The Methane Emissions from Municipal Solid Waste And Its Further Study in China

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ABSTRACT

In this paper, a brief review about the previous works on the methane emissions inventories from Municipal Solid Waste（MSW）in China was presented. It was concluded from the review that some problems should be carefully studied. The Chinese real data of population and solid waste production as well as other data collected from other Chinese researchers were analyzed. China was divided into three regions based on municipal solid waste generation rate and disposal rate in the cities. MSW composition in several sampling regions was determined and from that data, the DOC content of China’s waste was calculated. The Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: workbook was followed to calculate the methane emissions from MSW in 1990 and 1996 in China. The calculated results were compared with the real municipal solid waste production from Chinese cities and it was found that the results from three regions is much better and more accurate than the calculations using a uniform MSW generation rate and disposal rate.

Key words: Greenhouse Gas (GHGs), Inventory, Methane emission, Municipal Solid Waste

1. Introduction

Methane (CH_4) is a very strong greenhouse gas (GHGs), of which a large proportion is emitted from solid waste landfill or open dumps, and wastewater handling systems. Estimates of global methane emissions from solid waste disposal sites (SWDSs) range from less than 20 to 70 Tg/yr (Bingemer and Crutzen, 1987, US EPA, 1996), or about 5 to 20 per cent of total estimated emissions of 375 Tg/yr (IPCC, 1996) from anthropogenic sources globally. Methane, as a strong greenhouse gas, can influence the global climate and enhance the greenhouse gas effects on climate system and other ecosystems. Scientists of all over world paid more attention to the study of the methane emissions from various sources. The methane emission inventory is one of main parts of Greenhouse Gas Inventory for each member country of UNFCCC. It has caught extreme attention from the government and policy makers.

With the gradual improvement of peoples' living condition, the trend of output of waste (especially the waste from municipal waste) is obviously rising in recent years. This phenomenon is more obvious in developing countries. The annual output of global municipal solid waste has exceeded 450Mt; the average annual rising rate is 8.42%. The annual MSW output of China has reached 1 Mt. The annual output of municipal solid waste in China is 440kg/per capita, the daily production per person reaches 0.89kg, and the annual increase rate ranges from 8 to 10% (Yu, 1997). At same time, the components of solid waste have become more and more complex due to the use of macromolecule materials, plastic materials and others. So the damages from municipal solid waste, especially to atmosphere and groundwater, become more and more serious in the world. The methane emitted from municipal solid waste has become increasingly important to GHGs inventory. Although the production of garbage increases ceaselessly, the methods of disposal of garbage is very limited.

So far, the major methods that deal with municipal solid waste are open dumps, landfills and combustion as well as recycling. These methods could resolve some part of pollution induced by municipal solid waste, but other problems, such as methane emission from MSWDs, is one of major tasks that have to be dealt with. In fact, in order to maintain sustainable development and reduce methane emissions from municipal solid waste, each country today is trying to study and exploit new methods to reuse the municipal solid waste and change it to be a kind of recycling resource. There are a lot of typical examples in the world. For example, a 10 meter high cenotaph was erected in Italy using empty bottles and can boxes that were thrown away by tourists at the beach.

The concept of Close Substance Cycle was put forward in 1990's to control successfully the rising trend of municipal solid waste. In Germany, *The Regulation of Waste Management* was promulgated in 1972. According to the law, the priority order of waste management is avoidance, recycling, and disposal. Avoiding production of solid waste should be put in the priority position during production and consumption in every sector. In 1993, the solid waste output in Germany was 337Mt, a 10% reduction of solid output compared with solid waste output in 1990. During this period, the rate of recycling of municipal solid waste increased from 20% to 25%.

In developing countries, a large proportion of waste is municipal solid waste composed mainly of abandoned foods. However, in developed countries, the main components of municipal solid waste are paper goods that contain more carbon (more than 40% in mass) than that of foods (only 15% in mass). Paper and paper goods can release methane into atmosphere. Developed countries use incinerator to manage municipal solid waste in order to reduce the methane emissions, but in the developing country, open dumps and landfills are the commonly used methods to manage municipal solid waste. Nowadays, recycling of municipal solid waste and converting them to be resources is the way to develop for the future.

2. Research situation and development trend of CH4 emission from MSW in China

Methane emissions from solid waste landfills and open dumps are an indispensable part of greenhouse gases inventory and have been paid high attention by Chinese government and scientists. A large amount of funds have been put into this research field and a lot of scientists of China have undertaken the research. At the same time, there are many co-operations between China and international relevant organizations and groups. The results from former researches have taken very important role in the understanding methane emission from municipal solid waste in China. But due to the lack of the data and organized research on methane emitted from wastewater handling system, most of previous researches have not dealt with it. Methane emitted from municipal solid waste and wastewater-handling system is also major part of GHGs inventory. The main research results of methane inventory of China from different projects and author are listed below.

2.1 The problems and choices of Chinese greenhouse gases control: the sources and sinks of Chinese greenhouse gases in 1990

World Bank and Global Environment Foundation fund this project. State Environment Protection Administration (SEPA) took charge it. The base year was 1990 and it was submitted on February of 1995. This project was completed by the Design Institute of Environmental project of Tingshua University.

The methodology used in estimating methane emission from municipal solid waste landfills was the one recommended by OECD/IPCC (1994). In this calculation, recycling and utilizing of methane are out of consideration and the MSW landfill disposal rate is assumed to be 80%, which is recommended by IPCC for developing countries. The Emission Coefficients of methane were selected from the IPCC recommendation. The amounts of emission from municipal solid waste from 1985 to 1990 are listed in Table 1. It should be noted that the urban population listed in Table 1 is the total urban population, which include non-agricultural population. Actually only the MSW from those non-agricultural people in urban are disposed to municipal solid waste disposal system.

The methane generation rate is different in different regions. In developed cities or big cities, the municipal solid waste may be higher than that of developing regions or medium-small scale cities. The components of solid waste are complex and change distinctly in different regions of China. The result of this work gives approximately a brief introduction of Chinese municipal solid waste emissions.

The urban population presented in Table 1 includes the agricultural population. In China, the agricultural population in urban areas produces less methane emissions, so the results shown in Table 1 do not represent the real situation of China. It should be restudied further in the future.

Table 1. Methane inventory of MSW from 1985 to 1990.

Year	Urban Population (10^4 persons)	Generation Amount of MSW (10^4t)	Methane Emission Amount (Tg Ch4)
1985	25,049	457,966	0.659
1986	26,366	481,180	0.692
1987	26,674	505,051	0.725
1988	28,661	523,063	0.752
1989	29,540	539,105	0.775
1990	30,191	550,986	0.792

2.2 National Research on Chinese Climatic Change

In this project the efforts were made to incorporate China's real situation to improve the methodologies presented in the "1995 IPCC Guideline for National GHGs Inventory". For example, this research has considered the activity level of the emission sources. In addition, they improved the precision of GHGs emission factors by using existing statistical and monitored data in China. In the IPCC Guidelines, the default value of waste production is 1 kg/day/person in developed countries and 0.5 kg/day/person in developing countries with corresponding methane emissions of 86 kg/t and 21.5 kg/t, respectively. These differences between these two figures arise from variation in waste handling systems, waste constituents, climatic and ambient conditions, etc. But based on a detail study covering 46 cities in China (Yu, 1997), the integrated emission factor suited for Chinese real situation, is 32kg of CH_4 for every 1 ton of waste. The gross landfill municipal solid waste in China was 31.58 Mt, a value, which is significantly different from the results by using IPCC's default factor mentioned above. Results of this project show that methane emissions from solid waste in 1990 were 2.43 Mt (2.3 Mt~2.7 Mt), accounting for 7.62% of total methane anthropogenic emissions.

2.3 China's National Response Strategy for Global Climate Change

In this study, the method used for methane emission from waste landfills was the 1991 IPCC/OECD recommended method. The results show that in 1990 the total emission from municipal solid waste and wastewater in China was about 1.3 Mt on the average (0.6 Mt~2 Mt). The shortcomings of this study are similar to that of the World Bank Study mentioned above.

2.4 Research on Greenhouse Gas Emission and Countermeasure in Beijing (Co-operated with Canada).

This study also used the IPCC method to estimate methane emissions in Beijing in 1991. The methane emission coefficient in Beijing is 77.00 kg/t for landfills and 38.50 kg/t for waste dump respectively. In the IPCC methods, a default value of 3.5% of

DOC in China was given (IPCC, 1991), but it is only a coarse estimate value. In fact the DOC value varies greatly in different areas. For example, in this research it showed that the DOC value in Beijing should be as large as 15%. So, much effort should be made in order to give more reasonable DOC values in the different regions in the future research.

In this project, the output of municipal solid waste is about 3.97 million tones, and the methane emission is about 152.8 kt, which accounts for 46% of total anthropogenic methane emission in Beijing.

2.5. The Uncertainty Analysis of previous work

Comparing the results from above summarization, there are very huge uncertainties in calculating the inventory in China. The uncertainties of these projects are briefly presented in Table 2. The maximum value of methane emission from MSW is 2.7 Mt, but the minimum value is only 0.7 Mt (Table 2). These uncertainties are mainly due to the different emission factors used in the calculations. In the ADB and WB projects, the emission factors used in calculations were the ones recommended by IPCC, but in USDOE project, a uniform emission coefficient was used to calculate methane emissions from MSW. In fact, although this uniform emission coefficient was based on China's actual condition, a uniform emission coefficient cannot represent the real situation of China and it can also produce some uncertainties in the calculations. Moreover, methane emissions from wastewater handling system were not included in most projects that have been done. This cannot be ignored in National GHG Inventory, because the methane emissions from wastewater handling system accounts for a very important portion in total methane emissions.

Table 2. The uncertainties in the three projects.

Project	The Problems and Choices of Chinese GHGs Control	National Research on Chinese Climatic Change	China's national Response Strategy for Global Climate Change
Foundation	GEF/WB	US Department of Energy	ADB
Base year	1990	1990	1990
Recommended value (Mt CH_4)	0.792	2.5(2.3 to 2.7)	1.3(0.6 to 2.0)
Uncertainty (Mt CH_4)		0.6 to 2.7	

The causes of these large uncertainties mainly come from the following factors:

1. Based on different output data of municipal solid waste collected in each project
2. Different waste disposal rates were used
3. Different methane generation rates in waste handling system

4. Other parameters used in each project

According to the IPCC Guidelines for National Greenhouse Gas Inventory, if the value for each factor has an uncertainty of ±10 per cent, then the overall uncertainty in methane emissions will be about ±20 per cent. From the analysis above, we found that the fraction of MSW being disposed to solid waste disposal sites varies greatly from the low level of 0.4 to high level of 0.8. So the uncertainty in methane emission may be more than 100 per cent. Thus, it is necessary to make certain of the actual factors in different regions in order to reduce uncertainties in future works.

2. Further Studies on Methane Emission from MSW in China

It was found from the review above that the previous researches on methane emission from MSW in China had some problems. In order to provide a reasonable and reliable inventory on methane emissions from MSW, we should do some further research work to reduce its uncertainties.

3.1 Municipal Solid Waste Output and Its Generation Rate

China spans over nearly 40 degrees in latitude from the north to the south, and spans more than 60 degrees in longitude from the west to the east. The climatic condition and the standard of living of the people vary significantly. Consequently, solid waste output and its composition vary with region and climatic condition. With the improvement of the standard of living of the Chinese people, MSW output has increased rapidly in the recent ten years. In 1986, the total MSW output in China is about 500.87 million tons. In 1996, the MSW output has increased to 1082.54 million tons accounting to 116.13% increase in ten years (Table 3). Since 1979, the MSW output has increased by 8.98% per year. In some big cities like Beijing and Shanghai, the rate of increase reached 15 to 20%.

The MSW output changes in different regions in accordance to the people’s living habits. The list of provincial MSW generation rate in China is listed in Table 4.

From Table 3 and Fig. 1, it can be concluded that the annual MSW generation rate has very good linear relationship with time. The linear regressive function has a coefficient of determination of 0.9233.

$$MSW\_Generation\_Rate = 0.04331 * Y - 84.9128$$

Table 3. The trend of MSW output and its Generation Rate of China.

Year	Number of City	Population of Urban (10,000 persons) (Non-agricultural)	MSW Output (10,000 tons)	MSW Generation Rate (kg/cap/day)
1982	237	9568.4	3125.3	0.89
1986	348	12233.8	5008.7	1.12
1987	371	12893.1	5397.7	1.15
1988	424	13969.5	5751.3	1.13
1989	441	14377.7	6291.4	1.20
1990	455	14752.1	6766.8	1.26
1991	473	14921.0	7636.0	1.40
1992	506	15459.4	8262.0	1.46
1993	552	16550.1	8791.0	1.45
1994	612	17665.5	8852.0	1.37
1995	633	18490.0	10671	1.50
1996	688	18882.9	10825.4	1.52
1997	669	19469.9	10981.0	1.55
1998	667	19861.8	11301.8	1.56

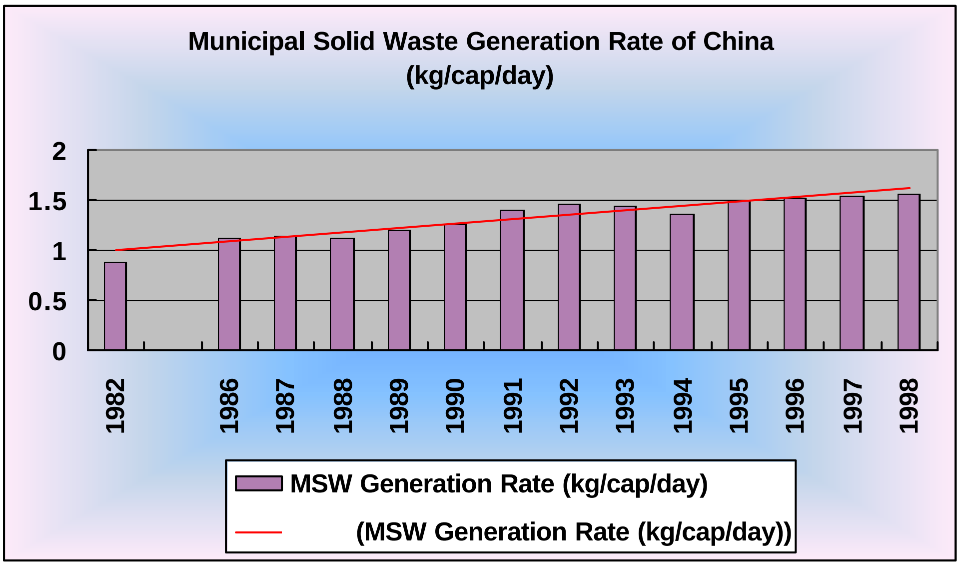

Fig. 1 the trend of annual MSW Generation Rate of China.

Table 4. The trend of Provincial MSW Generation Rate of China.

	1982	1987	1988	1989	1990	1992	1993	1994	1995	1996	1997	1998	AVERAGE
National	0.89	1.15	1.13	1.2	1.26	1.46	1.4	1.37	1.5	1.52	1.55	1.56	1.33
Beijing	0.98	1.54	1.5	1.54	1.7	1.92	1.95	1.99	2.03	2.02	1.99	1.97	1.76
Tianjing	0.81	1.2	0.98	1.27	1.31	1.4	1.21	1.24	1.06	1.08	1.16	1.2	1.16
Hebei	1	1.6	1.59	1.59	1.66	2.33	1.82	1.58	1.88	1.84	1.9	1.89	1.72
Shanxi	1.54	1.36	1.46	1.46	1.44	2.01	1.64	1.52	1.61	1.76	1.66	1.65	1.59
Neimenggu	1.34	1.52	1.41	1.56	1.08	1.68	1.81	2.04	2.19	2.23	2.41	2.02	1.77
Liaoning	1.17	1.4	1.45	1.39	1.5	1.59	1.6	1.67	1.71	1.67	1.51	1.55	1.52
Jilin	1.36	1.51	1.57	1.76	1.77	2.12	2.08	1.99	2	2.01	2.05	2.19	1.87
Heilongjiang	0.98	1.67	1.89	1.94	2.05	2.26	2.26	2.31	2.37	2.37	2.54	2.35	2.08
Shanghai	1.22	1.25	1.25	1.27	1.02	1.09	1.02	1.08	1.11	1.33	1.43	1.44	1.21
Jiangsu	0.51	0.79	0.78	0.84	0.88	1.18	1.09	1.07	1.05	1.07	1.16	1.15	0.96
Zhejiang	0.44	1.08	1.13	1.25	1.55	1.87	1.97	2.19	2.34	2.24	1.88	1.95	1.66
Anhui	0.56	0.7	0.69	0.74	0.95	0.87	0.93	0.99	0.98	1.1	1.2	1.24	0.91
Fujian	0.77	1.05	1.12	1.1	1.63	1.13	1.25	1.32	1.33	1.22	1.29	1.51	1.23
Jiangxi	0.51	0.51	0.47	0.51	0.55	0.65	0.84	1.17	1.47	1.06	1.02	0.95	0.81
Shangdong	0.73	0.89	0.84	0.9	1.06	1.15	1.21	1.44	1.31	1.19	1.25	1.32	1.11
Henan	1.55	1.15	1.08	1.17	1.25	1.31	1.38	1.35	1.34	1.36	1.37	1.38	1.31
Hubei	0.88	0.92	0.99	1.2	1.25	1.34	1.41	1.74	1.63	1.74	1.56	1.59	1.35
Hunan	0.38	0.86	0.74	0.69	0.68	1.03	1.16	1.16	1.16	1.22	1.26	1.35	0.97
Guangdong	0.62	0.97	0.94	1.02	1	1.43	1.37	1.62	1.71	1.73	1.44	1.65	1.29
Guangxi	0.35	0.63	0.61	0.57	0.66	0.84	0.91	1.18	0.39	1.24	1.33	1.3	0.83
Hannan			1.05[1]	1.16	1.25	4.13	3.7	4.25	1.81	1.76	2.31	1.63	2.31
Sichuan	0.43	0.82	0.76	0.8	0.92	1.18	1.19	1.27	1.55	1.23	1.32	1.29	1.06
Chongqing	~~0.34~~[2]	~~0.39~~	~~0.39~~	~~3.06~~	~~0.48~~	~~1.19~~	~~0.94~~	~~1.2~~	~~0.95~~	~~1.03~~	0.98	1.02	1
Guizhou	0.85	0.93	0.91	1.54	1.52	1.19	1.18	1.08	1.01	0.97	1.14	1.02	1.11
Yunnan	0.39	0.67	0.65	0.81	0.95	0.94	0.84	0.91	0.92	0.94	1.01	1.06	0.84
Tibet	0.24	0.39	0.13	0.25	0.27	0.43	0.71	~~16.66~~[3]	1.72	3.42	3.66	2.89	1.28
Shaanxi	0.67	0.76	0.84	0.91	0.87	1.02	1.11	1.15	1.02	1.06	1.14	1.12	0.97
Gansu	0.72	1.53	1.11	1.17	1.22	1.37	1.73	1.4	1.74	2.06	1.99	1.95	1.5
Qinghai	0.36	1.22	1.29	1.13	1.13	2.03	1.97	2.03	5.11	6.95	2.61	3.35	2.43
Ningxia	0.16	1.68	1.63	2.07	1.91	2.13	2.15	1.99	1.77	1.76	1.98	2	1.77
Xingjiang	0.68	1.18	0.74	0.75	1.07	1.22	1.31	1.43	1.76	1.78	1.98	2.1	1.33

To get the function above, the data for 1987 and 1997 were omitted in order to check the regressive results. The formulation listed above was used to calculate the MSW generation rate. The average relevant error of MSW generation rate from two

[1] Hannan was separated from Guangdong province in 1988 as a new province
[2] Chongqing city was separated from Sichuan province in 1997 as a metropolitan city.
[3] This data may be exceptional, so we omitted it in our calculation

years is about 0.76%.

MSW generation rate increased with time (Tables 3 and 4). Before 1993, the MSW generation rate increased rapidly, and the increasing trends went slowly, thereafter. Considering MSW generation rate and disposal rate of each province, the whole of China can be divided into three regions. In the northwest part of region I, the MSW generation rate increased more than 114 percent from 1982 to 1998, it showed that the standard of living of the people in that region had significant changes. The same phenomenon was found in Tibet of region III. The increase in MSW generation rates of Zhejiang, Guangdong and Guangxi provinces in region II were higher than that of other provinces. Each region has the same MSW generation rate and disposal rate (Fig. 2). The north regions of China (Including Northeast of China, North of China and Northwest of China) have MSW generation rate of 1.65 kg/cap/day, the Southwest of China 1.06 kg/cap/day and the other provinces 1.23 kg/cap/day. Based on this classification, more accurate methane emissions from MSWDs were derived. The whole country has an average MSW generation rate of 1.33 kg/cap/day. It should be noted that the results above were based on the nonagricultural population in urban areas. When the total urban population data are used to calculate the methane emissions, the MSW generation rate should be different from the values listed above.

Fig. 2. The regions partition of China.

3.2 The Composition of Municipal Solid Waste of China

The composition of municipal solid waste changes with the scale of city, geographic condition, and living habits of the resident, fuel types and standard of living. The MSW output of China increased rapidly in recent years and at the same time, the MSW composition underwent a big change. The main feature is the increase in organic and the flammable materials in the composition, and most of the MSW can be reused as new sources. The MSW from the resident has more recoverable wastes such as paper, plastic materials, metal glass and others than the other regions.

In developed regions, the paper waste accounts for main parts of MSW, but in the developing regions the food waste is main MSW. For example, in northeast of China, at winter time the resident has the habits to store cabbage and other vegetables. So, at the end of fall and the beginning of winter, the proportion of food waste is bigger than during the other seasons.

The MSW composition of China can be divided mainly into organic and inorganic waste. On the average, the organic waste accounts for 36%, the inorganic waste for 56%, and the other waste for 8%. In the regions where the gas is main energy source, the MSW has more organic waste (72.12%) than inorganic waste (16.84%), and the other waste (12.04%). In the regions where coal is main energy source, the organic wastes accounts for only 25.09%, significantly different from that in the gas regions. The inorganic waste, however, increased to 70.76% and the other wastes accounted for 4.52%. Figure 3 gives the MSW composition in some cities of China. It shows that the organic waste is less than the inorganic waste except for Tianjing. In Wuhan, Xi'an, Chansha, Guiyang, Fuzhou, Wuxi, Hefei and Nanjing, the inorganic waste accounts for more than 70 percent. This phenomenon reveals that the main energy sources used in China is coal.

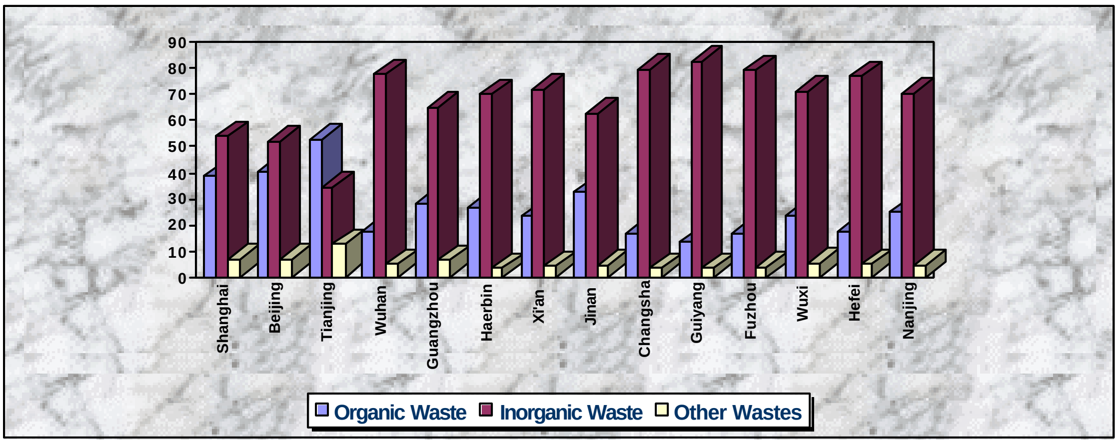

Fig. 3. The MSW composition in some cities of China.

Data from different fuel type regions were analyzed and results show that in the gas regions (where gas is used as the main energy source), the organic waste accounts for higher proportion than in the coal regions (where coal is used as the main energy sources).

According to Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: reference manual and workbook, DOC (Degradable Organic Carbon) content is based on the composition of waste, and can be calculated from a weighted average of the carbon content of various components of the waste stream. From Beijing (1996.12, two samplings) and Tianjing (1992.8, three samplings) samples, we can find the outline of waste composition in China and the weighted average of carbon content of various components of waste stream were determined. The classification of waste in China is different from IPCC recommendation. In China's classification, the garden waste, park waste and other non-food organic putrescibles were not included (Table 6). Food waste accounts for much high ratio of total waste in China (Table 6). Using the value percent DOC (by weight) and the values listed in Table 6, the DOC content of China's waste was calculated using equation 2 (IPCC Reference Manual). The fraction of DOC of MSW in China is equal to 0.10.

Table 5. The waste composition of different function region in some cities.

CITY	FUEL TYPES	ORGANIC WASTE(%)	INORGANIC WASTE(%)	OTHER WASTES(%)				
				Paper	Metal	Plastic	Glass	Cloth
Nanning	Gas regions	46.01	45.76	2.77	1.06	1.22	2.36	0.82
	Coal regions	17.02	78.60	1.61	0.64	1.09	0.43	0.61
Taiyuan	Gas regions	83.22	4.12	6.97	1.13	1.60	1.37	1.59
	Coal regions	10.86	86.38	1.57	0.30	0.17	0.21	0.51
Chongqing	Gas regions	69.91	19.91	2.94	1.19	2.12	1.95	2.01
	Coal regions	16.80	79.54	0.75	0.90	0.68	0.84	0.42
Shengyang	Gas regions	86.94	9.34	1.91	0.41	0.27	0.71	0.42
	Coal regions	37.97	60.97	0.35	0.17	0.09	0.24	0.21

Table 6. The Percent MSW of each Composition (%) by weight.

Sample	**Tiangjin**	**Beijing**	**Average**
Paper and Textiles	14.08	6.24	10.16
Food Waste	39.02	37.63	38.33
Wood and straw	3.4	1.15	2.28
Others	43.5	54.99	49.25

3.3 The present situation of MSW disposal of China

At present, the main disposal mode of MSW in China is landfill, which accounts for more than 70% of disposed MSW. The high temperature compost accounts for more than 20% of disposed MSW. The MSW disposal centers had increased from 23 sites in 1986 to more than 1020 sites in 1998. The disposal rate of the MSW has increased from 0.9% to 58.41%.

The MSW disposal rate data of each province in China from 1993-1998 was analyzed and it was found that the disposal rate of MSW changed with the city's development. The whole country was divided into three regions with each region having the same MSW generation rate. Each region had a constant disposal rate representing the regional condition. Most parts of the first region had limited economic development and the three years average disposal rate was 35.98 percent. In the second region where most parts were located in the coastal economic development zone and had high economic increase rate, the average disposal rate was more than 50.93 percent. The disposal rate of third region was 39.97 percent. The whole country has an average disposal rate of 42.93%. Figure 4 shows the change in MSW disposal with time.

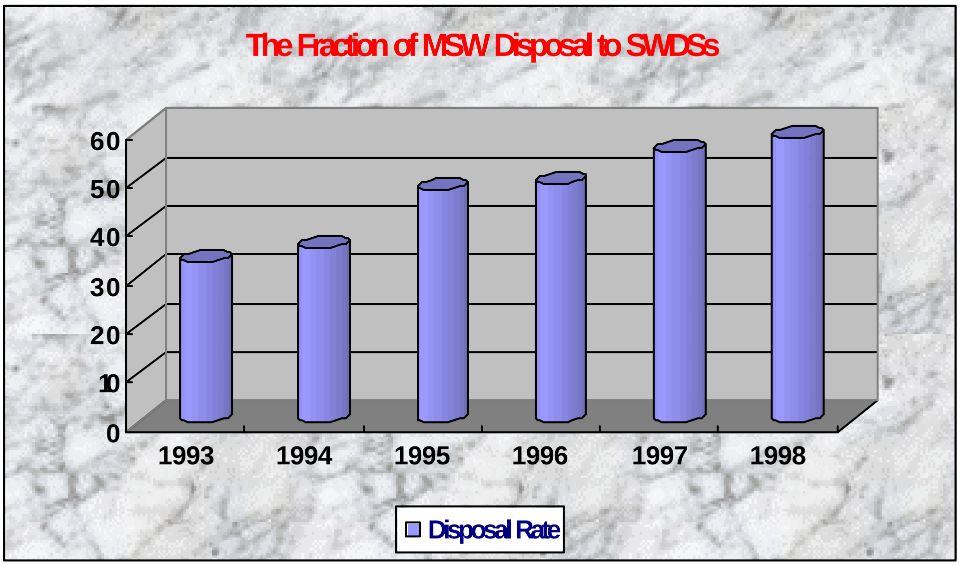

Fig. 3. The MSW disposal rate trend with time.

4. The Methane Emission Inventory from MSW in China

The 1990 and 1996 methane emissions from MSW in China were calculated using the data described above and the data from the Statistical Yearbook of Municipal Construction of China, following the IPCC Guidelines for National Greenhouse Gas Inventories: Workbook.

The Methane Correction Factor (MFC) used was the IPCC default value of 0.6. The values used for the fraction of carbon released as methane and the fraction of

DOC (DOC_F), which actually degrades, were the IPCC default values, which are 0.5 and 0.77, respectively. The fraction of DOC in MSW was calculated from Chinese data and the MSW generation rate and fraction of MSW disposed to SWDSs were taken from Chinese statistical data. Due to the lack of the methane recovery amount and the oxidation factor, IPCC default values were used.

The 1990 and 1996 inventories were calculated using two methods. One method used constant values for the MSW generation rate and disposal rate in China, which are 1.33 and 42.93%, respectively. The other method entailed dividing the whole country into three regions and each region had its own MSW generation rate and disposed rate. Table 7 shows the results of error analysis of the annual amount of MSW generation in 1990 and 1996. The actual MSW generation data were obtained from the Statistical Yearbook of Urban Construction of China. Results showed that the second method is the best method to calculate methane emission inventory (Table 7) and the relative errors were 4.58% and 12.29%, respectively, in 1990 and 1996. The relative errors of the first method were 5.83% and 15.32%, respectively.

It can be concluded that a much reliable and accurate methane emissions inventory was obtained by dividing the whole country into three regions based on MSW generation rate and MSW disposed rate. Due to the lack of the data, some parameters used in calculation were the IPCC recommended default values that do not represent the real situation in China. These should be studied further in the future. Table 8 presents the methane emission inventories using the two methods and the share amount of methane emission per person in different regions.

Table 7. The error analysis of annual amount of MSW generation of 1990 and 1996.

Year	Real annual amount of MSW generation (Gg MSW)	Calculated annual amount of MSW generation (Gg MSW)		The relative errors (%)	
		Method I	Method II	Method I	Method II
1990	67668	71614.07	68478.00	5.83	4.58
1996	108250	91667.04	94943.32	15.32	12.29

Table 8. The methane emissions inventory of 1990 and 1996 of China (Gg CH_4).

Name of Province	1990	1996	Methane Emission per capita
National Average	946.91	1212.06	0.0642
Total	**826.15***	**1094.39**	**0.0655**
Beijing	36.59	39.75	0.0660
Tianjing	29.93	30.96	0.0660
Hebei	39.46	50.28	0.0660
Shanxi	26.7	34.29	0.0660
Inter Mongolia	38.34	27.84	0.0660
Liaoning	88.04	98.99	0.0660
Jilin	45.26	49.49	0.0660
Heilongjiang	65.52	71.98	0.0660
Shaanxi	24.54	28.74	0.0660
Gansu	16.15	19.57	0.0660
Qinghai	4.2	4.68	0.0660
Ningxia	4.86	6.1	0.0660
Xinjiang	19.57	21.55	0.0660
Shanghai	52.8	59.28	0.0704
Jiangsu	63.06	76.82	0.0704
Zhejiang	31.31	38.03	0.0704
Anhui	32.66	45.12	0.0704
Fujian	19.03	25.89	0.0704
Jiangxi	24.5	32.24	0.0704
Shandong	56.99	87.16	0.0704
Henan	45.73	64.65	0.0704
Hubei	37.06	82.96	0.0704
Hunan	53	42.82	0.0704
Guangdong	18.58	100.43	0.0704
Guangxi	2.77	27.74	0.0704
Hainan		7.55	0.0704
Sichuan	38.85	56.73	0.0476
Guizhou	10.36	12.59	0.0476
Yunnan	10.17	12.75	0.0476
Tibet	0.62	0.74	0.0476

5. Conclusion

Based on the analysis presented in this paper, some significant results on methane emission from MSW of China are the following:

1. From the review of previous work on methane emission inventories in

[4] the results comes from method II (divided the whole country into three regions)

China, there are some problems that should be corrected. For example the MSW generation rate used in previous works not suitable for Chinese real condition. The other parameters used in calculation were the default values recommended by IPCC, which do not represent the real Chinese situation, and should be studied very carefully.

2. Based on the MSW generation rate and MSW disposed rate of provincial data from the Statistical Yearbook of Municipal Construction (1982, 1986-1998), the whole country was divided into three regions. In each region there is a uniform MSW generation rate and MSW disposal rate. The calculated result of the MSW generate amount from the second method (dividing the whole country into three regions) is more accurate than that from the first method (the whole country use an uniform MSW generation rate).
3. The north regions of China (Including Northeast of China, North of China and Northwest of China) have MSW generation rate of 1.65 kg/cap/day, the Southwest of China 1.06 kg/cap/day and the other provinces have MSW generation rate 1.23 kg/cap/day. Based on this classification, a more accurate methane emissions from MSWDs were obtained. The whole country has an average MSW generation rate of 1.33 kg/cap/day. It should be noticed that the results above were based on the nonagricultural population in urban. When the total urban population data are used to calculate the methane emissions, the MSW generation rate should be different from the value listed above.
4. A linear regressive equation with a coefficient of determination of 0.9233

$$MSW\_Generation\_Rate = 0.04331 * Y - 84.9128$$

   was obtained. The average relevant error of MSW generation rate of this equation is about 0.76%.
5. The MSW composition of China can be divided into organic and inorganic waste. On the average, the organic waste accounts for 36%, the inorganic waste for 56%, and the other wastes for 8%. But the MSW composition in regions where the gas is main energy source has more organic waste (72.12%) than inorganic waste (16.84%), and other wastes (12.04%). In the regions where coal is the main energy source, organic waste accounts for only 25.09%, significantly different from that in the gas regions. But the inorganic waste increases to 70.76% and the others account for 4.52%.
6. Analysis of the data from different fuel type regions showed that in the gas regions (where gas is used as the main energy source), the organic waste accounts for more ratio than that in the coal regions (where coal is used as the main energy sources). According to Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: reference manual and workbook, the fraction of DOC of MSW in China is equal to 0.10 from Beijing (1996.12, two samplings) and Tianjing (1992.8, three samplings) samples.
7. The number of MSW disposed center increased from 23 sites in 1986 to more than 1020 sites in 1998. The disposal rate of the MSW increased

from 0.9% to 58.41%. In the first region, due to the limitation of economic development in most parts, the three years average disposal rate was 35.98 percent. In the second region where most parts are located in the coastal economic development zone and with high economic increase rate, the average disposal rate is more than 50.93 percent. The disposal rate of third region is 39.97 percent. The average disposal rate for the whole country is 42.93%. The MSW disposal rate increased with time.

8. Methane emissions from MSW in 1990 and 1996 were calculated based on the data calculated from Chinese real data and from the Statistical Yearbook of Municipal Construction of China, following the IPCC Guidelines for National Greenhouse Gas Inventories: Workbook. It was found that the second method is the best method to calculate methane emission inventory, and the relative errors were 4.58% and 12.29%, respectively, in 1990 and 1996. The relative errors of first method are 5.83% and 15.32%, respectively.

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