

CHAPTER 5

INCINERATION AND OPEN BURNING OF WASTE

[Parts shaded in grey – the unchanged text from the 2006 *IPCC Guidelines*]

Second-order Draft

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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 methods of solid waste such as gasification and pyrolysis are not included. These new technologies have been used worldwide and became important in some countries. The refinement in this chapter provides CH₄ and N₂O emission factors of pyrolysis, gasification and plasma technology to be used in the estimation of emissions. This chapter updates the oxidation factors of open burning of municipal solid waste (MSW) from real experiment provided with its uncertainty.

The new technologies are usually applied to produce valuable fuels from solid wastes. The fuels generated from the new technologies are generally combusted to use as fuel at either the site or outside. Therefore, CO₂ emissions from the new technologies are similar to those of solid waste incineration and stationary combustion devices using fossil fuel.

Definition of incineration is defined in the *2006 IPCC Guidelines* 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 (new Box 5.0A).

Gasification is a process that converts organic materials into carbon monoxide, hydrogen, and carbon dioxide at temperatures above 700°C with steam and/or carbon dioxide and/or controlled amount of oxygen. The resulting gas mixture is called as synthesis gas (syngas), mainly used as fuel (new Box 5.0B).

Plasma is defined as a partial oxidation process of reacting organic materials in an oxygen starved environment 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 along with low quantities of inorganic solid product (slag and metals) (new Box 5.0C).

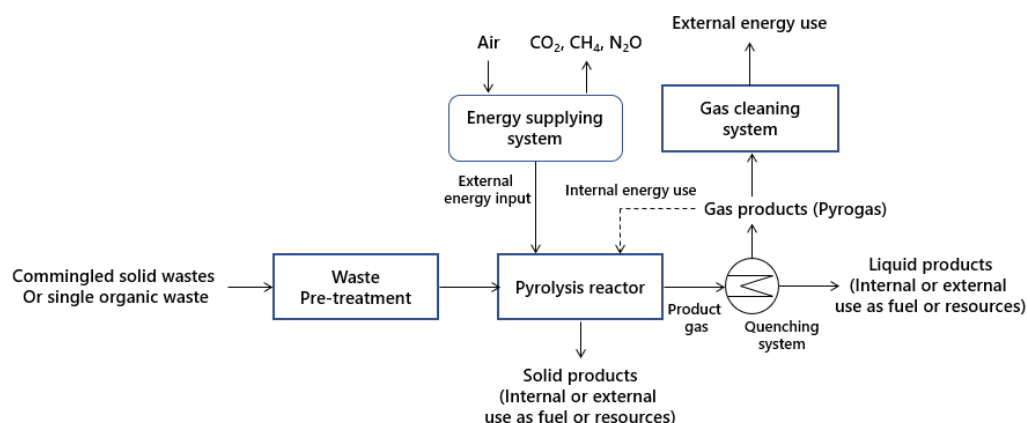
The new technologies have been mostly applied to recover the fuels and chemical feedstocks from waste tires and plastics, whereas they are also used to treat the MSW to reduce the generations of air pollutants. Although many pyrolysis, gasification, and plasma plants have been applied to treat wastes, many plants have been closed due to some technical problems as well as high cost. Rising environmental standards and clean energy demands have recently revived the interest in the new technologies and new plants are getting 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 systems for waste treatment without energy recovery are reported in the Waste Sector, while emissions from such technologies with energy recovery are reported in the Energy Sector, both with a distinct between fossil and biogenic carbon dioxide (CO₂) 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 Agriculture, Forestry and Other Land Use (AFOLU) Sector, Chapter 5 of Volume 4.

Since gas products containing CH₄ produced by pyrolysis, gasification, and plasma processes are collected and used mostly as fuel, CH₄ emissions from the new technologies into the atmosphere are expected to be quite low unless CH₄ is directly emitted without collecting and using as fuel. CH₄ emissions can be estimated under the Energy sector when the gas products are recovered and used as fuel. When the gas products generated from the new technologies would not be recovered, it is *good practice* to estimate CH₄ emissions in the Waste sector.

Box 5.0A (NEW)**PYROLYSIS**

Pyrolysis is reductive and endothermic reaction to convert carbonaceous substances into lower molecular compounds by applying external energy. The more energy is applied, the smaller size compounds are produced. CH₄ is one of the smallest compounds generated from pyrolysis process of carbonaceous substances. Pyrolysis of organic wastes is normally operated at temperature ranges between 300 and 700°C. The pyrolysis process can be shown as below:



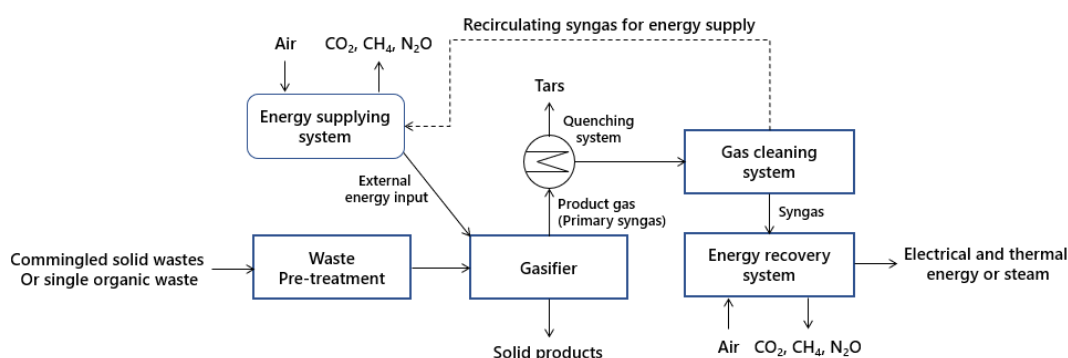
Solid wastes or single organic wastes (e.g., plastic and wood) are pre-treated to satisfy technical requirements for the succeeding pyrolysis reaction. Combustible components of solid wastes are thermally decomposed in pyrolysis reactor to produce gases and solid residues. The product gas is composed of condensable and non-condensable fraction which are separated into gas and liquid products, respectively, by quenching process. The gas products mainly composed of volatile organic compounds (eg., CH₄, C₂H₆, etc.), H₂, CO, and CO₂. Liquid products are composed of various aliphatic and aromatic compounds. Solid products are accounted for by carbon and inorganic components. In some cases, the gas products are recirculated as self-sustaining energy source into pyrolysis reactor or stored for external energy use. Although CH₄ is one of major components of gas products from pyrolysis reaction of organic wastes, its emission to the air rarely happens because the gas products are completely combusted for energy purpose. The energy-supplying system to the pyrolysis reactor is considered as the only emission source of greenhouse gases in the pyrolysis plant of organic wastes. The emissions of greenhouse gases from the energy-supplying system are estimated under the Energy Sector.

BOX 5.0B (NEW)**GASIFICATION**

Gasification is a conversion process of carbonaceous substances to gas fuel with a high heating value. Depending on reaction condition, gasification of solid carbon in the form of coal, coke, or organic wastes are accounted for by four primary reactions: partial oxidation reaction, Boudouard reaction, water gas reaction, and methanation reaction.

- partial oxidation reaction: $C + 1/2O_2 \rightarrow CO$
- Boudouard reaction: $C + CO_2 \leftrightarrow 2CO$
- water gas reaction: $C + H_2O \leftrightarrow CO + H_2$
- methanation reaction: $C + 2H_2 \leftrightarrow CH_4$

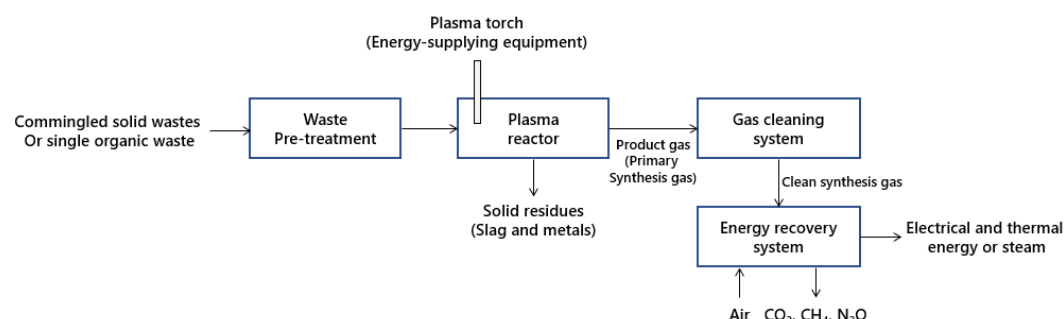
The above gasification reactions reveal that the product gas is mainly accounted for by H_2 , CO , and CH_4 and is named as synthesis gas (syngas). Solid wastes or single organic wastes (e.g., plastic and wood) are pre-treated to satisfy technical requirements for the subsequent gasification reaction. The gasification of combustible components of solid wastes produces the primary syngas. The gas cleaning system followed by gasifier removes acid gases, fine particulates, heavy metals, and moistures from the primary syngas. The clean syngas is used as fuel for generating electrical and thermal energy or steam. Some portion of syngas can be used to sustain the reaction. The gasification of combustible components of solid wastes produces syngas together with liquid and solid products. Liquid products separated from product gas by quenching process are known to be tars which are mainly composed of polyaromatic compounds, while the solid products are represented by carbon and inorganic components.



Since syngas generated from gasification process is used for fuel, CH_4 emissions are rarely expected during the gasification process. The energy-supplying system to the gasification process is considered as the only emission source of greenhouse gases in the gasification plant of solid wastes. The emissions of greenhouse gases from the energy-supplying system are estimated under the Energy Sector.

Box 5.0C (NEW)**PLASMA**

Plasma technology is regarded as an advanced and pure gasification process. Since plasma process is operated at extremely high temperatures in an oxygen deficient condition, combustible components of solid wastes can be completely converted into gas fuel and reaction residues are accounted by inorganics like slag and metals. Primary syngas is produced in plasma reactor where one or more plasma arc torches are installed for plasma generation. The primary syngas is treated by gas cleaning system to produce clean syngas.



Since syngas generated from plasma process is used for fuel, CH₄ emissions are rarely expected from the plasma process. The energy-supplying system to the plasma process is considered as the only emission source of greenhouse gases in the plasma plant of solid wastes. The emissions of greenhouse gases from the energy-supplying system are estimated under the Energy Sector.

5.2 METHODOLOGICAL ISSUES

Methodology from the *2006 IPCC Guidelines* can be used to estimate emission from gasification, pyrolysis and plasma. Emission factors of CH₄ and N₂O from pyrolysis and gasification are provided in new Tables 5.3A and 5.4A.

5.3 CHOICE OF ACTIVITY DATA

No refinement

5.4 CHOICE OF EMISSION FACTORS

5.4.1 CO₂ 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 for open burning of MSW. This refinement updates the default parameter of oxidation factor from experiment from Japan. The condition of combustion is smouldering with 35 percent of the moisture content. In updated Table 5.2 below, 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 3,6)	71	NO	NO	NO	NO
<p>NA: Not Available, NO: Not Occurring</p> <p>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).</p> <p>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.</p> <p>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. References: Yamada <i>et al.</i> (2010)</p> <p>Note 4: See Section 2.3.2 Sludge in Chapter 2.</p> <p>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).</p> <p>References: GPG2000 (IPCC, 2000), Lead Authors of the 2006 Guidelines, Expert judgement.</p> <p>Note 6: The residue after open-burning contains unburned fraction. The fate of this remaining carbon will be tracked and emission is accounted for adequate category. When open-burning takes place in SWDS, burned fraction of DOC is subtracted from the emission source from SWDS.</p>						

5.4.2 CH₄ emission factors

This refinement presents the emission factors of CH₄ for new technologies of pyrolysis and gasification. Although a plenty of information on CH₄ emissions from the pyrolysis and gasification of solid wastes are available from scientific research literatures (new Box 5.2), very few data are obtainable for commercial plants of new technologies. New Table 5.3A shows the CH₄ emission factors of MSW from a combined system of pyrolysis/melting and gasification/melting process on a commercial scale (new Box 5.3). In commercially operated pyrolysis/melting and gasification/melting plants, condensable and non-condensable gases including CH₄ generated from the pyrolysis and gasification reactor are mostly oxidized at the subsequent melting furnace, leading to the low CH₄ emission factors. If country-specific data for MSW pyrolysis/melting and gasification/melting system are unavailable, it is *good practice* to apply the default CH₄ emission factor in new Table 5.3A.

TABLE 5.3A (NEW)			
CH ₄ EMISSION FACTORS FOR PYROLYSIS/MELTING AND GASIFICATION/MELTING PLANT OF MSW			
Process	Operating temperature (°C)	CH ₄ Emission Factors (g/kg pyrolyzed waste on a wet basis)	Reactor Type
Pyrolysis and melting	Pyrolysis: 450°C Melting: 1300°C	0.006–0.0108 ¹ (average 0.0089)	Rotary kiln + melting furnace
Gasification and melting	No information	0.0069 ²	No information
¹ Yoon (2016) ² GIO (2017)			

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Box 5.2 (NEW)**INFORMATION ON METHANE EMISSION FACTORS IN LABORATORY SCALE**

A plenty of information on CH₄ emissions from pyrolysis and gasification process in laboratory scale are available for various waste types and reaction conditions. According to the scientific research literatures, CH₄ emissions from waste pyrolysis and gasification are dependent on the types of waste and technology as well as the operating conditions. CH₄ emissions from waste pyrolysis and gasification 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 CH₄. New Tables 5.3A, 5.3B and 5.3C show CH₄ emission factors by waste type and reactor type at various operating temperature (Rahman et al., 2001 and He et al., 2010) under pyrolysis/melting and gasification/melting, pyrolysis and gasification, respectively.

Since the CH₄ emissions are dependent on many operating conditions, it is recommended to determine plant-specific CH₄ emission factors. In all commercial plants, the pyrogas and syngas are collected and used as gas fuel. Hence, CH₄ emissions to the air are rarely observed from pyrolysis and gasification plant. If the pyrogas and syngas are combusted, it is good practice to adopt the CH₄ emission factors provided in Volume 2, Chapter 2, Stationary Combustion.

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TABLE 5.3B (NEW)				
CH ₄ EMISSION FACTORS FOR PYROLYSIS OF WASTE IN LABORATORY SCALE				
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
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)
⁴ Wu *et al.* (2016)
⁵Williams *et al.* (1999)

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TABLE 5.3C (NEW)				
CH ₄ EMISSION FACTORS FOR GASIFICATION OF WASTE IN LABORATORY SCALE				
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
Plastics ³	HDPE	Lab-scale batch	800	142
	PP		850	89
			800	282
	PS		850	79
			800	27
	Mixed		850	15
			800	209
			850	31
Waste wood ⁴		Lab-scale batch	800	32

¹ Wu *et al.* (2016)

² Klein and Themelis (2003)

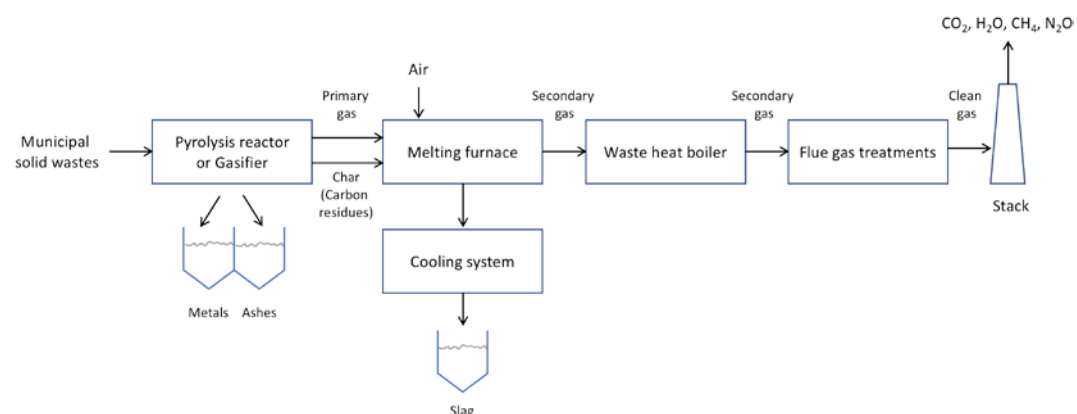
³ Wu and Williams (2010)

⁴ Altafini (2003)

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BOX 5.3 (NEW) COMBINED SYSTEM

For MSW treatment, a combined system of two processes was introduced. The first process of the combined system is either pyrolysis or gasification, whereas the melting process only represents the second one.



Municipal solid wastes are thermally decomposed to yield the primary gas with high heating values and char (carbon residues) in the absence of oxygen or oxygen starved environment. The primary gas and char are transported to the melting furnace operating at high temperatures (>1000°C) under oxidation conditions. Complete oxidation of primary gas and char are accomplished at the melting furnace. After removing the air pollutants from the secondary gas, the flue gas mainly composed of CO₂ and H₂O is emitted to the air through the stack. Since pyrolysis gas and syngas generated from pyrolysis and gasification, respectively, are completely oxidized at the melting furnace, the greenhouse emission from the stack is expected to be negligibly low.

5.4.3 N₂O emission factors

The emission factors of N₂O for pyrolysis, gasification, and plasma technology of waste vary with types of waste, reactor type, and operating conditions. In this refinement updated N₂O emissions from pyrolysis/melting furnace technology of MSW are provided.

Since most national regulations for air pollutants rarely require monitoring N₂O emissions from thermal treatment plants of solid wastes, a few official data are available for N₂O emission from pyrolysis, gasification, and plasma plants. Especially, N₂O emission data are unavailable for waste plasma technology. New Table 5.4A indicates the N₂O emissions from pyrolysis-melting and gasification-melting plants of MSW on a commercial-scale basis. The emission factor of N₂O from pyrolysis-melting plant is much lower than that from shaft furnace reactor, indicating that the reactor type plays an important role in N₂O generation. It is also expected that the waste type and operating conditions influence the generation patterns of N₂O.

Table 5.4A (New) N ₂ O EMISSION FACTORS FOR PYROLYSIS/MELTING AND GASIFICATION/MELTING PLANT OF MSW			
Process	Operating temperature (°C)	N ₂ O Emission Factors (g/kg waste gasified on a wet basis)	Reactor Type
Pyrolysis and melting	Pyrolysis: 450°C Melting: 1300°C	0.829 ¹	Rotary kiln + melting furnace
	No information	15.5 ²	Shaft furnace
Gasification and melting	No information	12.0 ³	
¹ Yoon. (2016) ² GIO (2017) ³ Lee <i>et al.</i> (2015)			

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234 **5.5 COMPLETENESS**

235 No refinement

236 **5.6 DEVELOPING A CONSISTENT TIME SERIES**

237 No refinement

238 **5.7 UNCERTAINTY ASSESSMENT**

239 No refinement

240 **5.8 QA/QC, REPORTING AND DOCUMENTATION**

241 No refinement

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