Chemosphere 93 (2013) 1912–1919

Contents lists available at SciVerse ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Determination of PM10 and its ion composition emitted from biomass burning in the chamber for estimation of open burning emissions

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HIGHLIGHTS

- Biomass samples were burnt in the chamber and measured for air pollutant emission.
- Leaf litter burning emitted higher PM10 amount than rice and maize residue burning.
- Potassium and chloride were major ions emitted from agricultural residue burning.
- Major ions in PM10 were related to fertilizer and herbicide used for crop planting.
- Forest fire was found to be a major source of air pollutants in the area.

ARTICLE INFO

Article history:
Received 23 November 2012
Received in revised form 17 April 2013
Accepted 27 June 2013
Available online 24 July 2013

Keywords:
Ion composition
PM10
Biomass burning
Agricultural and forest burning
Emission rate
Emission factor

ABSTRACT

Biomass samples including agricultural waste (rice straw and maize residue) and forest leaf litter were collected from Chiang Mai Province, Thailand for the burning experiment in the self-designed stainless steel chamber to simulate the emissions of PM10. The burning of leaf litter emitted the highest PM10 (1.52 ± 0.65 g kg^{-1}). The PM10-bound ions emitted from the burning of rice straw and maize residue showed the same trend, which was $K^+ > Cl^- > SO_4^{2-} > NH_4^+ > NO_3^-$. However, the emissions from maize residue burning were ∼1.5–2.0 times higher than those from the rice straw burning. The ion content emitted from leaf litter burning was almost the same for all ion species. Noticeably, K^+ and Cl^- concentrations were ∼2–4 times lower than those emitted from agricultural waste burning. It can be deduced that K^+ and Cl^- were highly emitted from agricultural waste burning due to the use of fertilizer and herbicides in the field, respectively. Based on emission values obtained from the chamber, the pollutant emission rate from open burning was calculated. Burned areas in Chiang Mai Province were 3510 and 866 km^2 in 2010 and 2011, respectively. Forest burning was 71–88%, while agricultural land burning accounted for 12–29% (rice field: crop field = 1:3) of total burned area. Therefore, emissions of PM10 from open burning in Chiang Mai were 3051 ton (2010) and 705 ton (2011). Major ions emitted from agricultural waste burning were found to be K^+ and Cl^-, while those from forest burning were SO_4^{2-} and K^+.

1. Introduction

Chiang Mai Province, as well as other provinces in upper northern Thailand, has been annually facing air pollution during almost every dry season. This pollution has been recorded as a serious problem for well over 10 years. Most cities in upper northern Thailand are located in a flat plain basin and are surrounded by mountain ranges. This geographical feature of mountains valley limits the dispersion of air pollution. Moreover, it also depends on both meteorological conditions (i.e. temperature inversion, wind velocity and precipitation) and emission source intensity. PM10 is considered the most significant air pollutant that contributes to the severity of the event that annually occurs in the dry season of Northern Thailand. Traffic density seems to be constant for the entire year, while open burning including forest fires and agricultural burning is mostly performed in the dry season, which coincides with the peak of the annual haze episode. Major air masses in the dry season during 2005–2009 came from the western continent of Thailand (the southwest direction of Chiang Mai) as well

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http://dx.doi.org/10.1016/j.chemosphere.2013.06.071

as locally (Chantara et al., 2012). Emission inventory conducted by the Pollution Control Department in 2002 for the city of Chiang Mai showed that 700 tons of the total particulate matter were emitted, of which 89% came from forest fires, 5.4% from solid waste burning and 2.3% from agriculture residue burning, while only 2.6% was from all mobile sources (Kim Oanh and Leelasakultum, 2011). A number of hotspots also showed the same trend. It was reported that 80% of the hotspots in Northern Thailand in March 9–15, 2007 were detected in the forest areas and 20% were in the agricultural areas (Kim Oanh et al., 2011).

Biomass is a biological material derived from living, or recently living organisms. In the context of biomass for energy, this term is often used to refer to plant based material. The components of biomass include cellulose, hemicelluloses, lignin, lipids, proteins, simple sugars, starches, water, hydrocarbon, ash, and other compounds. The concentration of each class of compound varies depending on species, type of plant tissue, stage of growth, and growing conditions. Due to the carbohydrate structure, biomass is highly oxygenated with respect to the conventional fossil fuels, including hydrocarbon liquids and coals. Biomass burning has induced global concerns in the past decades for its effects on visibility, human health and global climate by emitting particles and vapor pollutants (Fang et al., 1999; Yang et al., 2006). Biomass burning is usually composed of four types: grassland fires, forest fires, the field burning of crop residues and domestic biofuel combustion (Yan et al., 2006). In this study, only forest fires and the burning of crop residues, which are the major sources of air pollutants in Southeast Asia, were considered. Open burning of biomass is a common method for agricultural residue disposal and represents a considerable source of atmospheric pollutants (Korenaga et al., 2001). During the dry period, fires are set for the most part in northern Thailand to clear land for subsequent cultivation by the burning of agricultural waste. This method is an inexpensive means to advance crop rotation and control insects, disease and the emergence of invasive weed species (Estrellan and Iino, 2010). Many particulates and gas compounds (e.g. CO and volatile organic compounds) that come from biomass burning are known as hazardous to human health (Torigoe et al., 2000). The most important gases, which have affected the acidic dry deposition, are HNO_3, HCl and H_2SO_4. These gases can be transformed into aerosol by neutralization reactions (Hu et al., 2008). Semi-volatile NH_4NO_3 and NH_4Cl are formed via reversible phase equilibrium with NH_3, HNO_3 and HCl (Pio and Harrison, 1987). These equilibrium between gas- and particle-phase are strongly influenced by ambient temperature and relative humidity (Mozurkewich, 1993). At lower concentrations, NH_3 will primarily react with H_2SO_4. Only when extra NH_3 is available, neutralization reactions between HCl/HNO_3 and NH_3 would take place (Hu et al., 2008). SO_4^{2-} and NH_4^+ mainly exist in fine particles, NO_3^- can be found either mainly in fine particles or in coarse particles, depending on the meteorological conditions (Zhuang et al., 1999). Pierson and Brachaczek (1988) reported that NO_3^- in fine mode was NH_4NO_3 and NO_3^- in coarse mode was not only NH_4NO_3 but also $NaNO_3$. SO_4^{2-}, NH_4^+ and NO_3^- are referred as secondary water-soluble ions. In Europe, dominant ionic species in PM that are formed by agricultural waste burning are K^+, NO_3^- and Cl^- (Ezcurra et al., 2001). Similarly, significant increases in K^+, Cl^-, organic carbon (OC) and fine particulate masses have been observed during biomass burning events in Gwangju, Korea (Ryu et al., 2004). K^+ is considered to be present in relatively high concentrations in biomass burning plumes, and has been used as a tracer of biomass burning in source apportionment studies (Chow, 1995). Water-soluble ions generally account for one-third of particulate matter mass in the urban atmosphere and directly play a significant role in the earth's radiation balance by scattering incoming solar radiation, and indirectly, by altering cloud properties because of the uptake of water vapor (Hillamo et al., 1998; Andrews et al., 2000; Chow et al., 2006; Seinfeld and Pandis, 2006).

Only a few studies concerning pollutant emissions from open burning were conducted in Southeast Asia, where is one of the potential sources of air pollutant emission in the world. Therefore, the main objectives of this study are: (i) to determine the PM10 levels and its water-soluble ion components from the burning of different biomass types, and (ii) to calculate the emission factors from biomass burning in the chamber and to estimate the emission rates based on open burning data. This study provides 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.

2. Experiment

2.1. Biomass sampling and preparation

Three types of biomass including rice straw from rice fields and maize residue from crop planting areas, as well as leaf litter from the deciduous forest were collected from December 2009 to February 2010. Each biomass type was collected from three districts of Chiang Mai Province. Rice straw and leaf litter were collected from Mae Rim, Doi Saket and Chiang Dao districts, while maize residue was collected from Mae Rim, Mae Chaem and Chiang Dao districts (Fig. 1). One sampling site for maize residue was not the same as for that of rice straw and leaf litter because maize is not a major crop planted in the area of Doi Saket. On the other hand, Mae Chaem is the area where the planting of maize is dominant, along with its residual burning during the harvest season, which is a common practice. In each district, three locations were randomly selected for sampling. Biomass was sampled by using a 1 m^2 grid. In one location three grids were sampling. The biomass residue inside the grid was collected and put in a labeled plastic bag. In the lab, the samples from each location (three grids) were homogenized and approximately 500 g of biomass were collected into a plastic bag for the burning experiment. The number of samples for each biomass type from the three districts was nine and the total sample number was 27 (three biomass types).

2.2. Measurement of PM10 and combustion gases from the burning chamber

Rice straw, maize residue and leaf litter were separately burned in the combustion chamber (Wiriya, 2012). The chamber is an enclosed system constructed on stainless steel. It has two main connecting parts in a cylindrical shape, which consist of a burning chamber and a storage chamber (Fig. 2). It was designed for the protection of the re-burning process of PM within a burning chamber. The burning chamber has a diameter of 0.50 m and a height of 1.20 m, while the storage chamber has a diameter of 0.85 m and a height of 2.00 m. The volume of the two sections of the chamber was approximately 1.4 m^3. The burning section was equipped with a temperature sensor, while the storage section was equipped with a Minivol Portable Air Sampler (Airmetrics, USA), gas analyzer (350-XL, Testo, Germany) and vacuum pump (FY-1.5B, Mizu, Thailand).

Before the burning, air inside the storage chamber was pumped out until it a near vacuum condition was achieved. A biomass sample was put into a basket inside the burning chamber. Liquefied petroleum gas was used for ignition. Before burning, the oxygen content of the air was approximately 21%. The burning of each fuel type took about 1 min and the temperature of the burning was