CH_4 emission and recovery from Municipal Solid Waste in China*

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Abstract: Methane (CH_4) is an important greenhouse gas and a major environmental pollutant, second only to carbon dioxide (CO_2) in its contribution to potential global warming. In many cases, methane emission from landfills otherwise emitted to the atmosphere can be removed and utilized, or significantly reduced in quantity by using cost-effective management methods. The gas can also be used as a residential, commercial, or industrial fuel. Therefore, emission reduction strategies have the potential to become low cost, or even profitable. The annual growth rate of Municipal Solid Waste (MSW) output in China is 6.24%, with the highest levels found in South China, Southwest China and East China. Cities and towns are developing quickly in these regions. MSW output was only 76.36 Mt in 1991 and increased to 109.82 Mt in 1997, registering an average increase of 43.8%. In China, methane emission from landfills also increased from 5.88 Mt in 1991 to 8.46 Mt in 1997; so the recovery of methane from landfills is a profitable project.

Key words: Methane, Municipal Solid Waste(MSW), Recovery
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INTRODUCTION

After the deposition of Municipal Solid Waste (MSW), the biodegradable organic fraction undergoes a series of chemical and biochemical degradation. Based on the analysis of the emitted gases, five distinct phases of the landfill anaerobic degradation process, (i.e., initial adjustment, transition, acid formation, methane fermentation and final maturation) can be identified. In the 4th phase, methane content and production rate are the highest, and the produced methane is generally used as a source of energy (Sandeep *et al.*, 1999; Lovely *et al.*, 1982; 1986). In the world, landfill emitted an estimated 30 – 80 Mt of methane in 1990 (El-Fadel *et al.*, 1996; Manley *et al.*, 1993). Methane from landfills emitted accounting for 37% of total methane emission in the U.S.A., is about 11.6 Mt per year (USEPA, 1999).

Methane (CH_4) an important greenhouse gas and a major environmental pollutant, is also the primary component of natural gas that can be a valuable energy source. Methane emission reduction strategies offer one of the most effective means of mitigating global warming in the near term for the following reasons.

Environment Methane (CH_4) is one of the principal greenhouse gases, second only to carbon dioxide (CO_2) in its contribution to potential global warming. In fact, methane is responsible for roughly 18 percent of the total contribution in 1990 by all greenhouse gases. On a kilogram-to-kilogram basis, methane is a more potent greenhouse gas than CO_2 (about 24.5 times greater over a 100-year time frame). Methane has a shorter atmospheric lifetime than other greenhouse gases-methane lasts around 11 years in the atmosphere, whereas CO_2 lasts about 120 years (IPCC 1992). Due to methane's high potency and short atmospheric lifetime, stabilization of methane emissions will have an immediate impact on mitigating potential climate change (IPCC, 1995).

Energy and economics In many cases, methane that would otherwise be emitted to the atmosphere can be removed and utilized or significantly reduced in quantity by using

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cost-effective management methods. Methane can be used to meet the energy requirement for landfills and sewage and nearby areas. The gas can also be used as a residential, commercial, or industrial fuel. Therefore, emission reduction strategies have the potential to become low cost, or even profitable. For example, methane recovered from landfills and sewage can be used as an energy source. Biogas from landfills has been used for several decades in most industrial countries. Using biogas from biogas plant is an efficient technology; a well demonstrated cost - effective method of disposing organic waste, and producing electricity, fuels and fertilizers without releasing greenhouse gases into the atmosphere. A large quantity of organic waste can be almost completely converted into energy (for electricity production, heating, or truck and automobile fuel) and organic fertilizer by using biogas technology.

Safety At gaseous concentrations of 5 to 15 percent, methane is explosive. Thus the buildup of methane in landfills and sewage poses a serious safety hazard. Increased use of degasification systems may improve safety by lowering the methane level. Techniques for recovering methane form landfills and sewage can significantly reduce the amount of methane.

POTENTIAL GAS PRODUCTION

Several studies yielded models to describe methane production from landfills according to Darcy's law (Young, 1989), by physical characteristics, such as climate, refuse mass and age, substrate utilization and bio-kinetic characteristics (Peer *et al.*, 1992). In this paper, two main models of methane generation from landfills are analyzed.

Method 1: Rough approximation

According to IPCC Guidelines, the formula for calculating GHG emission from solid waste landfills is as follows (Xu *et al.*, 1999; IPCC, 1995):

$$E_{CH_4} = MSW \times \eta \times DOC \times r \times (16/12) \times 0.5$$

Where

E_{CH_4} is methane emission from land fills;

MSW is urban waste quantity, determined from statistical references;

η is percentage of urban waste actually landfilled; in this paper MSW equals the quantity of urban waste sent to landfills, so $\eta = 100\%$;

DOC is the content of degradable organic carbon in the waste, recommended to be 15% by IPCC;

r is the percentage of actually decomposed DOC in the waste, recommended to be 77% by IPCC.

According to the above formula and factors, methane emission from landfills can be calculated to be about 77kg CH_4/t MSW for China in 1990 – 1995.

Method 2: Rough approximation

Although test wells provide real data on on-site gas production rate at a particular time point, models also evaluate the gas production during the site filling period and after its closure. These models typically require the time period of landfilling, and the local amount and types of waste as the minimum data. The main model for emission estimation is the "First Order Decay Model" (Gradner *et al.*, 1993).

The basic first order decay model is as follows:

$$P = C_d X \sum_i F_i (1 - e^{-K_i t})$$

Where:

P = Total amount of landfill gas generated so far (t CH_4/t MSW);

C_d = Content of degradable organic carbon in the waste, recommended to be 15% by IPCC;

F_i = Content of different organic carbon in the waste;

K_i = Decay constant for the rate of methane generation (1/year);

t = Time since landfilling (years).

The "First Order Decay Model" describes varying gas generation rates over the lifetime of the landfill. The model, therefore, takes into account various factors, which influence the rate and extent of gas generation. The model requires that the above variables be known or estimated.

From the waste content in Hangzhou in 1995, we figured out the following composition of the MSW (see table 1).

Table 1　Composition of MSW in Hangzhou in 1995

Class	Half life (a)	Decay constant, K_i(1/year)	Content, F_i%
Easily degradable organic carbon	1	0.693	11.39
Degradable organic carbon	5	0.139	84.36
Hardly degradable organic carbon	15	0.046	4.25

The above formula and factors were used to calculate the accumulative total methane emission from landfills and plotted in Fig.1 and Fig.2.

Fig.1 shows that the emissions of CH_4 account for 95% of the total emission during the first 15 years; and that 15 years after landfilling, the emission rate becomes very low. In Fig.2, it is evident that the accumulative total methane emission from landfills is about 76kg/t in year 15, which is close to the result calculated by Method 1 (77kg CH_4/ t MSW); and that after year 15, the accumulative total methane emission does not change much.

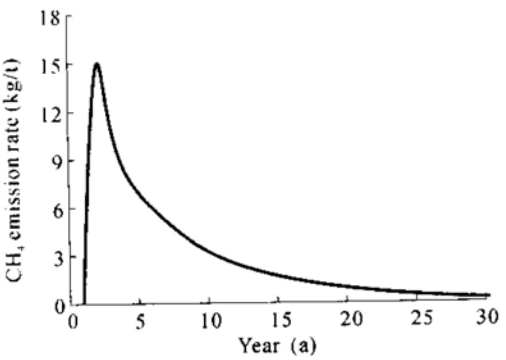

Fig.1　The emission rate of CH_4 from landfill

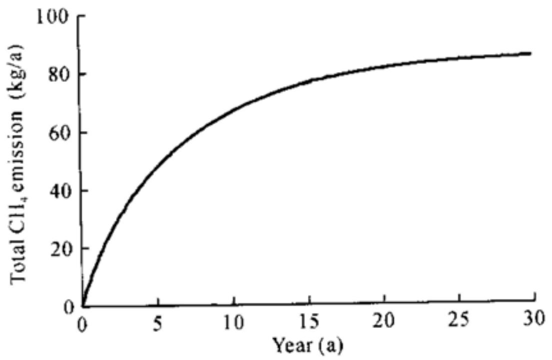

Fig.2　The accumulative output of methane in the landfill

CALCULATION OF CH_4 EMISSIONS IN CHINA

CH_4 emissions from MSW in different parts of China

According to the methods described in Chapter 2, an inventory of CH_4 emissions from MSW in China in 1991 and 1997 can be calculated by using IPCC Guidelines (1995). These results are shown in Table 2, Fig.3 and Fig.4.

Table 2　CH_4 emissions from MSW in China

Regions	*MSW*(Mt) 1991	*MSW*(Mt) 1997	CH_4 emission(Mt) 1991	CH_4 emission(Mt) 1997	Annual increase rate
North China	34.83	38.91	2.68	3.00	1.86%
Northeast China	21.17	24.16	1.63	1.86	2.22%
East China	16.32	25.54	1.26	1.97	7.75%
South China	13.80	25.62	1.06	1.97	10.86%
Southwest China	4.60	7.74	0.35	0.60	9.06%
Northwest China	5.55	7.83	0.43	0.60	5.90%
China	76.36	109.82	5.88	8.46	6.24%

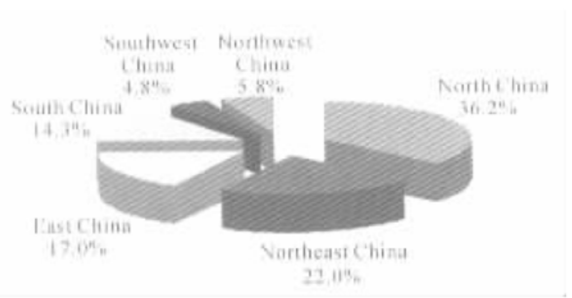

Fig.3　MSW output in different regions of China in 1991, Mt

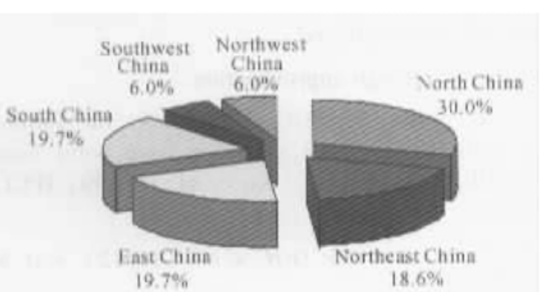

Fig.4　MSW output in different regions of China in 1997, Mt

Table 2 shows that the national annual increase rate of MSW output was 6.24%; and that the rates were in the orders South China > Southwest China > East China > Northwest China > Northeast China > North China. Cities and towns were developing quickly in these areas. The MSW output of only 76.36 Mt in 1991 increased to 109.82 Mt in 1997. The national increase rate of MSW output was 43.8% from 1991 to 1997, but in South China, the output of MSW increased by 85.7% during the same time.

CH_4 emissions from MSW in the 46 largest cities in China

The annual increase rate of MSW output was very high (> 10%) in China, especially due to the fast development of small cities and towns in the 1990s'. The average MSW output per person of the major cities in China in 1996 is listed in Table 3.

There are 46 major cities in China, including provincial capitals and other cities economically important and densely populated. Comprehensive statistics on the social and economic development of these cities are published by the National Statistics Bureau every year, which also include the residential disposal of MSW. The MSW output and CH_4 emission data are shown in Table 4.

Table 3 MSW output rates of main cities in China in 1996 (kg/d·person)

City	MSW
Beijing	1.20
Tianjin	0.99
Shanghai	1.23
Shenyang	1.00
Dalian	1.03
Hangzhou	0.92
Shenzhen	2.62
Guangzhou	1.20

Table 4 Annual change of MSW output and CH_4 emission for the 46 most important cities (kt/a)

City	MSW output (kt/a)					CH_4 emission from MSW (kt/a)				
	1991	1992	1993	1994	1995	1991	1992	1993	1994	1995
Beijing	3630	3960	4100	4250	4400	280	305	316	327	339
Tianjin	2230	2300	2030	2090	1800	172	177	156	161	139
Shijiazhuang	400	420	430	450	510	31	32	33	35	39
Qinhuangdao	310	320	280	290	330	24	25	22	22	25
Taiyuan	960	930	930	940	670	74	72	72	72	52
Hohhot	440	420	450	450	450	34	32	35	35	35
Shenyang	2090	1970	2030	2080	2330	161	152	156	160	179
Dalian	710	710	670	740	770	55	55	52	57	59
Changchun	1190	1030	1040	1060	1070	92	79	80	82	82
Harbin	1640	1610	1800	2040	2060	126	124	139	157	159
Shanghai	2960	3010	3340	3580	3720	228	232	257	276	286
Nanjing	660	700	710	750	770	51	54	55	58	59
Lianyungang	150	140	140	160	180	12	11	11	12	14
Nantong	90	90	100	110	100	7	7	8	8	8
Hangzhou	480	510	540	630	650	37	39	42	49	50
Ningbo	240	270	300	230	250	18	21	23	18	19
Wenzhou	250	410	450	470	480	19	32	35	36	37
Hefei	190	210	220	220	220	15	16	17	17	17
Fuzhou	280	270	380	440	440	22	21	29	34	34

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City	MSW output (kt/a)					CH_4 emission from MSW (kt/a)				
	1991	1992	1993	1994	1995	1991	1992	1993	1994	1995
Xiamen	240	250	210	230	240	18	19	16	18	18
Nanchang	210	240	320	440	460	16	18	25	34	35
Jinan	520	550	540	550	560	40	42	42	42	43
Qingdao	540	540	580	580	680	42	42	45	45	52
Yantai	160	140	170	180	830	12	11	13	14	64
Weihai	50	60	120	80	90	4	5	9	6	7
Zhengzhou	720	510	600	560	580	55	39	46	43	45
Wuhan	1330	720	1550	1650	1660	102	55	119	127	128
Changsha	380	420	500	550	630	29	32	39	42	49
Guangzhou	1250	1250	1550	1990	1550	96	96	119	153	119
Zhanjiang	200	230	240	300	300	15	18	18	23	23
Shenzhen	510	690	700	700	480	39	53	54	54	37
Zhuhai	120	130	170	170	290	9	10	13	13	22
Shantou	260	270	280	300	310	20	21	22	23	24
Nanning	180	200	220	260	290	14	15	17	20	22
Beihai	60	70	100	190	280	5	5	8	15	22
Haikou	170	170	220	300	250	13	13	17	23	19
Chengdu	750	870	980	980	880	58	67	75	75	68
Chongqing	530	1000	800	1040	950	41	77	62	80	73
Guiyang	500	620	630	550	450	39	48	49	42	35
Kunming	440	450	350	400	420	34	35	27	31	32
Lhasa	20	20	30	50	60	2	2	2	4	5
Xian	670	650	660	670	700	52	50	51	52	54
Lanzhou	790	500	790	500	550	61	39	61	39	42
Xining	300	360	340	360	1030	23	28	26	28	79
Yinchuan	230	220	220	220	170	18	17	17	17	13
Urumqi	750	590	600	650	820	58	45	46	50	63
Total	30780	31000	33410	35430	36710	2370	2387	2573	2728	2827

Table 3 and Table 4 show that the annual increase rate of MSW output was 4.50% for the 46 most important cities, but was 6.24% nationwide. The rapid development of small cities and towns in the 1990s' in China contributed to the rapid growth of MSW output in the last few years, which had exceeded 10%.

RESULTS

CH_4 use for energy Methane recovered from landfills can be used in various applications. In general, any equipment using natural gas as fuel can be operated using landfill methane. Additionally, landfill methane can substitute for oil and coal in many applications. The preferred methane use option at each landfill will depend on a variety of factors including the quantity and quality of the methane recovered and local energy needs. First, the main use options are described. Then, a process for selecting which options to consider in the preliminary assessment is presented.

The most attractive emission reduction projects are those in which the energy in recovered gas can be utilized or sold. There are three primary approaches to using the gas recovered: (1) direct use of the gas locally (on-site or in close proximity), (2) generation of electricity, steam or hot water (by cogeneration technology) and distribution through the power grid, and (3) injection into a gas distribution grid.

It is recommended that the estimated gas production be compared to on-site gas need on an energy basis. The energy content of the gas is estimated from its methane content. Pure methane has a heating value of approximately 37 million Joules per cubic meter (MJ/m^3) at standard temperature and pressure. Gas that is 50 percent methane from landfill will have a heating value of 50% percent that amount, or about 18.5 MJ/m^3.

If on-site gas use is not feasible, or if the amount of gas produced greatly exceeds on-site needs, electricity production may be an attractive option. Compare the on-site electricity requirements to the amount of electricity that can be generated from the gas expected to be produced. The generator heat rate varies somewhat among generation technologies, but can be assumed to be about 11.6 MJ/KWh (Aviel, 1996), which is appropriate for combustion turbines. Using these values , an example calculation of potential electricity production is as follows. Assume that 100 000 m^3/day of landfill gas produced is 50% methane. The heating value of the gas is 18.5 MJ/m^3. The total electricity that can be produced is therefore: 159 483 KWh/day. The generator capacity is this value divided by 24 hours, or about 6 650 KW, or 6.65 MW.

There is a good example of a profitable project involving electricity production and sale in Hangzhou, Zhejiang Province. However, many more landfills can implement economically viable CH_4 recovery and utilization projects. The CH_4 recovery project has just taken off in China. In some cases, national or local policies hinder these projects from being undertaken. Relevant policies should be evaluated to assess if they encourage or discourage methane recovery and utilization projects. Important issues to be discussed include energy production and pricing, environmental policies, financial issues, and technology transfer policies.

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