CHAPTER 7
CARBONACEOUS AEROSOLS FROM TROPICAL DECIDUOUS FOREST FIRES IN RATCHABURI, THAILAND

7.1 Chemical and Physical Properties of Emitted Carbonaceous Aerosols (CAs)

The morphology of particulate matter containing BC emitted from tropical deciduous forest fires investigated study shown in the SEM micrographs DD, DE, DG, MA and MF (Figure 7.1). From MA it is noticed that the pollen grain of vegetation can be suspended by the combustion. From Figure 7.1, it was found that BC is more emitted by DDF fires than MDF fires. Moreover, it was observed that the colour of the particulates collected from DDF fires were grey to black, indicating high presence of BC. In contrast, the colour of filters sampled from MDF fires were light brown to dark brown. From real-time measurements of BC and $PM_{2.5}$, it was found that BC represent about 8.25% of the total mass of $PM_{2.5}$ emitted from DDF fires.

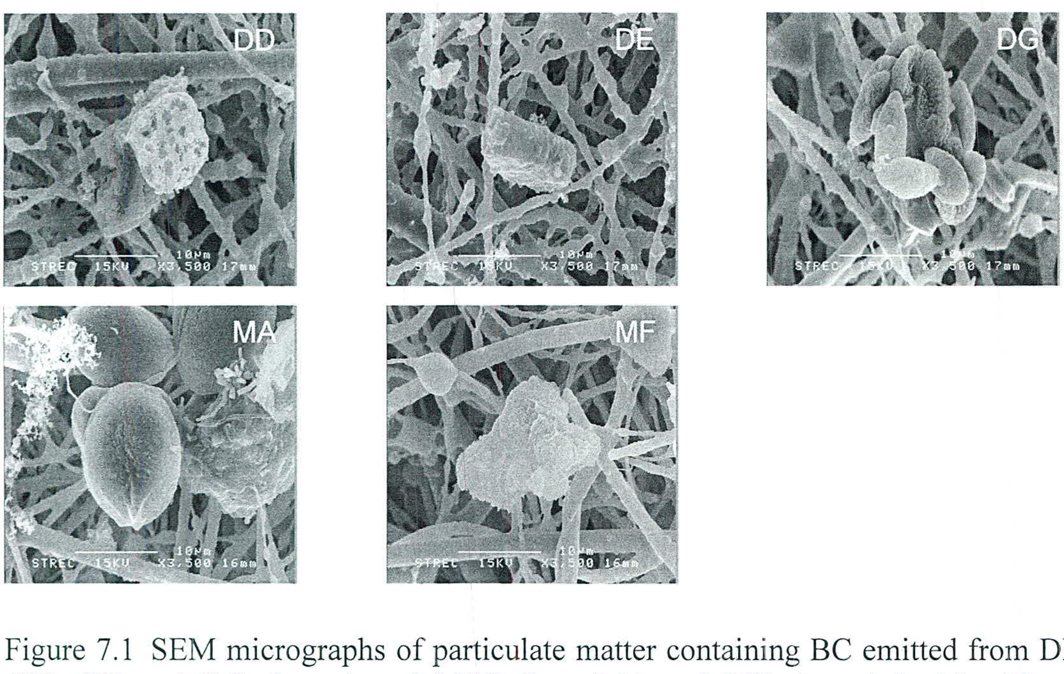

Figure 7.1 SEM micrographs of particulate matter containing BC emitted from DDF fires (DD, DE and DG shapes) and MDF fires (MA and MF shapes) in Mae Nam Phachi Wildlife Sanctuary, Ratchaburi, Thailand

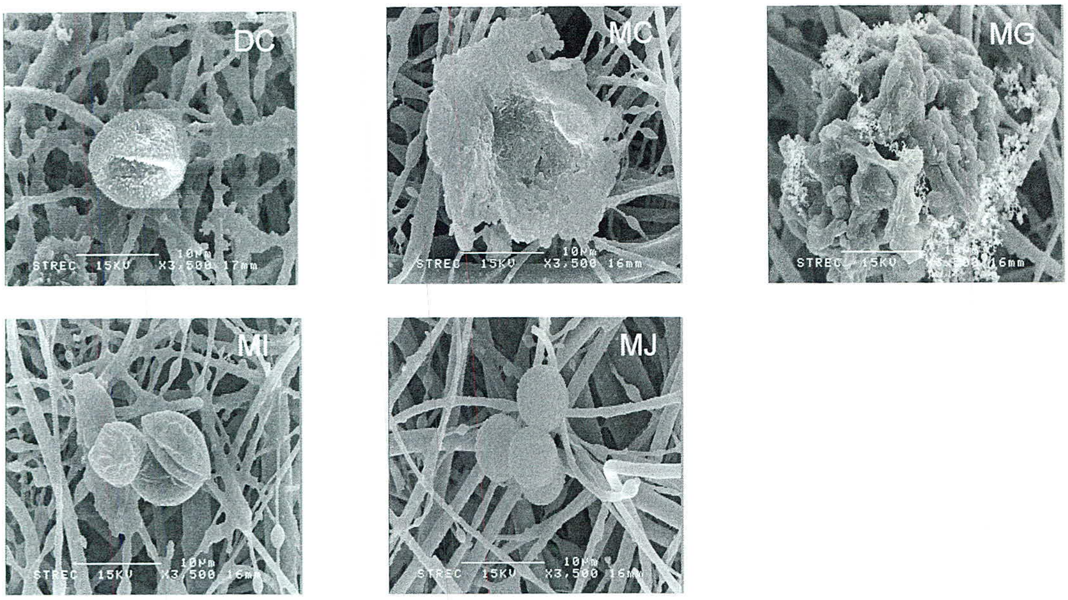

Figure 7.2 SEM micrographs of particulate matter containing OC emitted from DDF fires (DC shape) and MDF fires (MC, MG, MI and MJ shapes) in Mae Nam Phachi Wildlife Sanctuary, Ratchaburi, Thailand

The morphology of particulate matter containing OC emitted from tropical deciduous forest fires investigated in this study is reported in Figure 7.2. It was found that OC can be detected in various particulates emitted from MDF fires, as shown in the micrographs MC, MG, MI and MJ, while from DDF fires only DC displayed a presence of OC. This observation strongly suggests that MDF fires emitted higher amount of OC compared to DDF fires.

7.2 Relationship Between Carbonaceous Aerosols Emission Factor and C-released

Table 7.1 reports the BC and OC quantities emitted from DDF and MDF fires in this study. The amount of total carbon releases to the atmosphere calculated from the mass of carbon contained in CO_2, CO and $PM_{2.5}$ emitted from DDF and MDF fires is also displayed in Table 7.1. It should be noted that the quantity of biomass fuel, mainly leaf litter, of DDF fires was higher than that of MDF fires.

Table 7.1 Amount of BC, OC and C-released emitted from DDF and MDF fires in Mae Nam Phachi Wildlife Sanctuary, Ratchaburi, Thailand

Forest type	BC (mgC/m^3)	OC (mgC/m^3)	C-released (mgC/m^3)	BC/C-released	OC/C-released
DDF	0.62	5.29	220.72	0.0038	0.0240
MDF	0.54	11.37	136.90	0.0045	0.0830

Although the MCE in both DDF and MDF fire were quite similar (Tables 6.3 and 6.4), the OC released from MDF fires was about 4 times higher than that from DDF fires. Moreover, it was observed that whether from DDF or MDF fires, particulate matter contained more OC than BC. From our observations, it was shown that the emission of OC depends on the vegetation or biome type. Also, it was found that the emissions from DDF fires contain higher BC/OC ratios comparatively to that from MDF fires.

7.3 Influence of Vegetation Structure on Carbonaceous Aerosols Emissions

7.3.1 Vegetation Structure and Fuel Type

The dominant vegetation in DDF includes the family of Dipterocarparceae, which is the one of three types of the deciduous vegetation available in the world. Not only trees in this family but also the bamboo species are present in MDF. During dry season, the understory especially climbers, herb and grass dried. The major component of biomass fuel in both DDF and MDF was the leaf litter. In DDF, the litter is composed of DDF tree leaves shed during the dry season. In MDF, the litter includes mixed deciduous tree leaves and bamboo leaves.

The moisture content of leaf litter in both DDF and MDF was quite similar, but the leaf litter height in DDF was larger than in MDF. On the other hand, leaf litter load in MDF was higher than DDF, suggesting that the degree of fuel packing in MDF is higher than DDF, while can influence the combustion behavior of MDF fires. From field experiment observations, only the top of the litter in MDF was burned, while the whole layer was combusted producing ash and charred leaves in DDF as was shown in Chapter 4, Figure 4.3 and 4.4. The fireline intensity of DDF fires was is lower than MDF fires. In addition the rate of fire spread in both DDF and MDF was very similar significant difference was observed for combustion completeness (Table 7.2). Moreover, the MCE in both DDF and MDF was higher than 0.9 indicating that both DDF and MDF fires were flaming dominant.

7.3.2 Leaf Litter Fuel Bed Height

The leaf litter bed height in DDF varied highly compared to MDF, mass of leaf litter in MDF was higher than DDF It is found that leaf litter in MDF majorly composed of bamboo leaves was well arranged on the surface of forest soil with high compactness compared to DDF. The fuel bed compactness seemed to play an important role in influencing the fire behavior of MDF fires, i.e. burning of the top layer of the litter only.

7.3.3 Carbon Content of the Leaf Litter

The carbon content of the leaf litter in DDF and MDF was 46% and 37%, respectively, confirming that the difference of leaf litter composition can influence the carbon content of biomass fuel. In addition, leaf litter in MDF was dominated by bamboo leaves, since bamboo constituted the prevailing vegetation.

7.4 Comparisons of Carbonaceous Aerosols Emission Factors from Tropical Deciduous Forest and Other Forest Fires

The average values of emission factor of CO_2, CO, BC and $PM_{2.5}$ from DDF and MDF fires are presented in Table 7.3. The emission factor of CO_2 and CO in DDF is higher than MDF, while the emission factor of BC and $PM_{2.5}$. According to the ratios of BC and $PM_{2.5}$ was showed that the flaming phase dominant and the average of combustion efficiency is also higher than 80% in DDF plots (Table 4.2).

The comparison of emission factors from this study with others is displayed in Table 7.3. It was shown that the overall emission of CO_2 from other research was higher compared to this study. The BC and $PM_{2.5}$ emission factors and the ratio of CO to CO_2 from MDF fires were comparable to those from tropical and extra-tropical forest fires. Also, the emissions from DDF were characterized by high BC/OC ratio comparatively to MDF, tropical and extra-tropical forests (Table 7.3) are the same order magnitude with MDF experiment. BC emission factor from DDF is the lowest while the ratio of BC to $PM_{2.5}$ is the highest (Table 7.3).

Table 7.2 Fire behavior, mass of leaf litter consumed and emission factors of BC and OC in both DDF and MDF types

Forest type	Rate of fire spread (m/min)	Fireline intensity (kW/m)	Leaf litter consumed (g/gC)	EF (g/kg $_{dry\ biomass}$)		EF(g/m^2)	
				BC	OC	BC	OC
DDF	0.71±0.04	56.15±19.67	3.05±0.11	0.84	5.29	0.36	2.28
MDF	0.81±0.05	63.33±24.59	2.46±0.03	0.54±0.18	11.37±1.68	0.18±0.09	3.76±1.37

Table 7.3 Comparison of emission factors determined with other research studies

Forest type	EF(g/kg $_{dry\ biomass\ burned}$)					
	CO_2	CO	BC	$PM_{2.5}$	TPM	OC
DDF	1,416±19	98	0.84	10.22	-	5.29
MDF	1,146±42	72±4	0.54±0.18	19.86±2.52	-	11.37±1.51
[a]Savanna and grassland	1,613±95	65±20	0.48±0.18	5.4±1.5	8.3±3.2	3.4±1.4
[a]Tropical forest	1,580±90	104±20	0.66±0.31	9.1±1.5	6.5-10.5	5.2±1.5
[a]Extra tropical forest	1,569±131	107±37	0.56±0.19	13±7.0	17.6±6.4	8.6-9.7
[b]Amazonian forest						
Canisters	1,599	111.3		4.84	-	-
RT FASS[a]	1,617	137.6			-	-
[c]Primary tropical forest	1,601	107.8		14.8		
[c]Pasture maintenance fire	1,506	152.4		18.7		
[d]Tropical forest	1,643	93	0.52	9.1		4.71
[d]Extra tropical forest	1,509	122	0.56	15.0		

[a] Andreae and Merlet (2001), [b] Neto *et al*, (2009), [c] Yokelson *et al.*, 2008 and [d] Akagi *et al.*, 2011.

7.5 Carbonaceous Aerosols Emissions from Tropical Deciduous Forest Fires in Thailand

The emissions were calculated using the leaf litter consumed during the fires and area burned in Mae Nam Phachi Wildlife Sanctuary, Ratchaburi, Thailand during years 2007-2010. The average area burned in DDF and MDF were 7.25 and 27.88 ha. The amount of leaf litter consumed in DDF and MDF is reported in Table 7.2 was used to estimate the emission factor released from this area burned. The results are summarized in Table 7.4. It was found that the total BC and OC emissions from tropical deciduous forest burned areas in Ratchaburi were about 79 kg/year and 304 kg/year, respectively.

Table 7.4 Emissions of BC and OC from burned area in Mae Nam Phachi Wildlife Sanctuary, Ratchaburi, Thailand during 2007-2010

Forest type	Average area burned (ha/year)	Emission factor (kg/year)	
		BC	OC
DDF	7.25	26.10	165.30
MDF	27.88	52.97	139.12

Tables 7.5 and 7.6 present the emission estimation for DDF and MDF stated other research studies in Thailand, using the emission factors of BC and OC determined in this study. The estimation may be affected by some uncertainty because the amount of residues after burning and their carbon content were not available, and so the combustion completeness, in other research studied accounted in estimation. The amount of biomass fuel consumed in each study was calculated using the rate of fires spread and fireline intensity. The BC and OC emission flux, expressed in g/m^2, found for DDF located in HKK is in good agreement with our study. For MDF fires the emission flux of BC found in other studies was comparable to our value, while the OC emission flux in those studies was slightly lower to ours, as shown in Table 7.6. This result may indicate that the presence of bamboo leaves contribute to enhance the emission of OC. From our observations, it was also stressed that the BC/OC ratio is quite constant for DDF fires while it may vary highly depending on the vegetation structure, and so composition of the biomass fuel in MDF.

Table 7.5 Fuel load and fire behavior in DDF of the other research studies

Location study	Fuel load (g/m^2)	Fuel consumed (g/m^2)	Emission concentration (g/m^2)		Reference
			BC	OC	
Kanchanaburi	440	300	0.25	1.59	Weerapole, 2003
HKK	500	450	0.38	2.38	Himmapan, 2006
HKK	810	320	0.27	1.69	Himmapan, 2006
HKK	110	530	0.45	2.80	Sompoh, 1998
Phu Kradueng	470	290	0.24	1.53	Sudthichart , 1996
MNP	342	271	0.23	1.43	This study

HKK means Huay Kha Khaeng Wildlife Sanctuary, Uthai Thani Province, MNP means Mae Nam Phachi Wildlife Sanctuary, Ratchaburi Province.

Table 7.6 Fuel load and fire behavior in MDF of the other research studies

Location study	Fuel load (g/m^2)	Fuel consumed (g/m^2)	Emission concentration (g/m^2)		Reference
			BC	OC	
HKK	540	494	0.27±0.09	3.03±0.83	Sompoh, 1998
Phu Kradueng	490	410	0.22±0.07	2.52±0.69	Sudthichart , 1996
MNP	531	323	0.17±0.55	1.99±0.54	This study

HKK means Huay Kha Khaeng Wildlife Sanctuary, Uthai Thani Province, MNP means MaeNam Phachi Wildlife Sanctuary, Ratchaburi Province.

Table 7.7 Emissions of BC and OC from DDF and MDF fire in Thailand during 2002-2006

Forest type	Average area burned (ha/year)	Emissions (ton/year)	
		BC	OC
DDF	8,320.39	30.18	189.34
MDF	8,243.18	14.47	309.58

The emission factors of BC and OC from this study were used to estimate the emissions of BC and OC from DDF and MDF fires in Thailand during 2002 to 2006. We found that the emission of BC from DDF and MDF were 30.18 and 14.47 tons/year, and the emission of OC emitted from DDF and MDF are 189.34 and 309.58 tons/year, respectively, as reported in Table 7.7 Our result underlines that tropical deciduous forest fires in Thailand emitted more OC than BC annually. However, as DDF is the most burned vegetation, and the emission factor of BC for this type of fires was found to be higher than other forest open burning, the contribution of BC emissions to the regional or global climate change may be significant.

7.6 Contribution to Global Warming of Carbonaceous Aerosols Emissions from Tropical Deciduous Forest Fires in Thailand

Table 7.8 presents the emissions from annual DDF and MDF fires in Thailand in CO_2 equivalent, using the Global Warming Potential (GWP) of CO_2, CO, BC and OC, the main carbon components measured in this study.

Table 7.8 Contribution to Global warming of emissions from tropical deciduous forest fires in Thailand

Species	GWP		Emissions (ton/year)		CO_2 equivalent (ton/year)			
	20 y[a]	100 y[a]	DDF	MDF	DDF		MDF	
					20 y	100 y	20 y	100 y
CO_2	1	1	32,191	30,994	32,191	32,191	30,994	30,994
CO	6	2	1,756	1,971	10,534	3,511	11,827	3,942
BC	1,600	460	30	14	48,292	13,884	23,157	6,658
OC	-240	-69	189	310	-45,443	-13,065	-74,298	-21,361
Total contribution to global warming					45,574	36,521	-8,320	20,233
Total contribution to global warming without CO_2					13,383	4,330	-39,314	-10,761

[a]Permadi and Kim Oanh, 2013, (+) means warming and (-) means cooling.

The GWP metric is used to determine the relative radiation effect of a given emission mass of a species compared to CO_2 integrated over a chosen time horizon. Generally, 20 year and 100 year time horizons are used to calculate the GWP of a given compound. In addition BC and OC are usually estimated based on 20 year time horizon, because of their shorter lifetime compound to traditional GHG. We estimated the contribution with and without including CO_2, since the emitted CO_2 may totally or partially be used by the annual growth of the forest.

From Table 7.8 it was found that whether with or without CO_2 and whether the time horizon, DDF fires emissions contribute to global warming annually, while MDF fires may lead to cooling except in the case of including CO_2 and 100 year time horizons.