TSINGHUA SCIENCE AND TECHNOLOGY
ISSN 1007-0214 11/20 pp435-440
Volume 12, Number 4, August 2007

Prospects of Anaerobic Digestion Technology in China*

JIANG Jianguo (蒋建国)**, SUI Jichao (隋继超), WU Shiyao (吴时要),
YANG Ying (杨 颖)†, WANG Liming (王黎明)†

Department of Environmental Science and Engineering, Tsinghua University, Beijing 100084, China;
† Department of Electrical Engineering, Tsinghua University, Beijing 100084, China

Abstract: As the world's largest developing country, China must face the problem of managing municipal solid waste, and the challenge of organic waste disposal is even more serious. Considering the characteristics of traditional waste disposal technologies and the subsequent secondary pollution, anaerobic digestion has various advantages such as reduction in the land needed for disposal and preservation of environmental quality. In light of the energy crisis, this paper focuses on the potential production of biogas from bio-waste through anaerobic digestion processes, the problems incurred by the waste collection system, and the efficiency of the anaerobic digestion process. Use of biogas in a combined heat and power cogeneration system is also discussed. Finally, the advantages of anaerobic digestion technology for the Chinese market are summarized. The anaerobic digestion is suggested to be a promising treating technology for the organic wastes in China.

Key words: anaerobic digestion; bio-waste; methane; cogeneration

Introduction

During the past century, developed countries have experienced energy crises three times. Because mankind can not invent new resources but can only more efficiently utilize our existing resources, even with reduction in energy consumption, developed countries have been forced to move towards alternative energy supplies with emphasis on renewable sources, one of which is bio-waste.

Use of anaerobic digestion technology to treat municipal solid waste and other bio-waste in Europe is connected with the general tendency to tighten environmental regulations[1]. The European Landfill Directive requires member states to gradually reduce the quantities of biodegradable municipal solid waste sent to landfills. The total quantities of biodegradable municipal solid waste should be reduced to 75% of the total amount by weight of biodegradable waste produced in 1995 by 2006, to 50% by 2009, and to 35% by 2016[2], so new methods must be developed to dispose of bio-wastes, such as waste digestion and methane gas recycling.

The third concern is the recognized need for effective and environmentally friendly methods for the treatment and disposal of large quantities of bio-wastes which not only represent a threat to environmental quality, but also represent a significant renewable energy resource.

There are great variations in the composition of municipal solid waste between developed countries and China[3]. The disposal and treatment rates in China are much lower than those in developed countries. In China, bio-waste in municipal solid waste is not sorted before disposal, typically, in landfills or in incineration

Received: 2005-09-06; revised: 2005-10-18

* Supported by the Sino-Italian Facility (SIF) of the Ministry of Science and Technology, China and the International Cooperation Project of the Ministry of Science and Technology, China (No. 2006DFB93580)

** To whom correspondence should be addressed.
E-mail: jianguoj@tsinghua.edu.cn; Tel: 86-10-62783548

plants, so most biogas plants are based on the digestion of animal manure and are built in the countryside using low efficiency and locally developed technology. Waste separation and collection are being developed in some big cities such as Beijing, Shanghai, and Shenzhen to enable the conversion of bio-waste into biogas containing methane and the separation of solid materials from anaerobic digestion processes for use as fertilizers.

This paper presents an assessment of the sustainability of current anaerobic digestion methods in China.

1 Opportunities for Anaerobic Digestion Technology in China

Our modern lives are mostly supported by energy input from non-renewable fuels such as coal, oil, and natural gas. In China, the energy utilization has exceeded the energy supplies since 1995. Figure 1 shows the energy supply and demand levels during 1985-2000, while Fig. 2 shows the supply and demand rates for each energy source in 2000[4].

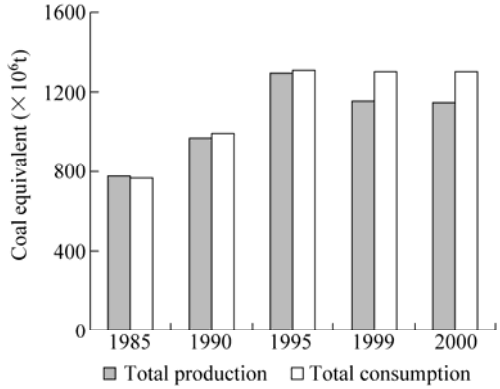

Fig. 1 Chinese energy supply and demand rates during 1985-2000

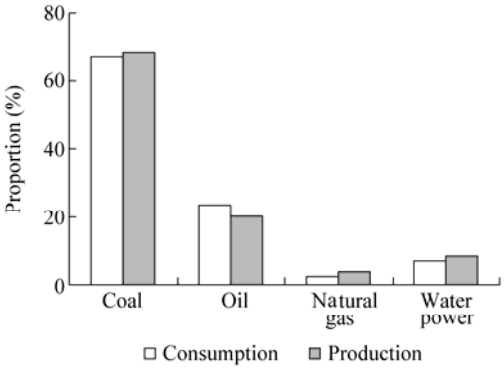

Fig. 2 Supply and demand rates for each energy type in 2000 in China

The Chinese economy now relies on expensive imports of commercial fuels for its industrial and commercial needs[5] and biomass for rural communities. Therefore, China needs technologies to provide secondary sources of energy to mitigate the coming energy crisis. In 1994, the Chinese government declared biogas to be one of the major waste-to-energy options to be developed in China[5].

Anaerobic digestion has been proposed as a cheap alternative to fuel China's energy needs. Figure 3[6] shows how the heating value, measured in kWh per kg of waste, decreases as the water content increases. Incineration of materials with heating capacities less than 3344 kJ/kg is probably not economical; moreover, incineration does not take advantage of the organic fraction, which can be digested or recycled to produce biogas.

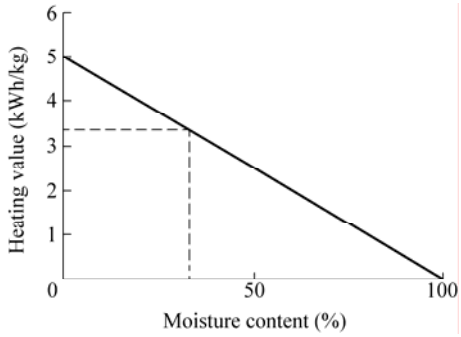

Fig. 3 Correlation between heating value and moisture content in wet waste

Both aerobic composting and anaerobic digestion are suitable for bio-waste treatment, but aerobic composting consumes much energy and produces low quality fertilizer at a high price. Comparatively, anaerobic digestion technology results in net energy production by providing methane, an important anthropogenic greenhouse gas, which is used as a renewable energy source.

There are also other ways of recycling energy from bio-waste such as thermal gasification, which produces rather low heating value gas, so economic application of thermal gasification is limited to feed with either low water content or those having the potential to be mechanically dewatered inexpensively. In any case, thermal gasification is still very much at the research stage.

Anaerobic digestion is a lower temperature and less

costly process which is drawing increased attention. The digestion takes place in a digester with the help of bacteria. Anything in the waste that is cellulose, starch, or classified as some kind of sugar, fat, or protein can be converted to a mixture of methane and carbon dioxide by digestion. In general, two anaerobic digestion processes are currently used for organic waste, the "wet-low solid" and "dry-high solid" anaerobic digestion processes.

2 Potential Assessment of Anaerobic Digestion Technology for Bio-Waste in China

2.1 Huge amount of biodegradable municipal solid waste

China has a large quantity of waste resources. In 2001, there were 662 cities in China with a total population of about 480 640 000. In the same year, 134.7 million tons of municipal solid waste was produced in China, which was about 27% of the municipal solid waste generated worldwide. With the popularization of central heating and gas-fired heating systems, the proportion of coal residue in the municipal solid waste has decreased gradually while the proportion of organic waste has increased. For example, the proportion of inorganic waste, including coal residue, decreased by 39% from 1985 to 1996. Tables 1 and 2 show that the main component of Chinese municipal solid waste is bio-degradable bio-waste which includes kitchen waste, hotel and restaurant waste, vegetable market waste, and garden waste.

Table 1 Composition of Chinese municipal solid waste in 2003[7]

	Composition	Ratio (%)
Organic components (37.5%)	Food residues	31.0
	Paper and card board	2.5
	Plastics	1.5
	Wood	1.5
	Textiles	1.0
Inorganic components (62.5%)	Metals	1.0
	Glass	1.0
	Gravel	26.0
	Other	34.5

Table 2 Percentage of bio-waste in several Chinese cities[8] (%)

Beijing	Tianjin	Shanghai	Shenyang	Shenzhen	Guangzhou	Jinan
37	54	59	62	57	57	41

Urbanization in China has developed at a high rate with large-scale industrialization. More than 8 times as many cities were founded in China between 1978 and 1997 than during the 30 years before 1978, and there were 3.6 times as many cities in 1997 as in 1978. On average, there are 25.6 new cities in China every year[9]. Table 3 lists predictions for the quantities of municipal solid waste in China in the near future[9].

Table 3 Future municipal solid waste generation rates in China

Year	Urbanization rate (%)	Population in cities ($\times 10^8$)	Municipal solid waste ($\times 10^8$ t)	Organic waste ($\times 10^8$ t)
2010	43	6	2.64	0.99
2030	60	9.3	4.09	1.53
2050	76	11.9	5.28	1.98

Note: The waste generated from each citizen is assumed to remain constant at 440 kg per year, which was the average in 1994.

2.2 Advantages of anaerobic digestion technology for municipal solid waste

With the increasing quantities of municipal solid waste, limited landfill areas and increased environmental impact awareness, alternative methods are being sought to treat municipal solid waste. Anaerobic digestion is attractive because it contributes to the solution of several important problems in China.

(1) Anaerobic digestion provides an environmentally friendly method for treating municipal solid waste. Landfills are currently the most common municipal solid waste disposal method (Fig. 4[10]) in China. In 2000, about 25 million m^3 of landfill leachate[11] contaminated adjoining land and water sources while 17.6 million tons of undesirable CH_4 gas (calculated as CO_2)[12], which is a strong greenhouse gas, were produced by bio-waste deposited in landfills. Worldwide, societies are realizing that bio-waste needs to be

disposed of in more environmentally friendly ways, such as waste digestion and methane gas recycling.

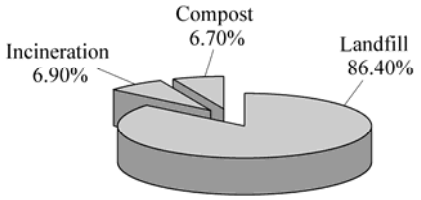

Fig. 4 Technologies used to treat municipal solid waste in China

(2) Anaerobic digestion will reduce land requirements for municipal solid waste disposal. 134.7 million tons of municipal solid waste was produced in China in 2001, and required about 500 million m^2 of land for disposal. With the increased urbanization in China, the cost of constructing and operating landfills will rapidly increase. Anaerobic digestion can substantially reduce the waste load on landfills.

(3) Anaerobic digestion can produce useful fertilizer. An attractive option for treating the organic fraction of these wastes by anaerobic digestion is to compost the digestion sludge and then apply the stabilized residue on the soil as a fertilizer.

Therefore, anaerobic digestion is the best technology for bio-waste disposal.

3 Development of Anaerobic Digestion Technology for Municipal Solid Waste in China

Considerable success in using anaerobic technology for processing bio-waste is being reported by several recently constructed facilities in Europe. A list of anaerobic digestion plants for processing municipal solid waste in Europe was given by Nichols[13]. Although anaerobic digestion has been used in China for over 100 years, it is usually used to treat human and animal manure along with agricultural by-products. Compared with the large advanced anaerobic digestion plants in Europe, China still has a long way to go in developing effective bio-waste processing systems.

3.1 Bio-waste collection system

In China, bio-waste is mainly collected without sorting and is then disposed of in landfills. The collection equipment and transportation vehicles always cause secondary pollution by leaking of leachate or dropping of waste from the vehicles to the environment.

Since municipal solid waste includes many components, the ratio of carbon to nitrogen of the waste may not be suitable for anaerobic digestion, which will hinder efficient operation of the anaerobic digestion plant. Therefore, the various components in the waste stream must be collected separately so that the ratio of carbon to nitrogen can be adjusted to a suitable range by mixing the waste from different sources. In addition, the use of food residues as direct feedstuff is being limited by new regulations and transportation concerns in Chinese cities. Therefore, regulations are needed to facilitate separate collection systems for bio-waste with appropriate disposal technologies.

If a bio-waste collection system can be set up and made compatible with existing collection systems, anaerobic digestion technologies for bio-waste disposal can be standardized. Since there are not yet any anaerobic digestion plants operating in any cities, an efficient design would be widely used throughout China.

3.2 Anaerobic digestion processing methodology

Most anaerobic digestion plants used around the world can be divided into single phase, two-phase, and batch style plants. Batch reactors have economic advantages in developing countries, but their organic load rate is much lower than continuous feed systems and the reactors take up a larger area. Two-phase anaerobic digestion reactors have good shock load tolerance for the separation of acidification and methanation processes, but the technique is complex and relatively expensive. Single-phase reactors provide an acceptable result at less cost.

Therefore, most recently built plants use single-phase reactors, with only 10.6% of the plants currently operating in Europe being two-phase plants.

3.3 Anaerobic digestion process efficiency

There are still some problems with the anaerobic digestion process efficiency not only for Chinese plants but also for the plants in developed countries.

The anaerobic digestion process is a biodegradation reaction whose conversion efficiency is relatively low. In addition, the digestion process can not go to completion, since the reaction rate slows as the digestible material is consumed. Therefore, to maximize the financial return on the investment in equipment, the

process cannot be allowed to go to the very end[6].

Conventional energy sources such as coal and petrol are primarily combustible molecules, but biogas contains about 40% CO_2, which reduces its combustion efficiency. Therefore, compared with other conventional energy generation sources, less energy is obtained from the anaerobic digestion process and the energy is obtained at a relatively slow rate.

New plants using high solid anaerobic digestion (with a total solid fraction of above 20% compared to low solid plants with 4%-8% solid fraction) can improve energy production somewhat due to their high digestion efficiency and the process residues can be more easily dehydrated, which saves a great amount of water. Valorga and Dranco mode high solid anaerobic digestion plants have reactor volumes of less than 3300 m^3 and heights usually less than 25 m. However, the high organic load rates and high salt and fat concentrations make high solid anaerobic digestion systems difficult to operate, so suitable control systems are needed for Chinese plants.

3.4 Pathogen control

Most reports state that the anaerobic digestion process can kill pathogenic bacteria, viruses, and parasites in the feedstock with adequate holding time and temperature; however, there are differences of opinion in different countries about the effectiveness. Therefore, this important issue needs further research and analysis[14].

For pathogen control, the thermophilic anaerobic digestion technology provides better control than the mesophilic technology, and subsequent treatments such as thermophilic compost of the residues can further improve the result.

3.5 Limitations to the spread of anaerobic digestion technology

The capital investment for energy production systems may be somewhat higher for anaerobic digestion systems than for conventional systems, and electricity is fairly inexpensive in China, unlike in many other countries. Nevertheless, the development of anaerobic digestion technologies is limited.

The costs of anaerobic digestion systems depend greatly on the local circumstances, including construction and labor costs, treatment capacity, the possibility of energy recovery, energy price, market, and taxes as well as the energy purchase tariff, land prices, and the worth of the digested material[15]. Although the equipment for high solid anaerobic digestion plants is expensive, the operating costs are relatively low considering their smaller sizes, higher digestion efficiencies and water savings.

However, with the increasing costs of landfills and energy taxes on fossil fuels, anaerobic digestion should be encouraged as a renewable energy source. Anaerobic digestion will be a highly competitive alternative for the treatment of municipal solid waste in the near future.

4 Use of Biogas for Combined Heat and Power (CHP) Systems in China

Fueled by electric industry deregulation, environmental concerns, unease over energy security, and many other factors, interest in CHP cogeneration technologies for distributed heat and power generation has been growing. Methane can replace natural gas as the fuel source in CHP systems.

CHP plants are electric power cogeneration plants that produce both heat and electricity from fuel. However, such facilities need to be strategically placed at or near customer facilities to efficiently supply the heating needs.

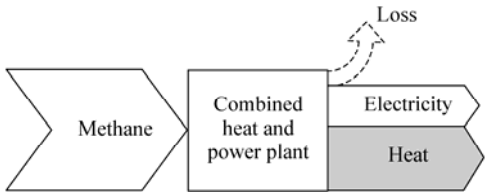

Fig. 5 Energy flow diagram for CHP

5 Conclusions

China is now trying to balance municipal solid waste disposal methods including landfills, incineration, and composting, but much better waste disposal methods should be devised based on the characteristics of each kind of waste. Bio-waste should be treated by anaerobic digestion to minimize the environmental impact. Anaerobic digestion systems will be a major shift to renewable resources to produce energy while reducing the discharge of anthropogenic methane into the environment. China's energy planning will seek to provide

sufficient energy at a reasonable cost to meet the increasing demand in ways that minimize environmental degradation and risks, conserve non-renewable resources, and realize the full potential of renewable energy sources. One great challenge is to quantify these benefits in physical and economic terms. Questions concerning environmental benefits of various anaerobic digestion solutions need to be answered in an increasingly more accurate manner in the near future. Special techniques are needed that are suitable for Chinese bio-waste because it has different components from European waste. A critical review is necessary to determine the reasons for failures in some plants. In addition, methods are needed to separately collect the various municipal solid waste components to increase the organic components in the feed to the digesters.

References

[1] Kalyuzhnyl S, Epov A. Evaluation of the current status of operating and closed landfills in Russia, Finland and Ireland with regard to water pollution and methane emission. *Water Science and Technology*, 2003, **48**(4): 37-44.

[2] Luning L, Zundert van E H M. Comparison of dry and wet digestion for solid waste. *Water Science and Technology*, 2003, **48**(4): 15-20.

[3] Ambulkar A R, Shekdar A V. Prospects of biomethanation technology in the Indian context: A pragmatic approach. *Resources Conservation & Recycling*, 2004, (40): 111-128.

[4] China Statistics Bureau. China Statistics Annals 2002. Beijing: China Statistics Press, 2003. (in Chinese)

[5] http://chanye.finance.sina.com.cn/hg/2004-02-09/198542.shtml.

[6] Bjorn D. Waste not-Burn it! International Directory of Solid Waste Management 1999/2000, the ISWA Yearbook, 228-236.

[7] Jin Guang, Wang Xiaotong. Analysis of bioenergy recycling from municipal solid waste in Chinese cities. *Energy Research and Utilization*, 2003, (1): 33-34. (in Chinese)

[8] Wu Yuping, Dong Suocheng. Status and prospect of current municipal solid waste treatment technology. *Urban Environment & Urban Ecology*, 2001, **14**(1): 15-17. (in Chinese)

[9] China Association of Mayors. Report on Chinese Urban Development. Beijing: Xi Yuan Press, 2003. (in Chinese)

[10] Xi Junqing, Jiang Huohua. Analyzing the current state and existing problems of city household garbage treatment. *Environmental Monitoring in China*, 2003, **19**(1): 21-22. (in Chinese)

[11] Zheng Yajie. The prediction of municipal refuse leachate in China and the control strategy for its pollution. *Urban Environment Urban Ecology*, 1997, **10**(1): 29-33. (in Chinese)

[12] Wang Wei, Han Fei. Study on methane generation from landfills in China. *China Biogas*, 2001, **19**(2): 20-24. (in Chinese)

[13] Nichols C E. Overview of anaerobic digestion technology in Europe. *Biocycle Energy*, 2004, **1**: 47-53.

[14] Tafdrup S. Viable energy production and waste recycling from anaerobic digestion of manure and other biomass materials. *Biomass and Bioenergy*, 1995, **9**(1-5): 330-314.

[15] Salminen E, Rintala J. Anaerobic digestion of organic solid poultry slaughterhouse waste—A review. *Bioresource Technology*, 2002, **83**: 13-26.