FEASIBILITY STUDY ON MUNICIPAL SOLID WASTE RESOURCILIZATION TECHNOLOGIES IN CHINA

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ABSTRACT

The principal strategy to manage MSW is to prevent the discharge of waste and, where waste must be discharged, to reuse or recycle as much as possible to reduce the quantity. The paper describes the current status of MSW management strategies and its feasibility of resourcilization from these processes in China, and the main focus of the article is to explore the feasibility of energy reuse and recycling form MSW incineration and landfill

Key Words : municipal solid waste, MSW resourcilization, reuse or recycling

During the past decade many efforts have been made in China to reduce the production and to control the management of municipal solid waste (MSW). A number of different laws, technical directives, ordinances, guidelines and memoranda has been issued by the central or local government in recent years in order to establish a rational and well operated integrated waste management system all over the country. Many of the measures initiated by these activities have only recently been started and the outcome is still difficult to evaluate.

The principal strategy to manage MSW is to prevent the discharge of waste and, where waste must be discharged, to reuse or recycle as much as possible to reduce the quantity. However, even if efforts are made to minimize the amount of waste, a large proportion still requires treatment on view of the activities of modern society. In the following an attempt will be made to describe in broad outline the feasibility of MSW resourcilization in China, the main focus of the article is energy reuse and recycling from MSW incineration and landfill.

1 Municipal solid waste incineration

1.1 Technology feasibility

The results of the MSW low calorific value in developed countries and areas contrasted with that in China is listed in table 1. The MSW composition characteristic in China is that the inorganic materials are more than organic materials and inflammable components are higher than flammable components, but this situation is quite different among the cities, the organic materials content of municipal solid waste in middle and small cities is always around 20%, but in big cities and relatively developed cities, the organic materials content of waste is as high as 40% or more.

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Table 1 The low calorific value of MSW in several countries and areas

Unit?(kJ/kg)

USA	UK	Japan	Hongkong	Paris
11669?13976	12142?13188	11723?12560	10048	7752
Munich	Vienna	Teheran	Beijing	Shenzhen
7752	8503	5070	4300?6560	5066

The raw materials occupy a large part of the organic materials, but the materials with high calorific value such as paper and plastics are relatively small, and it's quite different from that in the developed countries. The difference of the MSW composition determines that appropriate technologies must be used in treating with municipal solid waste in China, moreover, different technology should be used in different cities, and it's unhelpful to copy the technology from the other countries. It's considered that the waste can be combusted without any auxiliary fuel when the low calorific value of MSW is higher than 3349kJ/kg. The low calorific value of MSW in most of the cities in China is around 2512 to 4605 kJ/kg, and it's a little higher in Beijing to reach 3349 to 6560kJ/kg. With the continuous development of the living standards in cities, the popularization rate of gas and centralized heating in cities will increase greatly, so the calorific value of MSW will be increase continuously. In term of waste composition, part of the requisites for MSW incineration have been provided in big and middle cities and economically developed areas in China.

According to incineration facilities, the developed countries have had the experience for waste incineration for almost a century. Till now, it's still considered to directly import foreign advanced facilities to build large MSW incineration plants in the cities such as Beijing, Shanghai and Guangzhou. But it will cost about 0.45billion RMB yuan to import a set of foreign incineration plant (two incinerators) to generate electricity with a MSW treatment capacity of 600 tons per day and electricity generation capacity of 2 to 3MW, it's unacceptable for most of the cities in China. Moreover, since the large incinerators were imported from Japan Mitisubish Corp in Shenzhen city in 1988, most of the scientific departments and industries in China have tried to develop national waste incineration technology and facilities. Coal is the main fuel in China, and there is relatively strong basis on solid fuel incineration technology. In recent years, large numbers of China-made incinerators come in using. The third incinerator in the MSW incineration plant in Shenzhen was all adopted China-made facilities except the grid, and vapor over-heat machine used in the electricity generation systems, thus the electricity generation efficiency was improved greatly, and it still demonstrates that we have the technology requisites in MSW incineration in China. It's believed that the MSW incineration characteristics will be deeply understood and the experiences of incineration will be improved step by step with the popularization of China-made facilities, and there will be a rapid development of MSW incineration technology in the next few years.

China is vast in territory and the energy demand is various, thus different methods should be adopted to reuse the energy from waste incineration. For example, the regional centralized heating can be considered to use in the northern cities, waste heat generation electricity can be developed in southern cities, and industrial vapor can be provided for the enterprises in the developed regions.

As a national technical policy in future, China-made incineration facilities should be

developed to meet the country's condition.

1.2 Economical feasibility

Another important factor to develop MSW incineration is economical feasibility. The analyzing results indicated that to build and operate a large MSW incineration plant can be repaid from the energy reuse or recycling, and the incineration plant can be operate on the income to use the remaining heat fully and efficiently.

To give examples on MSW incineration plants in Mudanjiang and Shenzhen as following.

The treatment capacity of the ZSLJ spontaneous combustion style incinerators in Mudanjing city is 300 tons per day (150t/dx2), and its total cost was 95.07million RMB yuan, thereinto, the cost of main incineration facilities and other auxiliary facilities was 70.2million RMB yuan, the cost of building was 24.87million RMB yuan. The management cost and operation cost of incineration plant including cost of manual work, water and electricity bill, auxiliary fuel cost, cost of chemicals, transportation fee for cinder, and maintenance fee is 8.71million RMB yuan per year. The income of reusing the remaining heat is 8.64million RMB yuan, so the actual treatment cost is only 0.78 RMB yuan per ton waste.

The cost of the No.3 China-made MSW incinerator in Shenzhen city was 0.30 million RMB yuan per ton waste treated. If the lifetime of the incinerator was 15 years and works 300 days per year, then the cost of tonnage waste treating capacity would be 0.30million RMB yuan / (15x300)=67RMB yuan. There's still a China-made 3MW turbo generator installed, and the total investment including the electricity generation facilities was 21million RMB yuan, so the cost of tonnage waste treating capacity was 21million RMB yuan / (15x300x300)=15.6RMB yuan. Thus the total investment of facilities including the two items above was 82.6 RMB yuan per ton waste. If the electricity generation capacity was 72MWh per day and the electricity fee was 0.52 RMB yuan per MWh, then the income of the electricity generated from remaining heat should be 0.52RMB yuan x 72MWh/d=37440RMB yuan/d, the income of electricity should be 37440RMB yuan / 300ton = 124.8RMB yuan per ton waste. If the operation and management fee for one ton waste was 100 RMB yuan (not including the transportation fee), then the total cost for treating one ton waste should be calculated as: income of electricity 124.8 RMB yuan/ton - facilities cost 82.6 RMB yuan/ton - operation and management fee 100RMB yuan/ton = -57.8RMB yuan/ton.

To sum up, the cost to use China-made incinerator to treat municipal solid waste is a little higher than that to use landfills. But incineration has a strong attraction to big and middle cities with limited landfill area because incineration can greatly reduce the waste volume to be disposed of in landfills and transportation cost. The waste collection policy should be issued by the government as soon as possible to support the development of MSW incineration technology based on the principle "who must manage the waste himself after generate it".

1.3 Market feasibility

The national economy has had a rapid development in China in recent years, and China has become one of the countries with fastest economy growth in the world. With the enhancement of the integrated national power and the improvement of the people's living standards in China, the people's consciousness of environment protection is improved continuously, and the problem about the MSW management which is related to the people's daily life has become one of the highlighted problems to be concerned by the people.

MSW management has been paid much attention by the government. The Law on

Solid Waste Pollution Environment Prevention in China passed and issued by the Standing Committee of NPC came into effective on April 1st, 1996. China is still one of the signatory nations to treaty on the Brazil Convention. Moreover , the departments in the government such as NEPA have issued a whole set of laws, regulations, ordinances and standards on solid waste management. It has laid a legal foundation for the integrated management of municipal solid waste.

According to national plan issued by the Chinese government, the MSW management rate will be reach 50% by the year 2000, and MSW management facilities tallying with the environment standards will be constructed in every city by the year 2010 and all the waste should be treated or disposed of harmlessly. MSW management technologies have been listed in the national ninth-five-year project. Municipal solid waste non-hazardous management is requested in the directives for appraising sanitary cities and/or excellent environment integrated administrating cities. In one side these measures have greatly fastened the progress for MSW integrated management, in the other side relatively big market is requested for MSW management technology and facilities.

In terms of the trend of municipal solid waste in China, the increase rate of MSW generation will be slow down because the urbanization progress will be slow down and the gas used ratio in cities and centralized heating ratio will be improved greatly. The annual tonnage generation would be more than 0.22billion tons by the year 2010 if the waste increase rate would be 5% every year in the next ten years. If the ratio of different MSW management methods were 70% for sanitary landfilling, 20% for incineration and 10% for composting, then the incineration treatment capacity would be increased by 44million tons per year, it is equal to 147 MSW incineration plant with the treatment capacity of 1000tons waste per day. The market would reach 14.7billion RMB yuan at the investment of 10million RMB yuan for a 100 t/d incineration plant if all China-made facilities were used.

2 Municipal solid waste landfilling

2.1 Technology feasibility

The organic materials content of waste in China is about 20 to 30% in the regions where coal is the main fuel, and the organic material content of waste is about 50 to 80% in the regions where coal gas is the main fuel. Moreover, based on the positive role of the long-term waste recycling system in China, most of the refractory components with high calorific value such as plastics and paper are recycled, thus the raw material components such as kitchen wastes occupied most of the organic materials are disposed of in landfills.

Although the gas used rate and centralized heating rate have made big progress in many of the big and middle cities in China, there are still about half of the residents who use coal as the main fuel. Therefore, the cinder content of combined waste disposed of in landfills is comparatively high, thus relatively strong pH buffer capacity is provided by the large amount of base materials in cinder, and excellent alkaline condition is provided for the anaerobic organism in the landfill.

The other important characteristic of municipal solid waste in China is relatively lower C/N ratio. The typical value of C/N ratio of municipal solid waste in developed countries is about 49/1, but it is only about 20/1 in China. This is because of the relatively higher ratio of kitchen wastes in MSW in China. It's demonstrated that the optimum C/N ration for anaerobic microorganism's growth is between 20/1 to 30/1, from another respect it gives reason why the gas generation rate of waste in China is relatively faster.

Except several sanitary landfills tallying

with the environment standards were constructed in some cities in China, more than half of the municipal solid waste is disposed of in open dumps or in simple landfills. These traditional waste disposal sites are usually small scale with relatively shallow filling depth and lower compacting density, and strict daily cover and final cover haven't been used. Thus the aerobic area in these landfills will be bigger than that in the large sanitary landfills, so it results in a quicker decomposition rate of organic materials in the waste.

Because of the reasons mentioned above, the landfill gas is usually generated earlier in the landfills in China, the landfill gas generation rate is faster, and gas generation period is relatively short. The existing waste dumps in Haidian District of Beijing were investigated by the Department of Environmental Science and Engineering of Tsinghua University. The results indicated that large amount of landfill gas can be detected in the landfills used only one year, and the methane concentration in landfill gas reached the maximum at about one and a half years, then the figure decreases. The changing situation of landfill gas concentration in the four waste dumps in Haidian District, Beijing, is showed in table 2 and figure1.

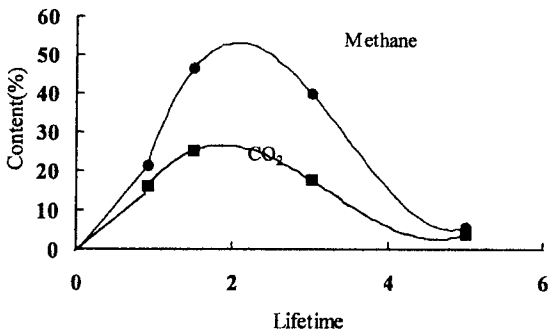

Fig 1: The relationship between landfill gas generation and landfill lifetime

The changes for MSW management have taken place from uncontrolled deposit to strict management in most of the big cities in China. The daily treatment capacities for the new-build MSW landfills in many cities are always over 1000 tons, and the total landfill volume is about 10million cubic meters for each landfill. In this respect, it becomes more important to control the landfill gas, at the same time, the increase of waste landfilling tonnage and the extend of landfill lifetime are all good conditions for landfill gas generation and reusing in large scale.

It has a long history to use agriculture wastes and night soil to produce biogas in the countryside in China, and the biogas project is also in the lead in the world. The biogas generated from the material such as straw and night soil has been used in lightening, heating, cooking and fruit fresh preservation, and the methane liquid is used in cultivating seeds, methane residue is used as the animal feed. There are about 8million methane-generation pits in the countryside in China. The experiences accumulated from the countryside methane-generation project such as facility maintenance, collection and reuse of the biogas have laid an excellent technical foundation for the collection and reuse of the landfill gas from MSW landfills.

2.2 Economics feasibility

The landfill gas is the decomposition products of decomposable organisms at anaerobic conditions, therefor, the basic conversation relationship between the decomposable organism amount and the landfill gas generation must be obtained in order to estimate the landfill gas generation amount. The research on the organism anaerobic bacterial decomposition was first carried out on the process of high concentration waste water treatment and sludge digestion, but its principle is still can be used in the anaerobic decomposition process of decomposable organisms in the landfill, that is:

$$(CHON) + H_2O \rightarrow CH_4 + CO_2 + NH_3$$

Table 2 Analysis on the landfill gas concentration in MSW deposit sites(%)

Deposit sites	landfill lifetime	CH_4	CO_2	O_2
A	0.9	21.3	16	12
B	1.5	46.6	25.3	6.11
C	3	40.2	17.8	8.23
D	5	5.5	4	17.2

The chemical reaction above can be written as:

$$C_a H_b O_c N_d + \frac{4a-b-2c+3d}{4} H_2O = \frac{4a+b-2c-3d}{8} CH_4 + \frac{4a-b+2c+3d}{8} CO_2 + dNH_3$$

According to the law of the conversation of matter and energy, the maximum possible landfill gas generation can be calculated, that is the theoretical relationship between total organic carbon (TOC) and chemical oxygen demand (COD). Namely:

$$1\text{gTOC} = 1.867\text{NLLFG}(CH_4 + CO_2)$$
$$1\text{gCOD} = 0.35\text{NL}(CH_4)$$

According to the achievements in the research on landfill gas generation, the decomposable organism content of MSW in China is about 89.5%, the ratio of decomposition materials is about 64.1%, and the theoretical landfill gas generation amount per ton waste is 48.1 Nm^3/t, the potential landfill gas generation amount in a actual landfill is about 29.3Nm^3/t. To consider all the factors affecting the organism anaerobic decomposition, the actual landfill gas generation amount is about 60% of the potential, thus it is about 17.6 Nm^3/t actually In the landfills with active gas collection system, the recovery rate of landfill gas is about 70% of the actual landfill gas generation, thus the amount of the recovery methane is about 12.3Nm^3 per ton waste.

As stated above, MSW generation in China will increase at 5% per year in the next ten years, thus the generation amount will reach 0.22billion tons per year by the year 2010. If 70% of the waste is disposed of in sanitary landfills, then 0.154 billion tons MSW will be disposed of in landfills every year in 2010. If all the landfill gas were reclaimed, then the recovery methane would be about 1.9billion Nm^3, and it equal to 3.8billion Nm^3 biogas(50%of the biogas is methane). The calorific value of biogas is about 5000kcal/Nm^3, then the total recovery energy would be about 3.8billion Nm^3 x 5000kcal/Nm^3=19 billion Mcal, and it is equals to 2.7 tons standard coal.

Moreover, in the respect of environment impact, methane is one of the main greenhouse gas, and its contribution to the greenhouse effect equals to 21 times of carbon dioxide. According to the calculation above, the potential landfill gas generation in whole China will be about 4.5billion Nm^3 by the year 2010, it equals to 4.6 to 16%of the total landfill gas generation amount in the world. If 1.9billion Nm^3 methane can be reused and to be conversed into heat or power energy, then it equals to reduce the discharge amount of carbon dioxide by 1.9 billion Nm^3 x 20=38billion Nm^3, so it's a huge contribution to control the global warming.

2.3 Market feasibility

At present, most of the big and middle cities in China have constructed or operated some big MSW sanitary landfills, and there will be still a large number of sanitary landfills to be constructed in the next few years. Moreover, there are also a lot of waste dumps and simple landfills in all the cities. It's obvi-

ously that the landfill gas is only less hazardous than most of the major pollutants in leachate, but methane gas can cause explosion or/and fire, so it's the most important factor which is puzzling the environment and sanitary departments and becoming the obstacle to be against to construct landfills by the public. It is to be considered in many cities to construct landfill gas control, collection and reuse systems, for example, the landfill gas reuse project has been implemented in the Tianzilin MSW sanitary landfill in Hangzhou city.

In terms of investment, the cost to construct a landfill gas collection and reuse system in a sanitary landfill with a treatment capacity of 2000t/d is about 20million to 30 million RMB yuan, it equals to 20% to 30% of the total landfill construction cost. But for such a scale sanitary landfill, the total recovery biogas per year is about 17.96million Nm^3, then the total recovery heat energy every year will be 17.96 million Nm^3 x 5000kcal/Nm^3=8.98 x 1010kcal (if the calorific value of biogas is 5000kcal/Nm^3). If the energy conversation rate is 30%, then the total electricity generated every year will be 31.33 million kwh, then the income from the electricity would be 0.52RMB yuan /kWh x 31.33million kWh/a=16.29million RMB yuan/a if the electricity fee were 0.52RMB yuan /kWh, that means the investment can be reclaimed in only 2 years.

According to the analysis above, relatively big market will be had for the landfill gas recovery not only for the investor but also for the manager if landfill gas recovery and reuse systems are constructed in large MSW landfills.

3 Conclusion

This article describes the current status of MSW management strategies and the feasibility of waste resourcilization from these processes in China, and the main focus of the article is to explore the feasibility of energy reuse and recycling form MSW incineration and landfill because over 90% MSW is disposed of in incineration plants or landfill sites in this country now. From the above analysis, the authors think the waste management situations can be improved greatly if energy reuse and recycling can be taken on successfully in these processes, and there will be a great market for the waste resourcilization in China in the future.

REFERRENCE

David A.Tillman et at., Incineration of Municipal and Hazardous Solid Waste. Academic Press Inc., 1989

George Tchobanoglous, Hilary Theisen et al. Integrated Solid Waste Management. USA: McGraw-Hill, Inc., 1993

Li Guoding, Jin Ziqi. Solid Waste Resourcilization Management. China: Tsinghua publishing company, 1990

Shin-ichi Sakai. Municipal Solid Waste Management in Japan. Waste Management, vol.16, nos5/6, pp. 395-405,1996

T.Taylor Eighmy, David S. Kosson. U.S.A. National Overview on Waste Management. Waste Management, vol.16, nos5/6, pp. 361-366, 1996

Wang Wei, Jiang Jianguo. The Municipal Solid Waste Resourcilization and its Treatment and Disposal Technology. Sino-Japan Technology Exchanging Fund. 1999.3

Wang Wei, Yuan Guangyu. The Status and Development of Solid Waste Treatment and Disposal in China. Environmental Science, 1997, 18(2):87-90