Systematic Solution for Reduction of Greenhouse Gas Emission From Refuse Landfills

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Abstract

Along with the rapid growth of municipal solid waste landfills in China, landfills have become the main source of CH_4 emissions. The effective collection and resource utilization of landfill gas will be the key field of greenhouse gas reduction. However, the current treating model of landfill gas, with low collection efficiency and level of utilization, and insufficient industrial development, is still the major restricting factor on the objective of landfill greenhouse gas reduction. On the premise of overall coordination between greenhouse gas emission control and landfill gas utilization, aimed at different stages of refuse landfills, this paper discussed the efficient collection, methane separation based on pressure swing adsorption, and landfill upgrading equipment, with several typical landfills in China as the actual case. The whole process systematic solution of efficient collection – purification and upgrading – resource utilization was proposed, which would provide technological support for greenhouse gas reduction from refuse landfills.

Keywords

refuse landfill, reduction of greenhouse gases emission, separation and purification of methane, pressure swing absorption, skid-mounted equipment

Introduction

In China, along with urbanization, population growth and industrialization, the quantity of municipal solid waste (MSW) generation has been increasing rapidly. No other country has ever experienced as large and as fast an increase in solid waste quantities that China is now facing. China has been the world's largest waste generator since 2004 and will likely produce twice as much MSW as the United States in 2030 [1]. It is estimated that the amount of solid waste produced by China will increase from 0.52 million tons per day in 2005 to 1.4 million tons per day in 2025 [2].

In general, China still has a long way to go in the management of solid waste with respect to solid waste recycling, treatment technology and management strategy when compared with many more developed countries, e.g., Germany, Sweden, Japan, and the United States. Throughout the country, the social, financial and environmental impacts of this growing waste generation are gaining attention and MSW management is becoming a major issue. Improvement in MSW collection, recycling and disposal will be an important goal for the governments of all cities in China in the years to come, and all aspects of China's MSW management systems will have to undergo great reform in order to achieve this goal.

Currently, waste composition in China is dominated by a high organic and moisture content, since the concentration of kitchen waste in urban solid waste makes up the highest proportion (at approximately 60%) of the waste stream [3]. Another major component of MSW in China is coal ash, which originates from household furnaces, as coal and wood are used for heating in the northern part of China and for cooking in major parts of the rural areas. However, the composition of MSW in China is extremely non-homogenous and the variation is caused by differences between cities: the level of industrialization and income, consuming habits etc.

MSW disposal in China is predominantly by means of landfill because it is cost-effective and it can accommodate large fluctuations in the amount and type of waste. In 2002, the amount of MSW disposal was 74.04 million tons, of which 89.3% was landfilled, 3.72% was incinerated, and 6.98% composted [4]. In 2006, the total MSW collected and transported was 148 million tons, of which 91.4% was landfilled, 6.4% was incinerated and 2.1% was composted.

The landfill gas (LFG) is generated by the biological degradation of organic matter, and is a serious concern in landfills. LFG has complicated compositions, which are CH_4, CO_2, H_2S, NH_3, H_2, and volatile organic compounds [5,6]. It has been estimated that CH_4 has 20 times greater global warming potential than CO_2. Along with the rapid growth of MSW landfills in China, landfills have become the main source of CH_4 emissions. The LFG is one of the major emission sources of anthropogenic greenhouse gases (GHGs) such as methane. Thus, the effective collection and resource utilization of LFG will be the key field of GHGs reduction.

On the other hand, the biogas production from LFG represents one of potential green energy or renewable energy from the viewpoint of sustainable development because its composition mainly includes GHGs (i.e. CH_4 and CO_2). The LFG after treatment is also a green fuel which can be used for electricity generation, a source of heat or a feedstock for fertilizer and methanol production.

On the premise of overall coordination between GHGs emission control and LFG utilization, aimed at different stages of refuse landfills, this paper discusses the efficient collection, methane separation based on pressure swing adsorption, and landfill upgrading equipment, with several typical landfills in China as the actual case.

Current situation and existing problems

The efficient collection and utilization will become the focus of GHGs emission reduction. The sanitary landfill of MSW in China started late, and the technical research of early landfill application was low, thus a large amount of LFG has been in the state of unorganized and uncontrolled discharge. It could cause serious environmental pollution and potential safety hazard. It's reported LFG explosion occurred in Shanghai, Beijing, Chongqing, Yueyang, and so on.

In recent years, along with the promulgations of a number of related polices and regulations, China has greatly promoted the reduction of landfill GHGs emissions. The release of "national action program of LFG collection and utilization in China" has vigorously promoted companies to participate in LFG collection and utilization projects and to give priority support. Besides, the release of "construction standards of MSW landfill project" has also strictly regulated the consumption and utilization of LFG. As far to 2014, there have been 604 landfill projects in China, with the processing capacity to 335316 t/d.

However, the current treating model of LFG, with low collection efficiency and level of utilization, and insufficient industrial development, is still the major restricting factor on the objective of landfill greenhouse gas reduction. Based on the analysis of the present situation of China's landfill industry, this paper puts forward the existing problems of high value utilization of LFG in China.

(1) extensive and inefficient collection of LFG

The LFG is an important source of GHGs, thus efficient LFG collection systems are the basis for achieving GHGs emission reduction. However, due to the technical means and equipment costs, there are extensive LFG inefficient collection problem in China and abroad. For example, among the 13 landfill sites in Beijing, only two sanitary landfills were designed to collect LFG [7]. What's worse, in some cities it is not very clear what the chemical composition of the gas produced from the landfills really is, nor what the health effects might be on workers of the facility who are exposed to the landfill gas, or the effects on the population nearby. Therefore, in order to control the GHGs emission reduction, the efficient collection technologies and systems of LFG need to be developed.

(2) limited means of LFG utilization

There are three conventional fates that entail captured LFG:

- Combined heat and power (CHP) production with a gas engine;
- The combination of heat generation for the asphalt production process in the summer and district heat production by a water boiler in the winter;
- LFG upgrading to biogas (corresponding to the quality of natural gas).

The primary objectives of these practices are to recovery energy and protect the people and the environment from the volatile nature of LFG, respectively. On the one hand, CHP generation efficiency is limited to factors, such as landfill scale, technical means and equipment costs, which makes most of the small and medium sized landfill projects are still using flare burning for LFG. On the other hand, the landfill projects are not in considerable need of electricity and heat, which result in the improvement of LFG utilization.

(3) insufficient development of industrial equipment with methane separation technology

The LFG separation application started late and had a lower level of equipment, especially the pressure swing adsorption (PSA) process and the emerging membrane separation process. Most of the cities rely on imports to introduce advanced LFG separation equipment from abroad. Lately, although a variety of LFG separation technologies have been applied and practiced in the country, the GHGs emission reduction is still limited by the lack of key technology and ancillary equipment of high value utilization of LFG.

Systematic solution for the reduction of GHG emission from landfills

1. Collection system of GHG

Higher gas collection efficiency increases the amount of LFG available for utilization purposes and hence enables higher GHG emission savings while direct gas emissions from the landfills to the atmosphere decrease. Considering the fact that the gas collection efficiency is a crucial factor in the mitigation of GHG emissions, it is important to pursue as high collection efficiency as possible. After the gas is collected, it can be treated, thus decreasing the global warming effect strongly. USEPA has given 75% as a default value for the collection efficiency when the collection system is in use and operates without problems. In this paper, the whole process collection system of GHGs from landfills is proposed. It is divided into two scenarios, GHGs collection system during the landfill operation and GHGs collection system after landfill closure.

(1) GHGs collection system during the landfill operation

At present, traditional anaerobic bioreactor landfill is mostly used in China. There is serious odour pollution, deep leachate accumulation and other issues. During the operation process of landfills, the CH_4 emission from the landfill operation is the main source of GHGs emission. Therefore, it's the key of GHGs reduction to effectively control the CH_4 emission. Based on that, for the landfills under operation, the collection system combined high-density polyethylene membrane (HDPE membrane) with horizontal well was recommended (Figure 1).

Horizontal trenches are laid between two waste layers, which is convenient to collect LFG during landfill operation. Using the HDPE membrane to cover the landfill, it plays a good gas sealing effect, with the addition of horizontal trenches under the HDPE membrane, it also improves the LFG collection efficiency. In addition, this system doesn't need specialized drilling equipment, with the simple construction, synchronized with the landfill operation. In 1997, the first MSW landfill using a HDPE membrane as liner material, Xiaoping Solid Waste Landfill in Shenzhen, was built and put into use [8].

Fig.1. On-site pictures of efficient collection system of GHG in refuse landfill of Liaoning province.

(2) GHGs collection system after landfill closure

After the closure of a landfill, the methane generation of LFG decreases making the utilization difficult. Although the amount of yearly generated methane reduces, the generation may continue decades after the closure and thus create notable cumulative GHG emissions in the long term. This paper proposes the combination of comprehensive coating technology, leachate three-dimensional guide process and vertical collection wells (Figure 2). The vertical wells can be laid from bottom of landfill, also can be built after landfill closure. It can realize the uniform distribution of water and smooth guide of leachate, at the same time, the control CH_4 emission from the closed landfills. In 1991, the first MSW landfill, Hangzhou Tianziling Solid Waste Landfill was built and put into use. A vertical cement curtain technology was first used in the landfill to prevent leachate from polluting the groundwater.

Fig. 2. On-site pictures of vertical shaft collection system in refuse landfill of Fujian province

2. Optimization of CH_4 separation technology based on pressure swing adsorption (PSA)

The raw LFG contains a large share of carbon dioxide (CO_2) which must be removed before utilization in many applications, for example, using the gas as vehicle fuel. Logically, gas utilization is more advantageous than treatment because the LFG utilization can replace the use of fossil fuels [9]. The LFG upgrading technology to separate CH_4 is the key to fulfill significant reduction of GHGs emissions. The process – LFG upgrading – can be performed with several technologies: water scrubbing, organic solvent scrubbing, amine scrubbing, pressure swing adsorption (PSA), and gas separation membranes. Table 1 lists the comparisons of the different technological characteristics.

Table 1. Comparisons of the characteristics among PSA, water washing, and medical washing.

Parameters	PSA	water washing	medical washing
pretreatment of gas	Yes	No	Yes
operation pressure (bar)	4-7	4-7	No
chemical agent	No	No	Yes
CH_4 yield of products	>96%	>97%	>99%
energy consumption (kWh/Nm^3)	0.25	<0.25	<0.15
recovery of CH_4	medium	high	high
heat	no	no	Yes (160 ℃)

PSA is a dry method used to separate gases via physical properties, i.e. the physical interaction between the gas molecules and the adsorbent material. The adsorbents used are porous solids with high specific areas to maximize the gas-adsorbent contact. The adsorbents are either of the equilibrium type, adsorbing a larger load of carbon dioxide than methane, or of the kinetic type, adsorbing carbon dioxide faster than methane due to controlled diffusion rates. Common materials are activated carbons, natural and synthetic zeolites, titan silicates, silica gels, and carbon molecular sieves [10]. The adsorbents are commonly irreversibly damaged by hydrogen sulfide, which thus must be removed from the gas before the PSA columns [11]. Figure 3 shows a simplified process flow diagram for a PSA unit. The PSA proved to be the best choice of technology for the separation of carbon dioxide from LFG nowadays.

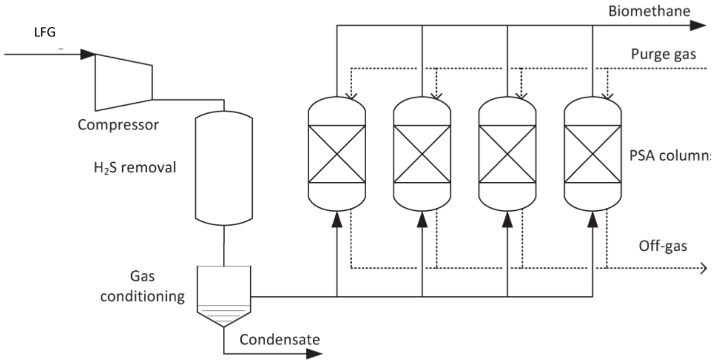

Fig.3 Simplified process flow diagram of a pressure swing adsorption unit

As for the development of efficient adsorbent used in PSA, our team conducted research on silica gel and activated carbon to promote the localization of adsorbent materials. The development of adsorbents will facilitate rapid cycling to enhance productivity, devising cycles to get both products of high purity.

The experiment reported that carbon dioxide was able to be increasingly adsorbed by modification 1% $BaCl_2$ on silica gel. The separation factor of CH_4/CO_2 mixture gas was up to 9.55, which showed the new type absorbent paved the way to increase the methane content. Application of PSA with modified absorbent in CO_2 removal from LFG should be expanded to apply the rightful utilization of renewable and sustainable energy for future.

3. Research and development of skid-mounted equipment for LFG upgradation

To improve the status quo of the low LFG separation technology and equipment level is a very important task in the future industry. In the field of LFG upgradation, the serialization, integrated design and application of processing unit of the equipment should be carried out. Skid-mounted mobile equipment are desirable for upgrading LFG for relocation at different sites. Taking the integration of methane separation and purification equipment in one landfill site of Guizhou Province as an example, this paper introduces the development process of skid-mounted equipment for LFG upgradation (Figure 4).

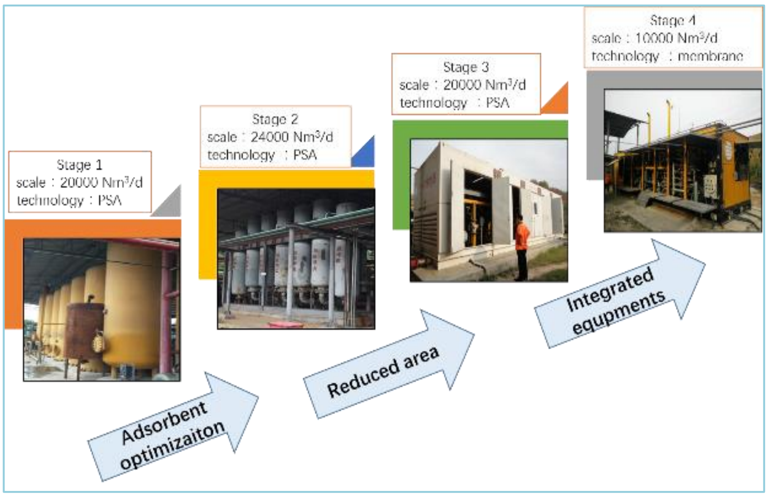

Fig. 4 Research and development of integrated landfill gas upgradation equipment in Guizhou province.

In the first stage, the LFG upgradation equipment based on PSA were applied. The processing scale could be 20000 Nm^3/d. Although the quality of produced gas met the national standards, it still had the problem of large plant size, high cost, et al. Then the project applied the modified adsorbent in the PSA process. On one hand, it promoted the localization of adsorption materials; on the other hand, it increased the absorption capacity one times larger. Besides, it decreased the plant size and also smaller the area of this project.

In the third stage, the project achieved the development of skid-mounted mobile equipment for LFG upgradation. Sensors, analysis equipment, control systems and valves were carried out in one container. The dimensions of the pipes and valves were also smaller. This innovated development and research not only reduced the plant size but also reduced the energy consumption by orders of magnitude.

In recent years, upgrading using membrane technology is now available and has been rapidly gaining interest from the market actors. The membranes used for LFG upgrading retain methane while the carbon dioxide is able to permeate through the membrane. During the separation of carbon dioxide from the raw gas, other compounds such as water vapor and hydrogen are removed from the methane. The advantages usually presented for membrane technology is the lack of demand for water or chemicals and the ability to scale down the process without large efficiency losses. So in the fourth but not final stage, this project applied the membrane technology in the LFG upgradation. It made the technology a viable alternative to the other technologies in the field of LFG upgradation.

Conclusions

Based on the practical experiences of domestic engineering cases, this paper put forward the whole process systematic solution as is shown in Figure 5. The whole process systematic solution of efficient collection – purification and upgrading – resource utilization would provide technological support for greenhouse gas reduction from refuse landfills.

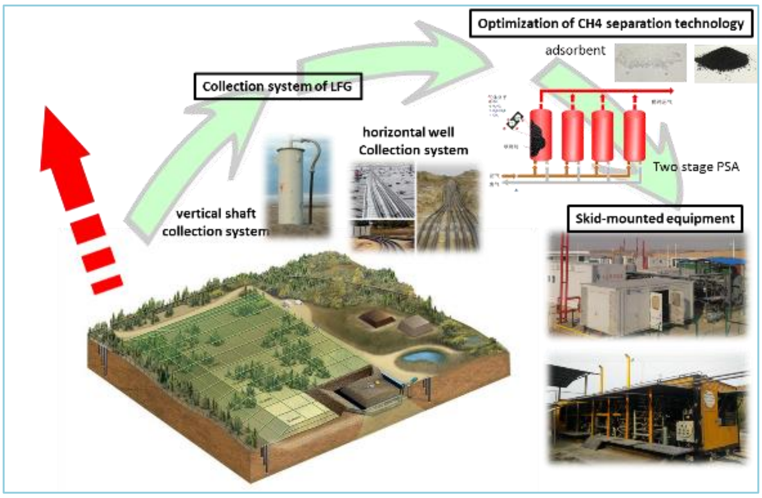

Fig. 5. Systematic solution for the reduction of refuse landfill greenhouse gas emission

The LFG production is increasing in China and around the globe, and so is the interest in the efficient use of upgraded LFG as vehicle fuel or in other applications. Besides, the GHGs emission reduction also has the significant meaning to the environment protection. The market for LFG upgrading and GHGs reduction will most likely be characterized by harder competition with the establishment of new upgrading technologies and further optimization of the mature ones to decrease operation costs. Except for optimization of the upgrading plants to minimize the need for energy and resources, the further integration of LFG upgrading with end-user applications is interesting for future development of the technologies.

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