. This study is expected to provide useful information on pollutant emission, which may lead to air quality management for both local and global scales. Furthermore, the emission factors obtained in this study might be useful as an input for air quality modeling and source apportionment analysis.

II. METHODOLOGY

A. Biomass sampling

Agricultural biomass (maize residues and rice straw) and leaf litters (LL) from dipterocarp forest (DDF) and mix deciduous forest (MDF) were collected from various places in Upper Northern Thailand (UNT). Four sampling sites of rice fields and four of maize fields were selected, while five sites of each forest type were selected as representatives of the area. Therefore 18 samples in total were collected. Samples were randomly collected 3 times in the same area by using a grid square (2 m x 2 m) and were counted as one sample. Biomass sampling and biomass characteristics are shown in Fig 1. Information of biomass samples is provided in Table I. The average dried weight of biomass per grid (4 m2) in descending order were rice straw (2.9±0.3 kg) > maize residue (2.5±0.7 kg) > LL (MDF) (2.1±0.4 kg) > LL (DDF) (1.8±0.6 kg).

B. Biomass burning in an open-system combustion chamber

The samples from each site (three grids) were homogenized and air dried. Each sample was divided into 3 bags and each bag contained about 1 kg of biomass. Each one of them was burned in the constructed open-system combustion chamber. The chamber consists of a combustion part and a smoke stack (Fig 2). Biomass sample was placed on the tray platform. The stainless hood was constructed above

the combustion part connected to the stack. Two PM samplers are equipped with the stack at ~3.50 m above ground to collect the $PM_{2.5}$ samples on quartz fibers (Ø 47 mm, Whatman, UK) with the flow rate of 5 L/min. The burning was completed within 5-15 minutes depending on biomass types [9]. The $PM_{2.5}$ samples were kept in a desiccator for 24 hours to desorb water before and after the sampling prior to be weighed by a microbalance (Toledo, Switzerland) in a control room (temperature ~ 23.9 ± 1.51 ˚C, humidity ~ 34.8 ± 2.39%). They were kept in a freezer (~ -4℃) until the extraction.

C. Extraction and analysis of water soluble ions of $PM_{2.5}$ samples

Each sampling filter was cut into halves by a stainless steel scissors. Each half of the filter was extracted in 45 mL deionized water using an ultrasonicator with 37 kHz frequency (Elma, Germany) at 35℃ for 30 minutes. The extracted solution was divided into two parts. The first past (25 mL) was measured for electro-conductivity (EC) (Cond Level 2, Inolab, Germany). The second part (20 mL) was filtered by a cellulose acetate syringe filter (0.45 µm pore size, 13 mm diameter) and analyzed for anions (Cl^-, NO_3^- and SO_4^{2-}) and cations (Na^+, NH_4^+, and K^+) by Ion Chromatograph (882 Compact IC plus, Metrohm, Switzerland). Determination of PM10 and its ion Detail of extraction and analysis methods can be found in Sillapapiromsuk et al., (2013)[5].

E. Statistical analysis

Pearson's correlation was used to determine relationships between various ionic species and $PM_{2.5}$ test by Multivariate analysis of variance (MANOVA) to test the differences of various ionic species and $PM_{2.5}$ emitted from four types of biomass.



Fig. 1 Characteristics of biomass samples collected in the fields (a.) rice straw (b.) maize residue (c.) leaf litter from DDF and (d.) leaf litter from MDF.

Biomass types	Sampling field	Number of sampling sites	Biomass (dried weight) (kg/grid*)	Biomass (dried weight) (Ton/km^2)
Rice straw (RS)	Rice field	4	2.9±0.3	725±66
Maize residue (MR)	Maize field	4	2.5±0.7	614±171
Leaf litters (LL)	DDF	5	1.8±0.6	447±57
Leaf litters (LL)	MDF	5	2.1±0.4	514±37

*grid area is 4 m^2

Table I. Biomass information.

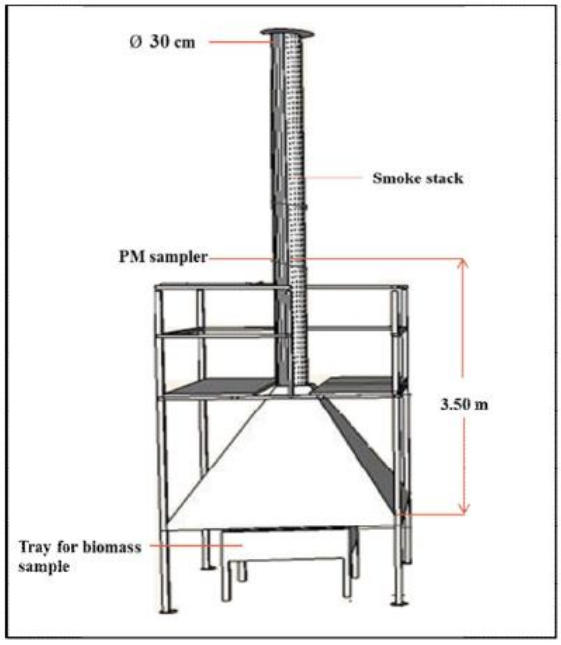


Fig. 2 Diagram of the open-system combustion chamber.

III. RESULTS AND DISCUSSION

A. Emission factors of $PM_{2.5}$ from biomass burning in open-system combustion chamber

Table II shows emission factors (EFs) of $PM_{2.5}$ from biomass burning in the open chamber, which were calculated from $PM_{2.5}$ mass and weight of burned biomass sample. The average EFs of $PM_{2.5}$ from biomass burning in descending order were LL (MDF) (4.4 ± 2.9 g kg^{-1}) ~ rice straw (4.3 ± 1.9 g kg^{-1}) > LL (DDF) (3.7 ± 1.4 g kg^{-1}) > maize residue (1.8 ± 0.6 g kg^{-1}). The EFs of $PM_{2.5}$ from maize residue burning was significantly lower than those of the other types of biomass burning. This is probably due to the planting areas. Most of the maize residue samples were collected from mountainous area, which probably have infertile soil and water shortage comparing to other sampling areas.

Ions species	Rice straw	Maize residue	LL (DDF)	LL (MDF)
	n=24	n=24	n=30	n=30
$PM_{2.5}$	$4.3±1.9^{a}$	$1.8±0.6^{b}$	$3.7±1.4^{a}$	$4.4±2.9^{a}$
Cl^-	$591.8±290.7^{a}$	$93.1±64.3^{b}$	$80.4±22.2^{b}$	$67.5±29.8^{b}$
NO_3^-	$20.6±8.5^{a}$	$11.7±8^{b}$	$16.1±13.3^{ab}$	$17.5±9.4^{ab}$
SO_4^{2-}	$103±26.4^{a}$	$77.0±14.4^{b}$	$67.9±17.1^{b}$	$116±56.1^{a}$
Total anions	$\mathbf{716.9±309.6^{a}}$	$\mathbf{181.8±43.1^{b}}$	$\mathbf{164.4±34.1^{b}}$	$\mathbf{200.9±49.2^{b}}$
Na^+	$22.0±27.8^{ab}$	$35.8±27.7^{a}$	$21.4±16.6^{ab}$	$16.6±19.4^{b}$
NH_4^+	$40.1±11.3^{a}$	$21.6±18.4^{b}$	$14.8±12.6^{b}$	$12.1±11.7^{b}$
K^+	$697.5±355.2^{a}$	$126.9±91.6^{b}$	$87.6±25.2^{b}$	$166±95.8^{b}$
Total cations	$\mathbf{759.6±38.9^{a}}$	$\mathbf{184.4±57.2^{b}}$	$\mathbf{123.9±40.3^{b}}$	$\mathbf{194.7±87.5^{b}}$
Total ions	$\mathbf{1475.4±30.9^{a}}$	$\mathbf{366.1±1.8^{b}}$	$\mathbf{288.2±28.6^{b}}$	$\mathbf{395.6±4.4^{b}}$

a, b significant difference ($p < 0.05$) from MANOVA test.

Table II. Emission factors of $PM_{2.5}$ (g kg^{-1}) and ion component (mg kg^{-1}) from biomass burning.

B. Emission factors of ion component of $PM_{2.5}$ emitted from biomass burning

$PM_{2.5}$ samples emitted from biomass burning in the open-system combustion chamber were extracted with deionized water and measured for electro conductivity (EC) values to estimate their ion content. The EC values of the extracted solutions in descending order were rice straw (17.89 ±5.96 µS cm^{-1}), maize residue (9.08±1.88 µS cm^{-1}) and leaf litters from MDF (8.39 ± 2.18 µS cm^{-1}) and DDF (7.57 ± 1.11 µS cm^{-1}). Rice straw burning emitted highest $PM_{2.5}$ mass concentration and also provided highest EC value.

Major ions both cations (K^+, NH_4^+ and Na^+) and anions (Cl^-, SO_4^{2-} and NO_3^-) were analyzed by IC and the results are shown in Table II.

EFs of total ions from all types of biomass burning in descending order were rice straw (1475.4±30.9 mg kg^{-1}), LL (MDF) (395.6±4.4 mg kg^{-1}), maize residue (366.1±1.8 mg kg^{-1}) and LL (DDF) (288±28.6 mg kg^{-1}). Burning of maize residue emitted low amount of $PM_{2.5}$, but its ion content was quite high comparing to leaf litters. Moreover, high amount of K^+ and Cl^- was emitted from all biomass types. EFs of K^+ emitted from the burning in descending order were rice straw (697.5±355.2 mg kg^{-1}), LL (MDF) (166±95.8 mg kg^{-1}), maize residue (126.9±91.6 mg kg^{-1}) and LL (DDF) (87.6±25.2 mg kg^{-1}). The same pattern was found in case of Cl^-, in which its EFs in descending order were rice straw (591.8±290.7 mg kg^{-1}), maize residue (93.1±64.3 mg kg^{-1}), LL (DDF) (80.4±22.2 mg kg^{-1}) and LL (MDF) (67.5±29.8 mg kg^{-1}). It can be concluded that K^+ and Cl^- were major ions emitted from rice straw burning. Their emissions were significantly higher (~3-5 times) than the other types of biomass. However, SO_4^{2-} was also another major anion emitted from all types of biomass burning particularly from rice straw and MDF leaf litter burning Zhang et al., (2017)[10], reported that EFs of $PM_{2.5}$-bound Cl^- (430±300 mg kg^{-1}), K^+ (390±280 mg kg^{-1}) and SO_4^{2-} (210±90 mg kg^{-1}) were high in rice straw burning. Comparing of ion concentrations emitted from burning of agriculture plant and forest, it was found that rice straw burning emitted much higher ion content (particularly K^+ and Cl^-) comparing to maize residues and forest leaf litter. Their emissions from agricultural waste burning were high due to use of fertilizer and herbicides in the fields [5]. As mentioned earlier, maize residue samples were collected from less fertile area (may be no fertilizer or pesticide application), therefore relatively low amount of ions were emitted from the burning comparing to rice straw burning.

CONCLUSIONS

Four types of biomass samples were collected from different areas in Northern Thailand for burning experiment in the open-system combustion chamber. $PM_{2.5}$ samples emitted were collected and analyzed for their ion content. The EFs of $PM_{2.5}$ from biomass burning in descending order were LL (MDF) (4.36±2.93 g $kg^{-1)}$, rice straw (4.3±1.9 g kg^{-1}), LL (DDF) (3.7±1.4 g kg^{-1}) and maize residue (1.8±0.6 g kg^{-1}). K^+ and Cl^- were the dominant ion species emitted from biomass burning. This finding confirms that K^+ an important $PM_{2.5}$ tracer of biomass burning. Agricultural residues burning emitted high amount of K^+ and Cl^- due to application of fertilizer and herbicides in the field.

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