METHANE GENERATION POTENTIAL AND BIODEGRADABILITY OF MSW COMPONENTS

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SUMMARY: As an important parameter for estimation of methane generation from landfills, we measured ultimate methane yields (M_0^{VS}) of various municipal solid waste (MSW) components, which were obtained by classifying bulk waste carried into S landfill in Korea. Food wastes exhibited the highest M_0^{VS} of 420mL CH_4/g VS. Misc. organics, paper, textile, wood, sludge, and leather showed M_0^{VS} as high as 295, 285, 231, 213, 154, and 150mL CH_4/g VS, respectively. M_0^{VS} of plastics and rubber was as low as 76 and 48mL CH_4/g VS, respectively. For plastics and rubber, which are known as nondegradable components, M_0^{VS} was considered to result from other degradable components intermixed during collection and transportation of bulk waste. Food wastes and paper represented the highest biodegradability of around 70%. Misc. organics, textile, and wood showed moderate biodegradability of around 50%. Biodegradability of sludge and leather was in the range of 25-30%. Plastics and rubber showed almost no biodegradability with the values less than 10%. Methane generation potential of bulk waste disposed at S landfill in Korea was in the range of 37-88m^3 CH_4/Mg wet waste, and fraction of the degradable organic carbon that can anaerobically decompose (DOC_f) was estimated as 0.6 by considering waste components except for plastics and rubber/leather.

1. INTRODUCTION

Methane produced at solid waste landfill site contributes approximately 3 to 4 percent to the annual global anthropogenic greenhouse gas emissions (IPCC, 2001). On the other hand, methane is considered as an alternative energy due to its high heat value. Thus, the estimation of methane emission from MSW landfill is important in terms of not only prevention of climate change but also recovery of energy.

A kinetic model, first order decay model, has been widely used to predict methane emission

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from disposed waste (IPCC, 2006; U.S. EPA, 2005). One of main factors of the model is the methane generation potential of wastes. There are three approaches to the prediction of methane generation potential: two theoretical methods and one experimental method.

As theoretical methods, stoichiometric approach has been widely used for methane generation estimation, which uses elemental composition of waste components (Tchobanoglous et al., 1993). Another theoretical method is to use organic carbon content of waste components (IPCC, 2006). However, those methods cannot reflect biodegradability of wastes in anaerobic condition. Therefore, in case of theoretical methods, it is needed to consider biodegradability of wastes. For example, IPCC (2006) suggested 0.5 as the fraction of the degradable organic carbon (DOC) that can decompose under anaerobic condition (DOC_f) of wet bulk waste.

As experimental method, some researchers performed anaerobic biodegradation experiment such as biochemical methane potential (BMP) test for wastes, but those studies were carried out only on limited waste components (Owens et al., 1993; Harries et al., 2001; Jokela, 2002; SUDOKWON landfill site management corp., 1997) or on bulk waste in which all components are mixed (Jokela et al., 2002). In addition, methane generation potential of waste components can be varied by countries. In Korea, it was difficult to predict methane generation considering all components because there were little data available; BMP tests have been performed mainly for organic wastes such as food wastes and sewage sludge (Shin, 1993; Bum, 2001; Heo, 2003).

Therefore, we carried out the BMP test to estimate the methane generation potential of MSW components in Korea and their biodegradabilty. In addition, we proposed DOC_f of wet bulk waste in Korea by applying biodegradability of each waste component.

2. MATERIALS AND METHODS

2.1 Waste samples

The waste samples were obtained at the unloading place of S landfill site and classified into 9 components considering classification for physical compoisition of MSW in Korea: food wastes, paper, plastics, wood, textile, rubber, leather, misc. organics, sludge. The samples were kept in storage in the condition of 4℃ after drying in 80℃ for 3 days and shredding below 3mm, but food wastes and sludge were stored in the same place without drying. As properties of the waste components, moisture content (MC), volatile solid (VS) content, ash content, elemental composition such as carbon (C), hydrogen (H), and oxygen (O), and carbon content as total carbon (TC), inorganic carbon (IC), and organic carbon (OC) were analysed.

2.2 Measurement of ultimate methane yield (M_0^{VS}) by BMP test

The BMP test is an experimental series that examines the gas production and the waste degradation under the optimal anaerobic condition. The BMP test that Shelton and Tiedje used was adopted in this study (Shelton et al., 1984).

The BMP tests were conducted in more than triplicate in serum bottles (635mL as effective volume) with 1cm butyl rubber stoppers and screw caps. In each bottle, 300mL of medium containing nutrients and trace metals was prepared according to Shelton et al. (1984) and then 30mL of second digested sewage sludge (Total Solid (TS) : 9,269mg/L, VS : 38.7% of TS), which was obtained from J waste water treatment plant located in Seoul and then sieved by No. 200 (0.075mm), was added as a microbial seed. 2g VS of waste and 1.2g of $NaHCO_3$/L of medium was obtained by adding proper amount of each waste sample and $NaHCO_3$ powder. The mixture was adjusted to pH 7 by using 1M HCl and 1M NaOH and sealed up in serum bottles. All procedure was conducted in anaerobic condition by flushing N_2 gas. The serum bottles were incubated in 35℃.

We determined the gas production from the bottles by allowing the glass syringe plunger to move and equilibrate between the gas and atmospheric pressure. To prevent gas leakage due to excessive pressure, the difference between internal and atmospheric pressure was set less than 0.5 atm through controlling the measurement period (Owen et al., 1979). Methane concentration of gas was analyzed using gas chromatograph with thermal conductivity detector.

The cumulative methane production from each waste component itself was calculated by subtracting that from microbial seed incubated in blank bottle. In addition, it was converted to that based on dry gas at 1atm and 0℃ by subtracting saturated water vapor pressure. Ultimate methane yield (M_0^{VS}) of each MSW component was calculated by using cumulative methane production measured by BMP test and SIGMAPLOT V.8.0.

2.3 Calculation of biodegradability of each waste component

Biodegradability of each waste component was defined as percentage of ultimate methane yield (M_0^{VS}) measured by BMP test to theoretical methane production (G_0^{VS}) calculated by using data for waste properties.

The theoretical methane production (G_0^{VS}) was calculated by two methods. One is a stoichiometric method using elemental composition of waste as shown in equation (1). The a, b, c is the mole fraction of C, H, O in waste (Tchobanoglous et al., 1993).

$$C_aH_bO_C + \left(\frac{4a\text{-}b\text{-}2c}{4}\right) H_2O \rightarrow \left(\frac{4a\text{+}b\text{-}2c}{8}\right) CH_4 + \left(\frac{4a\text{-}b\text{+}2c}{8}\right) CO_2 \quad (1)$$

The other is to calculate methane production using organic carbon content of waste as shown in equation (2). OC is the ratio of OC to waste, expressed as g OC/g VS. 0.5 is the default value for volumetric ratio of methane to gas generated. 22.4/12 is a conversion factor of OC to gas at 1atm and 0℃, expressed as L CH_4/ g OC. G_0^{VS} is expressed as mL CH_4/g VS (IPCC, 2006).

$$G_0^{VS} = OC \times 0.5 \times \frac{22.4}{12} \times 1000 \quad (2)$$

2.4 Calculation of DOC_f of bulk waste

Methane generation potential of wet bulk waste ($M_0^{wet\ bulk\ waste}$) should be calculated by considering physical composition of wet bulk waste, VS content by wet weight basis and M_0^{VS} of waste components consisting in wet bulk waste.

DOC_f of wet bulk waste can be determined by calculating the ratio of $M_0^{wet\ bulk\ waste}$ to theoretical methane production of wet bulk waste ($G_0^{wet\ bulk\ waste}$). It can be used as a valuable conversion factor for estimation of methane generation from wet bulk waste.

3. RESULTS AND DISCUSSION

3.1 Properties of waste samples

Properties of 9 waste components are shown in Table 1. Moisture, VS, and ash content were in the range of 5-78%, 12-94%, and 1-29% by wet weight basis, respectively. C and OC content

Table 1. Chemical properties of MSW components

Component	MC	VS	Ash	Elemental composition (%, dry)			Carbon content (%, dry)			CV[1] (%)
	(%, wet)			C	H	O	TC	IC	OC	
Food wastes	59.9	27.9	12.2	38.1	5.5	23.0	42.9	0.3	42.6	8.0
Paper	4.8	83.9	11.3	38.7	5.5	43.9	42.6	0.1	42.5	6.6
Plastics	8.4	88.2	3.4	79.4	13.5	3.3	74.5	0.1	74.4	4.6
Wood	43.5	54.5	2.0	47.5	6.2	42.3	51.7	0.1	51.6	5.8
Textile	5.9	93.5	0.6	52.9	5.6	40.5	48.4	0.1	48.3	6.5
Rubber	7.0	75.9	17.1	68.1	7.8	5.3	71.1	0.1	71.0	2.9
Leather	8.0	82.5	9.5	52.2	6.0	28.6	54.6	0.1	54.5	3.1
Misc. organics	34.1	37.0	28.9	27.6	3.9	24.0	30.9	0.1	30.8	7.7
Sludge	77.6	12.4	10.0	26.1	4.3	20.1	28.1	0.1	28.0	5.0

1) Coefficient of variation (standard deviation / meanx 100) between C and OC content

showed the range of 26-79% and 28-74% by dry weight basis, respectively. IC content was very low enough to neglect it. In addition, C and OC content of most waste components were considered almost the same from the fact that the coefficient of variation (CV) between C and OC content was low (3-8% by waste components).

3.2 Theoretical methane production (G_0^{VS}), ultimate methane yield (M_0^{VS}), and biodegradability of MSW components

Theoretical methane production (G_0^{VS}) by using two methods and ultimate methane yield (M_0^{VS}) by BMP test for 9 waste components are shown in Table 2.

Table 2. Theoretical methane production and ultimate methane yield of MSW components

(Unit: mL CH_4/g VS)

Component	Theoretical methane production (G_0^{VS})			Ultimate methane yield (M_0^{VS})	
	By stoichiometric approach	By using organic carbon content	CV[1] (%)	This study[2]	Reference[3]
Food wastes	615.3	571.5	5.2	419.9±30.0 (5)	315-356
Paper	409.6	450.1	6.7	284.9±57.5 (6)	223-272
Plastics	1,149.0	721.2	32.4	75.5±34.1 (5)	82
Wood	485.8	499.3	1.9	213.1±29.9 (5)	127-166
Textile	511.3	453.7	8.4	230.8±14.5 (3)	262
Rubber	1,024.4	812.0	16.4	47.5±15.6 (5)	n.a.
Leather	618.3	567.2	6.1	150.1±35.5 (7)	n.a.
Misc. organics	504.9	512.0	1.0	295.4±24.9 (5)	n.a.
Sludge	529.1	472.1	8.1	153.8±66.1 (7)	n.a.

n.a. : no data available

1) Coefficient of variation (standard deviation / meanx 100) between G_0^{VS} calculated by two methods

2) BMP test results, mean value ± standard deviation (number of samples)

3) SUDOKWON landfill site management corp., 1997; Bum, 2001; Shin et al., 1993

G_0^{VS} of 9 waste components by stoichiometric approach were in the range of 410 (paper) -1,149 (plastics) mL CH_4/g VS; those by using OC content were in the range of 450 (paper) – 721 (plastics) mL CH_4/g VS. CV of G_0^{VS} between two calculation methods fore each component was estimated. CV for food wastes, paper, wood, textile, leather, misc. organics, and sludge were evaluated to be low less than 10%. However, those for plastics and rubber were high. This is considered to result from overestimation by stoichiometric approach due to their elemental composition. While the mole fractions of C and H were high, that of O was low for plastics and rubber unlike other components.

The range of M_0^{VS} values of 9 waste components was 48 (rubber) – 420 (food wastes) mL CH_4/g VS. M_0^{VS} values of some waste components were similar, compared to those reported in the literature. The order of high value for M_0^{VS} is as follows: food wastes > misc. organics > paper > textile > wood > sludge > leather > plastics > rubber.

On the other hand, ultimate methane yields based on wet weight of waste components (M_0^{wet}), were in the range of 19 (sludge) – 239 (paper) mL CH_4/g wet waste (Table 3). The order of high value for M_0^{wet} was considered to be different from that for M_0^{VS} due to moisture content of each waste component. The moisture content of waste varies with the weather condition during collection. Therefore, it is recommended to calculate $M_0^{wet\ bulk\ waste}$ by using not M_0^{wet} but M_0^{VS} and moisture content of each waste component.

Table 3 shows the ultimate methane yield by wet weight basis (M_0^{wet}) and biodegradability based on two G_0^{VS} calculation methods for each waste component.

Biodegradability of each waste component was in the range of 5-70% and 6-74% based on two G_0^{VS} calculation methods: by using stoichiometric approach and organic carbon content, respectively. Food wastes and paper represented the highest biodegradability with the value around 70%. Misc. organics, textile, and wood showed moderate biodegradability with the value around 50%. Biodegradability of sludge and leather was low with the value around 25-30%. Plastics and rubber showed almost no biodegradability with the value less than 10%.

Table 3. M_0^{wet} and biodegradability of MSW components

Component	M_0^{wet} (mL CH_4/g wet waste)	Biodegradability(%)1)		
		This study		Reference2)
		Based on G_0^{VS} by stoichiometric approach	Based on G_0^{VS} by organic carbon content	
Food wastes	117.1±8.4	68.2	73.5	66.5-70.9
Paper	239.1±48.4	69.6	63.3	67.4
Plastics	66.6±30.3	6.6	10.5	n.a.
Wood	116.0±16.3	43.9	42.7	35.3
Textile	215.8±13.5	45.1	50.7	60.5
Rubber	36.0±11.8	4.6	5.9	n.a.
Leather	123.8±29.3	24.3	26.5	n.a.
Misc. organics	109.3±9.2	58.5	57.7	n.a.
Sludge	19.1±8.2	29.1	32.6	29.3

n.a. : no data available

1) Biodegradability (%) = ultimate methane yield (M_0^{VS}) ÷ theoretical methane production (G_0^{VS})× 100

2) SUDOKWON landfill site management corp., 1997; Shin et al., 1993; Heo et al., 2003

The low M_0^{VS}, M_0^{wet} and biodegradability of plastics and rubber, which are known to be nonbiodegradable, are considered to result not from the component itself but from the biodegradable organic matter which comes from other components during discharge, collection, and transport of bulk waste.

The ultimate methane yield (M_0^{VS}) and biodegradability of each waste component can be used as fundamental data that are required for the estimation of gas production from wet bulk waste considering the properties of each waste component in Korea.

3.3 Calculation of methane generation potential ($M_0^{wet\ bulk\ waste}$) and DOC_f of wet bulk waste

S landfill, the largest landfill in Korea, was selected to calculate $M_0^{wet\ bulk\ waste}$ and DOC_f of wet bulk waste.

Table 4 shows physical composition and methane generation potential of wet bulk waste disposed in S landfill. The fraction of food wastes and sludge were on the decrease with the change of waste management policies in Korea. On the other hand, the fraction of inorganics was on the increase with the increase of construction waste. In addition, that of misc. organics was on the increase.

For the annually disposed wet bulk waste, $M_0^{wet\ bulk\ waste}$ was estimated to be in the range of 37-88m^3 CH_4/Mg wet waste by considering waste components except for plastics and rubber/leather. It was considered to be lower than those proposed by EPA (U.S. EPA, 2005).

Table 5 shows DOC_f of wet bulk waste disposed in S landifll.

DOC_f was calculated from the two points of view. One is to consider the calculation methods for theoretical methane production of wet bulk waste ($G_0^{wet\ bulk\ waste}$): by stoichiometric approach and by using organic carbon content. The other is to consider the classification method of waste components as biologically degradable components; three cases were applied in calculation of $M_0^{wet\ bulk\ waste}$ and $G_0^{wet\ bulk\ waste}$: considering all components, except for plastics, and except for plastics & rubber/leather.

Table 4. Physical composition and $M_0^{wet\ bulk\ waste}$ of wastes disposed in S landfill

Site	Year	Physical composition (%, wet)								$M_0^{wet\ bulk\ waste}$ (m^3 CH_4/Mg wet waste)
		Food wastes	Paper	Wood	Rubber & leather	Plastics	Sludge	Misc. organics	In-organics	
Site 1	1992	24.78	14.46	5.41	2.18	4.98	9.73	1.02	37.44	73
	1993	25.53	17.61	4.92	3.95	5.38	6.17	8.70	27.74	88
	1994	23.78	7.29	2.88	2.92	4.27	5.55	5.89	47.43	56
	1995	29.24	7.20	2.57	3.13	3.58	7.67	8.07	38.53	65
	1996	26.90	13.29	5.03	2.54	6.00	10.31	8.85	27.08	81
	1997	24.68	13.26	5.95	2.34	6.13	11.36	9.57	26.71	80
	1998	23.75	13.97	6.05	2.50	6.25	11.81	11.24	24.42	83
	1999	18.83	14.55	7.25	2.26	6.65	6.98	13.82	29.65	82
	2000	13.18	11.76	5.64	2.55	6.30	3.27	15.97	41.33	68
Site 2	2000	10.62	9.99	5.50	2.10	4.97	4.31	13.25	49.26	58
	2001	6.64	8.40	4.79	1.51	4.75	2.40	12.28	59.22	47
	2002	5.23	5.67	3.22	1.54	4.11	1.78	11.84	66.60	37
	2003	4.66	6.46	3.13	5.76	13.27	1.70	14.93	50.10	41
	2004	2.88	8.71	4.12	1.74	5.29	1.39	14.13	62.34	44

Table 5. DOC_f calculated by various methods

Site	Year	Based on $G_0^{\text{wet bulk waste}}$ by stoichiometric approach			Based on $G_0^{\text{wet bulk waste}}$ by using organic carbon content		
		All components	Except for plastics	Except for plastics & rubber/leather	All components	Except for plastics	Except for plastics & rubber/leather
Site 1	1992	0.42	0.56	0.61	0.49	0.58	0.63
	1993	0.42	0.54	0.61	0.48	0.56	0.63
	1994	0.39	0.51	0.58	0.47	0.56	0.64
	1995	0.41	0.51	0.57	0.50	0.57	0.64
	1996	0.40	0.54	0.59	0.48	0.58	0.62
	1997	0.40	0.54	0.58	0.47	0.57	0.62
	1998	0.40	0.54	0.58	0.47	0.57	0.61
	1999	0.39	0.54	0.58	0.46	0.57	0.61
	2000	0.37	0.52	0.58	0.45	0.55	0.60
Site 2	2000	0.38	0.52	0.57	0.45	0.55	0.60
	2001	0.36	0.53	0.57	0.44	0.55	0.59
	2002	0.34	0.50	0.56	0.42	0.54	0.59
	2003	0.22	0.42	0.55	0.29	0.45	0.59
	2004	0.34	0.52	0.57	0.41	0.54	0.58
Average		0.38	0.52	0.58	0.45	0.55	0.61
Coefficient of variation (%)		14	7	3	11	6	3

When stoichiometric approach applied, CV of DOC_f for wet bulk waste was calculated as 14%, 7%, 3% for the case of considering all components, except for plastics, and except for plastics & rubber/leather, respectively; when organic carbon content was used, 11%, 6%, 3%, respectively. In case of except for plastics & rubber/leather, the CV was the lowest, which was considered to reflect the realistic DOC_f of wet bulk waste. In addition, DOC_f calculated by two $G_0^{\text{wet bulk waste}}$ calculation methods showed similar value in case of except for plastics & rubber/leather. Therefore, it was recommended to exclude plastics & rubber/leather for calcultation of DOC_f of wet bulk waste. This is the same approach that IPCC adopted for estimation of methane generation (IPCC, 2006). In addition, it was considered that 0.6 is the proper DOC_f of wet bulk waste in Korea. It is higher than 0.5, the default value of DOC_f suggested in 2006 IPCC guidelines (IPCC, 2006).

4. CONCLUSIONS

As important parameters for estimation of methane generation from landfills, we analyzed properties and ultimate methane yields of various waste components. In addition, biodegradability of each waste component was calculated. The results obtained in this study could be used as fundamental data for estimating methane generation potential of wet bulk waste in landfills. It was also possible to calculate the fraction of the degradable organic carbon that can decompose under anaerobic condition (DOC_f) of wet bulk waste by using the data measured for various waste components.

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