

Application of Waste Anaerobic Digestion in HVAC

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Abstract: Anaerobic digestion (AD) involves the decomposition of organic matter by micro-organisms in an oxygen-free environment. It results in two by-products: biogas (approximately 60% CH₄ and 40% CO₂) and a digested organic sludge. Biogas can be used in combined cooling heating and power (CCHP) system to generate electrical power. Anaerobic digestion is becoming more and more attractive for the treatment of organic solid waste since it produces, rather than consumes, energy and can be carried out in relatively small, enclosed tanks. The theory, technical flow and development of anaerobic digestion of waste to produce biogas were introduced. Compared with dispose of in landfills, compost or incinerate, the advantage and barrier of using the technique of anaerobic digestion to treat municipal solid waste was also analyzed. Then application of waste anaerobic digestion in a CCHP project was presented in detail. Analysis showed that it had good environmental protecting and economic benefit to apply waste anaerobic digestion in CCHP.

Keywords: waste's resource recycling; anaerobic digestion; CCHP

1. INTRODUCTION

Biomass resources include wood and wood wastes, agricultural crops and their waste by-products, municipal solid waste, animal wastes, waste from food processing and aquatic plants and algae. Biomass is used to meet a variety of energy needs, including generating electricity, heating homes, fuelling vehicles and providing process heat for industrial facilities. The conversion technologies for utilizing biomass can be separated into four basic categories: direct combustion processes, thermochemical processes, biochemical processes and agrochemical processes^[1]. Now every country is paying great attention to utilization of biomass resources under the instruction of sustainable development.

Municipal solid wastes (MSW) are a significant biomass resource that can be exploited for their energy potential, and its recovery is an effective way to save energy, protect resource and environment^[2]. There are four basic conversion technologies to utilizing MSW, include biochemical process, pyrolysis, gasification and direct combustion processes. Biochemical process converts MSW into biogas or ethanol through anaerobic digestion (AD)^[3]. Biogas may be readily obtained by the anaerobic digestion of organic waste and can be used in combined cooling heating and power (CCHP) system to generate electrical power. CCHP system refers to an integrated energy system that integrates cooling, heating and power based on "ascending-descending" utilization of energy. CCHP converts fuel on site, improves energy utilization efficiency, reduces emission of contamination and greenhouse gas greatly, and support an effective method to ease electric peak demand and ensure the safety of grid. According to

calculation, CCHP can bring the building energy efficiency up to 90%^[4]. If CCHP system is used to generate electricity the heat recovered can be used to maintain temperature levels within the anaerobic digester. CCHP systems covers a range of technologies but indicative energy outputs per m³ of biogas are 1.7 kWh electricity and 2.5 kWh heat. The combined production of electricity and heat is highly desirable if it displaces fossil fuel energy demand elsewhere and therefore reduces the amount of carbon dioxide released into the atmosphere.

2. ANAEROBIC DIGESTION OF MSW

2.1 General description

MSW is an inhomogeneous waste, which may be divided into a number of sub fractions^[5]: (1) Digestible organic fraction. Bioorganic matter, which is readily degradable, i.e. kitchen wastes, grass cuttings etc. (2) Combustible fraction. Slow digestible and indigestible organic matter, i.e. wood, paper, cardboard, plastics and other synthetics etc. (3) Inert fraction. Stones, sand, glass, metal, bones etc. In general about 50% of MAW consists of organic matter.

In most countries MAW is collected as a mixed stream and disposed of, typically, by landfill or incineration. These disposal methods are not definitive solutions, as they do not eliminate completely the waste materials and do not take advantage of the properties of the organic fraction or its potential for composting and recycling nutrients and organic matter. Generally only a small part of the MSW is recycled (waste paper, bottles etc.) usually excluding the digestible fraction. The methane content of landfill gas is a potent greenhouse gas, and landfills make a significant contribution towards the world's anthropogenic emissions of methane. As

to incineration, it easily produces soot and poisonous gas during the process and leads to second pollution. It can be predicted that only some poisonous waste will be disposed of by incineration. In recent years both source separation and recycling have attracted increasing attention. Many countries are striving towards targets of waste minimization, recycling, and more environmentally safe technologies, and anaerobic digestion has become an established and proven technology for treatment of the organic fraction of MSW^[6]. It is the preferred waste treatment process since it produces, rather than consumes, energy and can be carried out in relatively small, enclosed tanks.

2.2 Technology of anaerobic digestion

Anaerobic digestion (AD) is a natural process of decomposition and decay that takes place in the absence of oxygen and by which organic matter is broken down to its simpler chemical components. It results in two by-products: biogas (approximately 60% CH₄ and 40% CO₂) and a digested organic sludge. AD treats waste by converting putrid organic materials to carbon dioxide and biogas. This decomposition takes place in three stages: (1) hydrolysis whereby the insoluble solids are broken down into soluble monomers; (2) acid formation whereupon the soluble monomers are converted to volatile fatty acids; and (3) methane formation in which the acids are converted to biogas and a residue or sludge^[7]. The conversion of solids to biogas results in a much smaller quantity of solids that must be disposed.

The main steps in the treatment of MSW using AD are pretreatment, anaerobic digestion and post treatment^[8].

Pretreatment

Before anaerobic treatment it is necessary to pretreat the MAW in order to increase the digestibility and ensure an end product that can be applied on farmland and gardens. Pretreatment processes are described below. In some cases the process steps as described below serve more than one purpose. For example, in wet systems separation and particle size reduction can take place more or less simultaneously or in one piece of equipment. As a general rule handling in a biogas plant is far easier when MSW is source separated.

(1) Sorting

The quality of MSW as received will determine whether further mechanical or even handsorting may be required. Indeed, even source separated organic MSW will require some further separation to remove wrongly sorted materials such as plastics, metals and larger sized materials.

In some cases the source-sorted organics are delivered in bags (the use of plastic bags should however be discouraged). In these cases a bag opener may be necessary. Separation is performed either before or after digestion, but usually before.

The separation is performed either under wet or dry conditions. Wet separation is most suitable for wet digestion systems, whereas dry separation is most appropriate for dry concepts. Wet separation is usually performed in a pulper. The pulper not only

provides separation, but also results in particle size reduction and even 'suspension' of the softer parts of the organic matter. For dry separation rotating drum systems are widely applied.

(2) Particle size reduction

Size reduction is necessary to render the organic matter to an appropriate and more homogeneous size distribution. The size reduction is performed using screw cutting, milling, drumming, pulping, shredding, etc.

Digestion

Organic matter decomposes mainly in two ways depending on the availability of oxygen. In an atmosphere without oxygen (anaerobic conditions) organic matter will decompose and produce biogas: a mixture of methane and carbon dioxide. In the presence of oxygen (aerobic) no useful biogas will be produced.

Anaerobic digestion is a complex biology process, and occurs by itself in nature where the right physical conditions are created like the bottom of lakes, in swamps, peat bogs and in landfills. However, by controlling (in plant) conditions such as temperature, concentration, pressure, humidity, microbial activity and waste properties, the process may be stimulated and accelerated. The optimum temperatures for anaerobic digestion are either 35°C or 55°C depending on the application and its operating conditions. The optimum pH and C: N ratio are around 5-8 and 25:1-30:1, respectively. The anaerobic digestion takes place through the action of a consortium of four different types of micro organism: hydrolytic, fermentative, acetogenic and methanogenic.

The gas yield depends mainly on factors such as digestibility of the organic matter, the efficiency of the adapted bacteria culture, the retention time in the digester and the digestion temperature. In thermophilic digestion (50-55°C) the rate of digestion is more rapid than at mesophilic digestion (35-40°C). Furthermore, the gas yield is increased by increased retention time. The Solids Retention Time (SRT) is the most important factor controlling the conversion of solids to gas. It is also the most important factor in maintaining digester stability. Although the calculation of the solids retention time is often improperly stated, it is the quantity of solids maintained in the digester divided by the quantity of solids wasted each day. The volatile solids conversion to gas is a function of SRT. At a low SRT sufficient time is not available for the bacteria to grow and replace the bacteria lost in the effluent. If the rate of bacterial loss exceeds the rate of bacteria growth, "wash-out" occurs. The SRT at which "wash-out" begins to occur is the "critical SRT". Jewel established that a maximum of 65 percent of dairy manure's volatile solids could be converted to gas with long solids retention times^[9]. Burke established that 65 to 67 percent of dairy manure COD could be converted to gas. Long retention times are required for the conversion of cellulose to gas^[10].

Anaerobic digestion may be performed in various ways. Currently, the leading concepts are: dry continuous systems, dry batch systems, wet continuous systems and co-digestion (mainly using liquid manure or sewage sludge). In general, these

systems perform digestion in one stage. Except for the wet continuous systems, these are often operated in two stage plants.

Anaerobic filters usually comprise two or multi-stage systems where the hydrolysis and acidification occurs in the first reactor and methane fermentation in the second reactor. High concentrations of methadone's are retained in trapping devices onto which the bacteria can adhere and not be flushed out. All solids must be removed to avoid clogging of filters.

The digestion procedures can be divided into plug flow, completely mixing or anaerobic filters (see above). Plug flow refers to the biomass flows in a way that prevents fresh biomass from being mixed with partially digested biomass. In the completely mixed mode, fresh biomass is pumped at interval directly into and out of the reactor and thereby immediately mixed with the biomass undergoing digestion. The mixing can be done either mechanically or by gas injection.

Post-treatment

After digestion the material usually needs some kind of refining before it can be used for horticulture or agriculture.

If the MSW is treated wet the material can be spread directly on the farmland as slurry or it can be separated in a solid and liquid fraction. The solid fraction can be matured to compost for about 2-4

weeks and the liquid fraction can be spread on farmland or treated in a wastewater plant. If the MSW is treated in a dry process the digested material is usually dewatered and matured to compost. The liquid effluent can be used for mixing and inoculation of the incoming MSW, but there will usually be effluent in excess that has to be spread on farmland or cleaned in a wastewater plant.

Typically 1 ton of organic MSW produce in the range of 100-200 m³ of biogas. And a typical composition is given below:

Table 1: composition of AD/MSW products

Energy content	20-25 MJ/m ³
Methane vol. %	55-70%
Carbon dioxide vol. %	30-45%
Hydrogen sulphur	200-4000ppm

2.3 Advantage of AD

The decision to implement AD of MSW rather than alternative technologies depends on a number of factors, and now the portion of AD of MSW gradually increase, mainly because AD of MSW has many advantages (see table 2)^{[10],[11]}. Kubler has reported that, 1-ton MSW that was treated with sorting plus AD can produce 0.2 ton greenhouse gas less than that with sorting plus landfill method^[12].

Table 2: advantage of AD

Energy benefits	Net production of energy, providing the biogas is used Reduced CO ₂ emissions, by displacement of fossil fuels Potential to treat the "wet" fraction of MSW which is less amenable to incineration Potential for the economics to benefit from (future) higher energy prices and/or buy back tariffs The power generated is "distributed power" which minimizes the need to modify the power grid. The impact of new power on the power grid is minimized
Environmental benefits	Environmental benign waste treatment Recycling benefit, providing the compost is used Reduction of odours and greenhouse gas emission Lower land requirement compared to aerobic composting Potential to treat the organic fraction of MSW in countries considering banning land filling of waste Potential salt reduction in compost, compared to aerobic composting Nonpoint source pollution is substantially reduced
Waste treatment benefits	Volume reduction of the waste for subsequent disposal Potential for co-disposal with other organic waste streams (e.g. industrial wastes such as food processing waste and agricultural wastes such as manure)

2.4 Forum 2004 CCHP project

Three basic options can be distinguished for the utilization of biogas: (1) production of electricity: generally, gas engines or gas turbines or fuel cells are applied, mainly making use of the residual heat (cogeneration). Typically a gas engine has an electric efficiency of 33%. (2) Production of heat in a boiler: generally implying the sale to an energy consumer or for district heating. (3) Upgrading of the biogas to distribution grid quality. Now the biogas is mainly used in CCHP system to utilize energy efficiently. Jan has researched the application of biogas in a fuel cell CCHP system, and concluded that biogas presents an attractive option among emerging applications for fuel cells, especially for the high temperature ceramic type solid oxide fuel cells (SOFCs). Compared to natural gas, it shows advantages of being indigenous

and renewable, free of non-methane hydrocarbons, with the exception of landfill gas and containing a large fraction of a methane-reforming agent (CO₂)^[13]. Utilization of biogas as energy in a CCHP system has attracted great attention, and let's see the district CCHP system of the first Universal Forum.

The first Universal Forum held in Barcelona, Spain from May 9 to September 26, 2004 spanned 141 days. The 29th UNESCO Conference set the themes of the "Forum" as follows: cultural diversity, sustainable economic development and world peace. The environmentally friendly project, which includes garbage recycling/regeneration plant, a cogeneration plant and a power heat recovery cooling system that provides air conditioning for the Forum complex, has become the highlight of the Forum. Figure 1 shows the district energy system diagram. Under the guide

sporting events or performances. (3) Higher reliability. It can still meet the cooling load requirement even if one chiller or one water pump stops, for its cooling storage capacity is several times greater than the chiller cooling capacity. (4) More energy saving. Chiller can run continuously for 24 hours. This is good for chiller's stability and life span. The chiller can also run continuously at the most energy saving status, for COP of an absorption chiller reaches its highest at 40% to 80% part load. In spring and autumn, chillers can be started once every several days. During most of the time, only the chilled water pump is needed to provide cooling to the whole system. This avoids chillers operating at an extremely low load, which is low efficiency. Furthermore, it saves much electricity consumption of the cooling water system.

According to calculation, the CCHP system can reduce CO₂ emission and 32 % primary fuel consumption through recycling of waste.

3.CONCLUSION

AD has the potential to deliver multiple environmental benefits, including reduced water pollution potential, lower greenhouse gas emissions, and reduced odours from agricultural slurries. In places that have high concentrations of animal waste threatening water quality AD can play a significant role in managing the problem. Anaerobic digestion of MSW represents the direction of waste recycling, and more and more country pay attention to application of anaerobic digestion of MSW, especially in the CCHP system. Whereas there are some barriers exist. Cost is the major barrier, as AD is (slightly) more expensive than composting in many cases. AD of MSW does not treat whole waste, just a fraction of it. The use of AD to treat MSW is a novel application, and information on economic and practical issues is not widely disseminated. But we believe that choosing for AD now is choosing for a more sustainable future.

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