CHAPTER 5

INCINERATION AND OPEN BURNING OF WASTE

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5 INCINERATION AND OPEN BURNING OF WASTE

5.1 INTRODUCTION

In Chapter 5, Volume 5 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (*2006 IPCC Guidelines*) new thermal treatment of solid waste such as gasification and pyrolysis is not included. These new technologies have been used worldwide and become important in some countries. The refinement in this chapter provides methane and nitrous oxide emission factors of pyrolysis, gasification and plasma technology to be used in the estimation of emissions. It is noted that CH_4 and N_2O reported in this chapter are from leakage emission whereas gases used for energy purposed will be report from energy sector. This chapter updates the oxidation factors of open burning of municipal solid waste (MSW) from real experiment provided with its uncertainty.

Definition of incineration is defined in the *2006 IPCC Guidelines* as "…..Waste incineration is defined as the combustion of solid and liquid waste in controlled incineration facilities….". In general, thermal treatments of waste are classified into incineration, pyrolysis, gasification, plasma, and open burning of waste. In this refinement, definition of pyrolysis, gasification and plasma technology are provided.

Pyrolysis is defined as a reduction process that thermochemical converts organic materials into gas and liquid products mainly containing hydrocarbon components and a solid residue with higher carbon content at elevated temperatures in the absence of oxygen.

Gasification is defined as a partial oxidation process that converts organic materials into carbon monoxide, hydrogen, and carbon dioxide at high temperatures above 700℃ with steam and/or carbon dioxide and/or controlled amount of oxygen. The resulting gas mixture is called as syngas or producer gas used as fuel.

Plasma is defined as a partial oxidation process of reacting organic materials with limited amounts of oxygen at high temperature to produce gas and solid products. Highly reactive plasma zone consists largely of electrons, ions, and excited molecules along with high energy radiation. In a plasma zone, organic materials are cracked to high portion of gas products such as carbon dioxide, water, carbon monoxide, hydrogen, and light hydrocarbons and low quantities of inorganic solid product (slag).

Pyrolysis, gasification, and plasma have been introduced to treat waste in a more environmentally friendly manner as well as to recover valuable products by reduction and/or partial oxidation processes.

The new technologies have been mostly applied to recover the fuels and valuable produces from waste tires and plastics, while to treat the MSW for the purpose of reducing the generations of air pollutants. Although many pyrolysis, gasification, and plasma plants have been applied to treat wastes, a few facilities have been only operated due to some technical problems as well as high cost. High standard for environment and clean energy have recently revived the interest in the new technologies and new plants have been installed in developed countries. Few official data for GHG emissions are available from the new technologies. Especially, GHG emission data from plasma technology are rarely found.

Emissions from incineration, pyrolysis, gasification, and plasma of waste without energy recovery are reported in the Waste Sector, while emissions from incineration, pyrolysis, gasification, and plasma with energy recovery are reported in the Energy Sector, both with a distinct between fossil and biogenic carbon dioxide (CO_2) emissions. The methodology described in this chapter is applicable in general both to thermal treatments with and without energy recovery. Co-firing of specific waste fractions with other fuels is not addressed, so co-firing is covered in Volume 2, Energy. Emissions from agriculture residue burning are considered in the AFOLU Sector, Chapter 5 of Volume 4.

Since gas products containing CH_4 produced by pyrolysis, gasification, and plasma processes are collected and used mostly as fuel, CH_4 emissions from the three processes into the atmosphere are expected to be quite low unless CH_4 is directly emitted without collecting and using as fuel. CH_4 emissions can be estimated under the Energy sector when the gas products are recovered and used as fuel. If gas products of the three processes would not recovered, CH_4 emissions should be estimated in the Waste sector.

5.2 METHODOLOGICAL ISSUES

Methodology in the *2006 IPCC Guidelines* can be used to estimate emission from gasification, pyrolysis and plasma. Emission factors of CH_4 and N_2O from pyrolysis and gasification are provided in Tables 5.3a, 5.3b and 5.4a.

5.3 CHOICE OF ACTIVITY DATA

No refinement

5.4 CHOICE OF EMISSION FACTORS

5.4.1 CO_2 emission factors

5.4.1.1 TOTAL CARBON CONTENT

No refinement

5.4.1.2 FOSSIL CARBON FRACTION

No refinement

5.4.1.3 OXIDATION FACTOR

The *2006 IPCC Guidelines* provide default oxidation factors of open burning of MSW. This refinement updates the default parameter of oxidation factor from experiment in Japan. The condition of combustion is smouldering combustion with the moisture content is 35 percent. Table 5.2, except the default value of oxidation factor of MSW, all values are retrieved from the *2006 IPCC Guidelines*.

TABLE 5.2 (UPDATED)
DEFAULT DATA FOR CO_2 EMISSION FACTORS FOR INCINERATION AND OPEN BURNING OF WASTE

Parameters	Management practice	MSW	Industrial Waste (%)	Clinical Waste (%)	Sewage Sludge (%) Note 4	Fossil liquid waste (%) Note 5
Dry matter content in % of wet weight		see Note 1	NA	NA	NA	NA
Total carbon content in % of dry weight		see Note 1	50	60	40 – 50	80
Fossil carbon fraction in % of total carbon content		see Note 2	90	40	0	100
Oxidation factor in % of carbon input	incineration	100	100	100	100	100
	Open- burning (see Note 3)	71	NO	NO	NO	NO

NA: Not Available, NO: Not Occurring

Note 1: Use default data from Table 2.4 in Section 2.3 Waste composition and equation 5.8 (for dry matter), Equation 5.9 (for carbon content) and Equation 5.10 (for fossil carbon fraction).

Note 2: Default data by industry type is given in Table 2.5 in Section 2.3 Waste composition. For estimation of emissions, use equations mentioned in Note 1.

Note 3: When waste is open-burned, refuse weight is reduced by approximately 49 to 67 percent (US-EPA, 1997, p.79). A default value of 71 percent is provided from the experimental study in Japan. Its uncertainty is +/-8 percent.

Note 4: See Section 2.3.2 Sludge in Chapter 2.

Note 5: The total carbon content of fossil liquid waste is provided in percent of wet weight and not in percent of dry weight (GIO, 2005).

References: *GPG2000* (IPCC, 2000), Lead Authors of the *2006 Guidelines*, Expert judgement.

5.4.2 CH_4 emission factors

This refinement presents the updated emission factors of methane emissions from new technology of gasification and pyrolysis to the extent of current literatures.

CH_4 emissions from waste pyrolysis are dependent on the types of waste and technology as well as the operation conditions. CH_4 emissions from waste pyrolysis increase with increasing operating temperature. Table 5.3A and

Table 5.3B show default CH_4 emission factors by waste type and reactor type at various operating temperature (Rahman et al., 2001 and He et al., 2010) under pyrolysis and gasification, respectively.

CH_4 emissions from waste pyrolysis are dependent on the types of waste and technology as well as the operation conditions. Table 5.3A shows the CH_4 emission factors of MSW and refuse derived fuel (RDF) at various operating temperatures (Rahman et al., 2001, He et al., 2010). CH_4 emissions from waste pyrolysis increase with increasing operating temperature. The higher pyrolysis temperature can supply more energy to break down the high-molecular-weight organic components of solid wastes into low-molecular-weight compounds like CH_4.

Direct measurements of CH_4 in the flue gases from the stack were carried out to determine the average CH_4 emission factor of 0.0089 g CH_4/kg wet weight (8.9 g CH_4/t wet weight) from the pyrolysis-melting plant having a serially connected system of pyrolysis and melting reactor with a capacity of 150 tons/day in Korea (Lee et al., 2015). The CH_4 emission factors of the pyrolysis-melting plant are comparable with those of incinerators (Table 5.3A), whereas are much lower than those derived from lab-scale pyrolysis reactors reported in Table 5.3A. In the pyrolysis-melting plant with a commercial scale, condensable and non-condensable gases including CH_4 generated from the pyrolysis reactor were mostly oxidized at the subsequent melting furnace, leading to the low CH_4 emission factors. If country-specific data for MSW pyrolysis combined with melting system would be unavailable, *it is good practice* to apply the default CH_4 emission factor in Table 5.3A.

In the case of direct emission of pyrolysis gases to surrounding atmosphere without oxidizing or collecting for fuel use, *it is good practice* to use default CH_4 emission factors of MSW pyrolysis for three operating temperatures: 1) low-temperature operation (<600°C): 30 g CH_4/t wet weight, 2) medium-temperature operation (between 600 and 800°C): 61 g CH_4/t wet weight, 3) high-temperature operation (>800°C): 88 g CH_4/t wet weight. For RDF pyrolysis with direct emission to surrounding atmosphere, *it is good practice* to use the default CH_4 emission factors for two operating temperatures: 1) low-temperature operation (<700°C): 33 g CH_4/t wet weight and 2) high-temperature operation (>700°C): 56 g CH_4/t wet weight. For pyrolysis of mixed waste plastics with direct emission of pyrolysis gases, *it is good practice* to apply the weighted average of the default CH_4 emission factor of each plastics in Table 5.3A, provided that the country-specific information would be unavailable.

Since the default CH_4 emission factors in Table 5.3A except for pyrolysis-melting plant are adopted from the experimental results of lab-scale reactors, it is recommended to develop country-specific CH_4 emission factors for waste pyrolysis plants.

If waste pyrolysis utilizing gas products including CH_4 as fuel would be applied, *it is good practice* to adopt the CH_4 emission factors provided in Volume 2, Chapter 2, Stationary Combustion.

TABLE 5.3A (ELABORATION)
CH_4 EMISSION FACTORS FOR PYROLYSIS OF WASTE

Waste type		Reactor type	Operating temperature (°C)	CH_4 Emission Factors (g/kg waste pyrolyzed on a wet basis)
MSW		Lab-scale batch	450[1]	2
			550[1]	15
			600[1]	30
			Low-temperature average	16
			650[1]	30
			750[2]	61
			Medium-temperature average	46
			800[2]	77
			850[2]	86
			900[2]	100
			High-temperature average	88
		Rotary kiln + melting furnace[3]	450 (Pyrolysis), 1,300 (Melting furnace)	0.006~0.0108 (average 0.0089)
Refuse derived fuel (RDF) [4]		Lab-scale fluidized bed	600	20
			650	32
			700	46
			Low-temperature average	33
			750	56
Waste plastics[5]	HDPE	Lab-scale batch	700	57
	LDPE			34
	PP			28
	PS			16
	PVC			23
	PET			21

[1] Rahman et al. (2001)
[2] He et al. (2010)
[3] Yoon (2016)
[4] Wu et al. (2016)
[5] Williams et al. (1999)

The generation rates of CH_4 from waste gasification are varied with the types of waste, reactor types, and operating conditions. Table 5.3B exhibits that CH_4 emission factor values range widely from 0.0069 to 282 g CH_4/kg wet weight. Japan (2017) reports the average CH_4 emission factor of 0.0069 g CH_4/kg wet weight (6.9 g CH_4/kg wet weight) for gasification-melting plants presently operated in Japan. Since most gas products including CH_4 generated from the gasification reactor of the gasification-melting plant in Japan are oxidized at the following melting furnace, the CH_4 emission factors are distinctly low to compare with those from lab-scale gasification operations which assume the releases of all gas products to the surrounding atmosphere.

In the case of direct emission of gasification gases to the air without oxidizing or collecting for fuel use, *it is good practice* to use the default CH_4 emission factor of MSW gasification, 44 g CH_4/kg wet weight in Table 5.5, provided that the country-specific data would be inapplicable. For RDF gasification with direct emission to the air, *it is good practice* to use the default CH_4 emission factors for two operating temperatures: 1) low-temperature operation (<700°C): 30 g CH_4/t wet weight and 2) high-temperature operation (>700°C): 57 g CH_4/t wet weight. If the country-specific CH_4 emission factors would be unavailable, *it is good practice* to apply the default CH_4 emission factors for waste plastic gasification with direct emission of gasification gases.

CH_4 emission factors of waste gasification are significantly influenced by waste type, reactor type, and operation conditions. It is recommended to develop country-specific CH_4 emission factors for waste gasification plants instead of using the default values in Table 5.3B.

For waste gasification to generate synthetic gases used as fuel, *it is good practice* to apply the CH_4 emission factors provided in Volume 2, Chapter 2, Stationary Combustion.

TABLE 5.3B (ELABORATION)
CH_4 EMISSION FACTORS FOR GASIFICATION OF WASTE

Waste type		Reactor Type	Operating temperature (°C)	CH_4 Emission Factors (g/kg waste gasified on a wet basis)
RDF[1]		Lab-scale fluidized bed	600	23[1]
			650	36[1]
			Low-temperature average	30
			700	58[1]
			750	55[1]
			High-temperature average	57
MSW		Fluidized bed[2]	826	45[2]
			870	42[2]
			Average	44
		Gasification + melting furnace[3,] (see Note 1)	-	0.0069[3]
Plastics[4]	HDPE	Lab-scale batch	800	142
			850	89
	PP		800	282
			850	79
	PS		800	27
			850	15
	Mixed		800	209
			850	31
Waste wood[5]		Lab-scale batch	800	32

[1] Wu et al. (2016)

[2] Klein and Themelis (2003)

[3] GIO (2017)

[4] Wu and Williams (2010)

[5] Altafini (2003)

Note 1: Serially connected system of gasifier and melting furnace or integrated system of gasification occurring at the inlet region of reactor and melting system at the outlet region of reactor

5.4.3 N_2O emission factors

The emission factors of N_2O from pyrolysis, gasification, and plasma technology of waste vary with types of waste, reactor type, and operation conditions. In this refinement updated N_2O emissions from pyrolysis/melting furnace technology of MSW are provided.

Since most national regulations for air pollutants rarely require monitoring N_2O emissions from thermal treatment plants of solid wastes, a few official data are available for N_2O emission from pyrolysis, gasification, and plasma plants. Especially, N_2O emission data are unavailable for waste plasma. Table 5.4A indicates the N_2O emissions from pyrolysis-melting and gasification-melting plants of MSW on a commercial-scale base. The emission factor of N_2O from pyrolysis-melting plant is much lower than that from shaft furnace reactor, indicating that the reactor type plays an important role in N_2O generation. It is also expected that the waste type and operation conditions influence the generation patterns of N_2O.

TABLE 5.4A
(ELABORATION) N_2O EMISSION FACTORS FOR PYROLYSIS AND GASIFICATION/MELTING FACILITY OF MSW

Process	**Operating temperature (°C)**	**N_2O Emission Factors (g/kg waste gasified on a wet basis)**	**Reactor Type**
Pyrolysis and melting	Pyrolysis: 450℃ Melting: 1300℃	0.8291	Rotary kiln + melting furnace
	No information	15.52	Shaft furnace
Gasification and melting	No information	12.03	

[1] Yoon. (2016)
[2] GIO (2017)
[3] Lee et al. (2015)

5.5 COMPLETENESS

No refinement

5.6 DEVELOPING A CONSISTENT TIME SERIES

No refinement

5.7 UNCERTAINTY ASSESSMENT

No refinement

5.8 QA/QC, REPORTING AND DOCUMENTATION

No refinement

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