CHAPTER 4
DEVELOPMENT OF EMISSION FACTOR

This chapter aims to quantify emission load from open burning of agricultural residues, including rice, corn, and sugarcane. The experiments were conducted in the field and in the simulated open burning chamber to monitor carbonaceous aerosol and key greenhouse gases release from rice, corn, and sugarcane residues open burning. Procedures of emission load quantification are based on Equation 1.1. Sources of information that was required for estimating emission load from agricultural open burning in the field are obtained from various sources which are presented in Appendix C.

In this chapter, development of emission concentration measurement will focus on field and chamber experiments to measure emission concentration from open burning of rice, corn, and sugarcane residues in the field; and calculation method to obtain emission factor. For aerosol concentrations, the measurements were conducted by total filtration method and real time method. The total filtration method was carried out to quantify mass, and analyze for TC and OC. The real time measurement was conducted to evaluate as function of time to consider emission in each combustion phase. The combustion phase was considered by concentration of CO and CO_2. Detail of the measurement and analysis is explained as followings.

4.1 Field Experiments

4.1.1 Studied Sites

Summary of studied sites to conduct field open burning experiments are presented in Appendix C. The experiments were conducted in the sites which had agricultural residues open burning as common practice.

For rice, field burning experiments were conducted after harvesting in irrigated area, and rain-fed rice field. In irrigated area, burning was traditional practice after harvesting for 2-7 days to prepare the land for the next cultivation. The experiment in rain-fed rice field was carried out after harvesting for 9-14 days because the land was abandoned after harvesting for a long period - around 6 months.

Corn was harvested once a year. Corn residues open burning experiments were conducted in rain-fed corn field in central and northeast region of Thailand. The corn residues can be burned immediately after harvesting because farmers let the product dry on the tree naturally in the field before harvesting manually.

Sugarcane burning season is in the harvesting duration of October to May; it depends on sugar factory operation. Purpose of burning residues in sugarcane is to remove sharp leaves for easy harvesting, so burning is done before harvesting. Burning of sugarcane leaves is usually done at night (19:00-22:00). The sugarcane residues were collected to simulate open burning in the chamber.

4.1.2 Background Concentrations

Background concentrations of $PM_{2.5}$, BC, CO and CO_2 were measured at the field before field burning experiment by the measurement equipment. Results of background concentration at rice field and corn field are presented in Table 4.1.

Table 4.1 Background concentrations of $PM_{2.5}$, BC, CO and CO_2 in rice field and corn field

Location	Date	BC mg/m^3	CO2 mg/m^3	CO mg/m^3	$PM_{2.5}$ mg/m^3
Samutsakhon	20/11/2008	-	-	-	0.09
Nakhonsawan, Thatako	14/12/2008	-	1,386.94	0.00	0.05
Samutsakhon	17/9/2009	-	1,811.35	0.00	0.02
Mueang, Nakhonsawan	20/9/2009	-	2,274.68	0.00	0.01
Nakhonsawan, Thatako	29/12/2009	0.02	409.03	0.00	0.08
Pakchong	17/1/2010	0.05	245.86	0.00	0.03
Ambient Air Quality from Pollution Control Department					
Province	Month	Station	BC, CO_2	CO ppm	PM_{10} mg/m^3
Samutsakhon	11/2008	27T	-	0.9	0.035
Nakhonsawan	12/2008	41T	-	0.7	0.045
Samutsakhon	9/2009	27T	-	0.3	0.028
Nakhonsawan	12/2009	41T	-	0.9	0.060

Source: PCD, 2010 (http://www.aqnis.pcd.go.th)

The ambient air quality was measured in rice field (Samutsakhon and Nakhonsawan), and corn field (Nakhonratchasima). Background concentrations of $PM_{2.5}$, BC, and CO were not significant because they were very low in both rice and corn field. But CO_2 concentration was significant in the ambient air. The result of $PM_{2.5}$ was consistent with monthly average PM_{10} concentration at ambient air quality monitoring station in the same province measured by Pollution Control Department.

4.1.3 Open Burning Experiments

a) Open burning experiments at the agricultural field in this study

Detail of the field experiments are presented in Chapter 3. Design of the experiment was sampled background and emission concentrations at downwind by keeping position of the samplers in the plume and keeping inlet of the samplers close together to obtain the same plume mass. The background concentration was used for subtracting the monitored emission concentration to quantify the emission. In principle, every type of the measured pollutants was subtracted by the background concentration; however, only the background concentration of CO_2 was high. The background concentrations of $PM_{2.5}$, BC, and CO were very low in the ambient air (Table 4.1).

The experiments that were used for field emission factor determination included experiment sites as followings: for paddy field, experiments in Samutsakhon and Nakhonsawan; for corn field, experiments in Nakhonsawan and Nakhonratchasima province. Examples of emission concentration results from field experiments are presented in Appendix C.

In the initial experiments, emission concentration measurements were installed at the bamboo wood by using one bamboo for one instrument. The disadvantages of this method were as follows: (i) too close to the fire so too high temperature for electronic equipments; (ii) different air sample inlet into the equipments because of different positions i.e. some equipments were in plume but some were out of plume; and (iii) many colleagues were needed for each piece of equipment.

Therefore, the measurements were improved in the later experiments by installing all equipments at the same position on the same stand at 1.5 m height above ground.

The advantage of this method was as follows: inlets of equipment stayed close together so all equipments received the same air mass so we can consider emission concentrations in each combustion phase.

Findings of the open burning from field experiments were: high concentration of $PM_{2.5}$ and CO during smoldering dominant and high concentration of BC and CO_2 during flaming dominant. Flaming and smoldering dominant were considered by

$$MCE = CO_2/(CO+CO_2) \qquad \text{Equation 4.1}$$

MCE is modified combustion efficiency and CO, CO_2 are concentration of CO and CO_2, respectively. Flaming phase is dominant when the MCE is above 0.9 (Reid et al., 2005). The concentration of CO and CO_2 was monitored in this study to consider phase of combustion.

However, high surrounding influences were found in field open burning experiment. Major surrounding influence on monitoring emission concentration was meteorological condition, especially wind direction and wind speed. When calm wind was presented, the plume was raised into the air in vertical direction. In this calm wind case, the equipments could not catch the plume at high level. When wind direction was changed, the monitored equipments were out of plume.

b) Open burning experiment at the agricultural field by other studies

The experiment method of this study is different from other studies that conduct field experiment to estimate emission concentration and/or EF from agricultural open burning. Prescribed burn was conducted by burning wheat straw and maize stover in China by collecting straw to pile in windrow for burning (Li et al., 2007). This method changes traditional way of biomass arrangement because density of biomass is changed, but our study keeps condition exactly the same as traditional way in a small unit.

Field experiment was conducted in wheat straw in India by measure emission concentration from traditional burn. The real time stationary monitoring station was located at a point 3-4 m downwind of the fire for four days to cover the fire events, which fire event was the third date. The aerosol was sampling during fire event for 3 h and beyond fire event for 8 or 12 h (Sahai et al., 2007). This experiment can represent traditional burn in the field but if takes a long period to do the experiment - four days - while traditional field burning period is 3 h. One day experiment can cover biomass sampling, background air quality measurement, prescribed burn, and traditional burn emission concentration measurement in our study.

However, the field experiment has some limitation or obstruction. During open burning field experiment, many surrounding parameters have effect on combustion and consequently an influence on emission concentration which mainly are from topography i.e. flood or high moisture in soil; biomass contain high moisture; and climate i.e. temperature, humidity, wind direction, and wind speed. These parameters have effect on ignition, combustion, and also measurement that cannot keep in the plume in the case of wind direction change or plume rise up to the air directly and cannot access position of the plume in hot area, flood area, or bush area. Therefore, agricultural residues samples were collected to do experiment in the chamber that simulates conditions of open burning in the field. The chamber for open burning experiment is explained as followings.

4.2 Experiments in Open Burning Simulation Chamber

4.2.1 Description of chamber

Agricultural residues that are used for simulated open burning were main burned biomass in the field, consisting of rice straw, corn residues (leaves, stem, and envelope), and sugarcane leaves. This research conducted experiments in the chamber that are designed by no added air to help in combustion at the combustion zone. The burning zone was limited in 1m×1m area. The chamber is located at King Mongkut's University of Technology Thonburi, Ratchaburi Campus. The simulated open burning chamber is presented in Figure 4.1.

Figure 4.1 Chamber of simulate open burning at KMUTT, Ratchaburi Campus.

From Figure 4.1, the chamber consists of two major parts: combustion zone and chimney. Total height of the chamber is 3.50 m. The combustion zone is 1m×1m×1m size made of steel plate that can resist fire and high temperature. Three sides of chamber are closed and one side is opened. The Plate is movable. Three sides are separated and can move to another side. The combustion zone can adjust slope to 15, 30, and 45 degrees. However, the experiments were conducted at horizontal plain to represent burning practice in agricultural field. The chimney consists of two parts: a 25cm square stack and an inverted funnel shape made of Zinc. The top of the stack is designed as a base for installing a centrifugal fan. The sampling points were at 3 m above ground through 4 channels 5cm×10cm size for 2 channels and 5 cm diameter size for 2 channels. These channels can be closed. Design of this chamber is similar to combustion chamber of Lobert et al., (1990), but simpler - there is no balance for weight loss during combustion.

Advantages of open burning experiment in the chamber compare with the field experiment are as follows: exact weight of biomass is known before and after burn; we are able to keep measurement equipment in the plume all the time; there is a reduction in the effect of influence from topography and climate of surrounding parameters in the field.

4.2.2 Meteorological Condition

A weather station (Lacrosse, model WS1600) was installed near the chamber - 4-5 m away at 2-3 m height, setting N point to the north direction. Parameters consist of wind speed, wind direction, relative humidity, temperature, and pressure. The meteorological data was recorded manually every minute. The experiments were conducted in dry season or winter season of Thailand so meteorological condition was low humidity 42.82±9.38%, temperature 38.07±3.04°C, wind speed 0.35±0.16 m/s, and pressure 1,016.39±13.11 hPa, respectively. Most meteorological condition was calm wind; wind direction changed frequently. The calm wind condition was similar to the meteorological condition of experiments in the field. The advantages of experiment in the chamber as follows: no effect from changing wind direction on measurement and sampling of emission concentrations due to wind protection by the chamber.

4.2.3 Ambient Air Quality Condition

Ambient air quality was monitored at the chamber by the same method as the experiments. Background concentration was measured before and/or after the experiments during September 2009-February 2010. The background concentrations of $PM_{2.5}$, BC, and CO were not significant, except high CO_2 concentration that was the same as experiments in the field. Background concentrations of $PM_{2.5}$, BC, CO and CO_2 (mg/m^3) at Ratchaburi are presented in Appendix C.

4.2.4 Biomass Preparation

Condition of biomass samples for open burning experiment in the chamber is described. Rice straw and sugarcane residues samples were dried naturally to prevent fungi. Average moisture content in rice straw for open burning experiment in the chamber was 3%-8% and sugarcane leaves was completely dry. Corn residues consist of stem, leaves, and envelope that contain high moisture, especially from Suwan farm that corn residues were fresh contain 22% moisture. But corn residues sample from Pakchong was quite dry because farmers let the corn dry naturally for a month before harvesting to gain production value. Therefore, emission concentration of different moisture content in corn residues open burning was considered in samples from Suwan Farm. The corn residues were dried naturally at the upper floor of the chamber. The moisture was decreased from 22% to 5% in 43 days (29/11/09 to 11/01/10), which was the same period as corn residues in Pakchong that let the corn dry naturally in the field for a month and moisture content was 6%. Biomass and meteorological condition of this study is compared with wind tunnel experiment of rice and corn in USA (Jenkins et al., 1996). The biomass load of rice, corn, and sugarcane is presented in Appendix C.

The biomass load was in form of wet weight because sample of biomass was measured as wet weight at the chamber and sampling to analyze for moisture content at the laboratory. Because of limitation in size of combustion zone in the chamber (1×1 m^2), appropriate amount of biomass for chamber experiment was 500 g for rice straw and corn residues, and 200 g for sugarcane leaves. Rice and corn sample weight is similar to burned biomass load in the field, but sugarcane leaves weight is half of amount in the field. Preparation of biomass was done by weighing the biomass, placing the biomass on the 1m×1m tray, and placing in the chamber. Biomass arrangement can also have effect on combustion so biomass should be spread thoughout the tray.

4.2.5 Emission Concentration Measurement

At the initial experiments, emission concentration was measured inside the stack at sampling channel 2.5 m high above ground. The plume was pulled up by centrifugal fan. However, the temperature was too high and caused error in electronic equipments. Moreover, the flow (15 m/s) was too strong when compared with wind speed at the field experiments. Therefore, position of sampling site was changed to be the same method as field experiment.

The equipment for measuring emission concentration was set the same as field experiment. The emission concentration was measured at 1 m height in front of the chamber by keeping the inlets in plume direction. The sampling channels at the stack were closed. Although some plume was leaked, most plumes were released at an opened side of the chamber. This measurement method is simulated from the field experiment that set up the equipment at ground level next to the agricultural burning; however, an advantage of the chamber is the equipment can be kept in the plume during all the experiment period.

When the burning experiment was finished, ash and unburned residues were collected to be analyzed in the laboratory for moisture content and combustion efficiency. The amount of biomass, ash, and unburned residues in chamber experiment was more precise than the field experiment because exact weight of biomass is known before and after burn. At the field, topography was limited by contamination of soil or flooding.

Amount of corn residues were also varied to consider difference in emission concentration, and it was found that there was no difference among concentrations from corn residues 17, 391, and 783 g_{dm} in open burning experiments on 02/12/09. We also considered concentrations of emissions from different moisture content in corn residues with 22%, 10%, and 5% moisture, respectively. Higher concentrations were found in lower moisture content of corn residues due to high combustion efficiency. Wet fuels were difficult to ignite, so low emission concentration was found.

4.3 Analysis of Emission Factor

After experiments, raw data was downloaded from the real time equipment and the data was arranged in the same file in Excel program. The data should be arranged by the same measured time. The first step of EF calculation is changing unit. The units of BC (ng/m^3), CO (ppm), and CO_2 (ppm) concentration were changed to mg/m^3 for both ambient air concentration and emission concentration.

$$BC\ (ng/m^3) \times 10^6 \quad = \quad BC\ (mg/m^3) \qquad \text{Equation 4.2}$$

$$CO,\ CO_2\ (ppm) \times mw/Vair \quad = \quad CO,\ CO_2\ (mg/m^3) \qquad \text{Equation 4.3}$$

Where, mw is molecular weight, 28 (CO) and 44 (CO_2), V_{air} is volume of air at experiment temperature, which can be calculated by

$$Vair \quad = \quad V_{25} \times T_{25}/Tair \qquad \text{Equation 4.4}$$

where, V_{25} = 24.45 L/mol, T_{25} = 298 K, Tair = T (°C)+273 K that is obtained from meteorological measurement at the field.

The unit has been changed and the data that is less than 0 is removed i.e. BC and CO. Concentration of CO_2 is calculated by minus background concentration because CO_2 concentration in the ambient air is significant. Data of BC, CO, and $PM_{2.5}$ less than ambient air concentration is removed. Emission factors from measurement of emission concentration from agricultural residues open burning in the field and in the chamber are obtained by following equation.

$$EF = C_i/BR \quad \text{Equation 4.5}$$

where, C_i is emission concentration of pollutant i (mg/m^3) and BR is burned rate of biomass per time (g/s). Burned rate results are presented in Appendix C. Results of emission factor from field experiments are presented in Table 4.2.

Table 4.2 Emission factor results of agricultural residues open burning in field experiments

Biomass	BC (g/kg)	CO_2 (g/kg)	CO (g/kg)	$PM_{2.5}$ (g/kg)	Literature	Source
Rice	0.06 ±0.02	1,018.07 ±917.89	61.58 ±50.85	19.21 ±15.76	-	-
Corn	0.48	178.47	13.13	1.89 ±0.79	EC 0.35 ± 0.10	Li et al., 2007

From Table 4.2, all EF from burning of rice residues is higher than burning of corn residues in the field, except BC. Both experiments in rice and corn field are flaming dominant (MCE>0.9). High BC was found in corn residues burning, which indicated flaming phase, because BC was presented in flaming condition. More space for air was found in corn residues so flaming was more dominant than rice residues that contained low space for air due to homogeneous characteristics of rice straw. Results of emission factor from chamber experiments are presented in Table 4.3.

Table 4.3 Emission factor results of agricultural residues open burning in chamber experiments

Biomass	BC (g/kg)	CO_2 (g/kg)	CO (g/kg)	$PM_{2.5}$ (g/kg)	Literature	Source
Rice	0.77 ±0.31	1,185.12 ±270.92	133.20 ±75.25	27.63 ±13.79	EC 0.17±0.04 $PM_{2.5}$ 12.95±0.30; PM_{10} 3.7 CO 34.7	Hays et al., 2005; Kadam et al., 2000[a]
Corn	0.55 ±0.34	1,185.95 ±593.75	68.11 ±45.78	8.72 ±9.31	-	-
Sugarcane	0.71	1,180.55 ±248.09	123.76 ±45.40	20.31 ±15.02	-	-

Note: [a]Jenkins, 1996a emission factor and a standard field density 6.7 ton/ha of rice straw

Characteristics of emission concentration from experiment in the field and in the chamber are similar in that CO_2 and CO increased and decreased at the same period. Aerosol is quite fluctuating in the field. Peak of aerosol is finished in a short period, which is usually occurred when flaming is dominant.

Characteristics of rice straw and sugarcane leaves are homogeneous, consisting of only leaves. Therefore, they are burned easily in the chamber with short period for 1.07±0.22 g/s in straw and 1.07±0.12 g/s in sugarcane leaves, respectively. Burned rate of corn residues in the chamber is longer period than others because it is with difficulty that corn stem is burned. For field experiment, burned rate is obtained from prescribed burn 1m×1m in paddy field and 1.5m×1.5m in corn field. However, burned rate of agricultural residues in the field is higher than in the chamber.

Agricultural residues BC 0.75 g/kg (Turn et al., 1997) BC 0.69 ± 0.13 g/kg, CO_2 1,515±177 g/kg, CO 92±84 g/kg, $PM_{2.5}$3.9 g/kg (Andreae and Merlet, 2001), BC 1.0 g/kg (Bond et al., 2004)

Emission factor of agricultural residue open burning by field experiment is scarcely found in literature review. Most EF is obtained from chamber experiment and not specific to biomass type. The EF of each pollutant is in the same magnitude among studies. Low EF was found in the field experiment because emission concentration is influenced by surrounding parameters.

From results of ultimate analysis, chemical component among rice, corn, and sugarcane are not different so emission concentration should be the same. Different EF among crop type comes from physical characteristics of residues and surrounding parameters. Agricultural residues are homogeneous, except corn residues that consist of stem, leaves, and envelope. The EF of BC, CO, and $PM_{2.5}$ are lower than rice and sugarcane because stems make space that air can inlet and consequently complete combustion.

The result of $\%C_{CO2}$ is consistent that approximately >90% of carbon from agricultural residues open burning is released in form of CO_2.

4.4 Carbonaceous Aerosol Analysis

The aerosol samples were collected during prescribed burn in 1 m^2 for 2-3 samples/plot and collected during traditional burn for 1 sample/plot. Aerosol on the filter with diameter 5 mm was wrapped in Universal Tin Container. The chemical standard that has been used for aerosol sample is Urea, which consists of 46.65%N, 20.00% C, and 6.71% H. The weight of aerosol samples of quartz filter was measured by weighing the full filters before and after the sampling. The sampled filter was folded in half and cut at aerosol sample contained area for 5 mm diameter.

Each batch of the ultimate analysis, samples that put in the elemental analyzer consist of empty universal tin (blank), approximately 4 mg Urea contained in universal tin (standard), 2 pieces of 5 mm filter contained in universal tin (field blank filter), and 2 pieces of 5 mm aerosol contained in filter wrap in universal tin (unknown). The ultimate analysis was done sequentially as followings. Firstly, put empty Universal Tin container into the elemental analyzer as a blank for two replicates. Then put chemical standard contained in Universal Tin container for two replicate. After that, field blank filter in Universal Tin container was placed into the analyzer for two replicates. Then sample of aerosol filter in Universal Tin container was placed into the analyzer for three replicates. After that, put chemical standard contained in Universal Tin container for two replicate. Finally, finish by put empty Universal Tin container for two replicates.

The OC and EC analysis were distinguished by all carbon content was lost at temperature 900°C and OC was gone at 650°C. Therefore, total carbon was obtained at 900°C and OC was detected at 650°C, which two experiments were separated. The first experiment was conducted at 650°C and wait for heat up to 900°C for the next batch of experiments. EC is calculated by

$$TC = EC + OC \qquad \text{Equation 4.6}$$

where *EC* is elemental carbon, *TC* is total carbon, and *OC* represents for organic carbon, respectively. *TC* and *OC* are available from laboratory results by Eq. 4.7 and 4.8, respectively.

$$TC = \%C_{900°C} \times PM \qquad \text{Equation 4.7}$$

$$OC = \%C_{650°C} \times PM \qquad \text{Equation 4.8}$$

From Eq. 4.7 and 4.8, *PM* represents for aerosol concentration (mg/m^3) which is obtained by

$$PM = \frac{W_{PM}}{Flow \times time} \qquad \text{Equation 4.9}$$

where W_{PM} is aerosol weight (mg), *Flow* is flow rate of sampling (m^3/s), and *time* is sampling period (s). $\%C_{950°C}$ and $\%C_{650°C}$ are percentage of carbon from elemental analysis at 900°C and 650°C, respectively. Percentage of carbon is obtained by

$$\%C \text{ from CHN analyzer} = (W_{STD} \times \%C_{STD}) \times \left(\frac{Area_{UNK} - Area_{Blankfilter}}{Area_{STD} - Area_{blank}} \right) \qquad \text{Equation 4.10}$$

where, W_{STD} is weight of standard sample, $\%C_{STD}$ is percentage of carbon in the standard chemical (Urea Standard), and $Area_{UNK}$, $Area_{Blank}$, $Area_{Blankfilter}$, $Area_{STD}$ are area under the curve of unknown sample, blank filter, blank, and standard chemical, respectively. Blank of unknown contained filter in analysis but blank of standard was analyzed without filter.

$$\%C \text{ of PM in total filter area} = \%C \text{ from CHN analyzer} \times \left(\frac{R^2}{r^2}\right) \times \left(\frac{1}{W_{PM}}\right) \quad \text{Equation 4.11}$$

where, R is radius of filter that contain aerosols (18.5 mm), r is radius of filter contained PM input into the EA (2.5 mm), and W_{PM} is weight of aerosols on total filter. Results of ultimate analysis for aerosol samples are presented in Table 4.4.

Table 4.4 Ultimate analysis results of aerosols

Parameter	Ultimate results		
	%N	%C	%H
Rice TC	16.13±14.58	72.02±39.29	6.91±4.82
Corn TC	3.65±4.49	79.32±13.61	3.42±3.17
Sugar TC	4.19±2.18	78.85±28.65	5.69±1.95

Results of carbon analysis at 900°C were total carbon (%TC) and at 650°C were organic carbon (%OC) in aerosol samples. Carbonaceous aerosols contribute ~79% of $PM_{2.5}$, which is higher than estimated by Ram and Sarin (2011) that ~50% of $PM_{2.5}$ mass, which collected samples from urban area in India that combined biomass burning and urban activities sources.

However, analysis OC at temperature 650°C in this study cannot be distinguished from TC because of limitation on aerosol sample amount is not enough to be detected. To overcome this problem, BC was obtained by real time optical measurement method with Micro Aethalometer and OC was obtained by subtracting BC out of TC. The TC was determined by %TC from thermal analysis and $PM_{2.5}$ concentration from real time optical method measured by DustTrak. Results of carbonaceous aerosol (TC, BC and OC) from this applied method are presented in Table 4.5.

Table 4.5 TC, BC and OC concentration from agricultural field residues open burning

Crop type	$PM_{2.5}$ (mg/m^3)	TC (mg/m^3)	OC (mg/m^3)	BC (mg/m^3)
Rice	19.87±12.15	9.57±5.99	8.78±6.11	0.51±0.26
Corn	15.55±11.91	5.62±2.69	3.98±2.63	1.59±0.75
Sugarcane	3.25±0.00	2.56±0.03	1.91±0.03	0.66±0.00

Carbonaceous aerosols were released mainly from rice residues open burning in the field (TC 8.95±5.61 g/kg, BC 0.43±0.21 g/kg and OC 8.22±5.72 g/kg), the second is from corn residues open burning (TC 2.58±1.24 g/kg, BC 0.73±0.34 g/kg and OC 1.83±1.21 g/kg), and the third is from sugarcane leaves open burning (TC 2.39 g/kg, BC 0.61 g/kg and 1.78 OC g/kg), respectively.

4.5 Estimation of Carbon Released into the Atmosphere

Carbon Released into the Atmosphere is determined by carbon balance. Balance of carbon in biomass open burning is: amount of carbon in burned biomass equalled with amount of carbon in ash and carbon that is released into the air. Purpose of the carbon balance is to estimate amount of carbon that is released into the air, which is mainly in the form of CO_2 or more than 90% (Andreae and Merlet, 2001); others are in form of CO, CH_4, NMHCs, PM (OC and BC). Basic calculation of carbon balance is presented as follows:

$$C_{released} = C_{burned\ biomass} - C_{ash} \qquad \text{Equation 4.12}$$

where, $C_{burned\ biomass}$ = Amount of carbon in burned biomass (g)

= $\%C_{biomass} \times$ (biomass – unburn)

$C_{released}$ = Amount of carbon that released to the atmosphere

= $C_{CO2}+C_{CO}+C_{CH4}+C_{NMHCs}+C_{OC}+C_{BC}$

C_{ash} = carbon mass in the ash (g) = $\%C_{ash} \times$ ash (g)

The carbon balance is calculated in percentage to compare with amount of carbon released, based on burning of 100 gC in biomass.

$$\%C_{released} = \%C_{burned\ biomass} - \%C_{ash} \qquad \text{Equation 4.13}$$

where, $\%C_{biomass} = 100$, $\%C_{release} = 100\times(C_{release}/C_{biomass})$, $\%C_{ash} = 100\times(C_{ash}/C_{biomass})$, and $\%C_{unburn} = 100\times(C_{unburn}/C_{biomass})$, respectively. Biomass means agricultural residues that are mainly burned in the field, which is rice straw for rice; leaves, stem, and envelope for corn; and leaves for sugarcane, respectively. Results of carbon balance from agricultural residues open burning in the chamber are presented in Table 4.6.

Table 4.6 Carbon balance of agricultural residues open burning

Crop type	Burned biomass (gC/m^2)	Ash (gC/m^2)	Released into atm. (gC/m^2)
Rice	150±17	10±1	140±18
Corn	244±13	9±2	235±12
Sugarcane	390±87	6±2	384±86

From Table 4.6, open burning of biomass in the field released most carbon into the air, the rest of carbon is remained in ash.

Burning of biomass released carbon into the air 96%±1% from rice straw burning, 93%±1% from corn residues burning, and 98%±0% from sugarcane leaves burning. The released C was in form of CO_2, CO, aerosol (BC and OC) and other gases (i.e. CH_4, NMHC). Major form of C released was CO_2 for 94%±3% from rice straw burning, 84%±1% from corn residues burning, and 99%±0% from sugarcane leaves burning.

Percentage of carbon remain in ash is 7%±1% for ash of rice, 4%±1% for ash of corn, and 2%±0% for ash of sugarcane.

From the carbon balance, burning of agricultural residues released most carbon into the atmosphere in form of gases and aerosol. Major form of $C_{released}$ is CO_2, which is expected to be brought back into the biomass by the next cultivation. Therefore, main forms of $C_{released}$ that should be focused on to consider their effects are CO and aerosol (BC and OC).

4.6 Conclusions

1) Methodology of emission concentration measurement from agricultural open burning has been developed to estimate EF in this study by learning from field experiment to construct chamber that is simulating open burning in the field. Meteorological condition is usually calm wind so the chamber let air in without any force. Inlet of every emission concentration measurement equipments are installed close together to sample the same air mass, which is different from the previous method of sampling by different locations, so some equipment receives ambient air and some equipment receives emission concentration

2) Disadvantages of EFs from emission concentration measurement of field experiment are influenced by surroundings, especially meteorological condition (wind speed and wind direction), and moisture content (in biomass and soil)

3) Influence parameters on EFs from emission concentration measurement of agricultural residues open burning in the chamber are moisture content in biomass and fuel arrangement (pile or spread)

4) Emission factors of BC, CO, and CO_2 obtained from measurement of emission concentration from agricultural residues open burning in the chamber are the same range as well known literature (Andreae and Merlet, 2001) but $EF_{PM2.5}$ is in the same range as Hays et al. (2005) and Oanh et al., (2010) in piling condition.