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Application and development of biogas technology for the treatment of waste in China

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ABSTRACT

China has a long history of utilizing biogas technology for the treatment of waste and the production of energy. This paper reviews the development and technology of the three types of biogas digesters used in China: household-scale digesters, biogas septic tanks, and biogas plants for the treatment of municipal, industrial, and agricultural waste. The structure of household-scale digesters is simple and practical; the basic type is the fixed-dome digester, also called the hydraulic digester. The biogas septic tank for sewage treatment is a combination of the traditional digester, an anaerobic filter, and a facultative filter.

Biogas plants apply several different processes depending on the type of waste treated. The treatment of municipal waste biogas is conducted using the completely stirred tank rector (CSTR). The upflow anaerobic sludge blanket (UASB) is the most common technology used in the anaerobic treatment of industrial wastewater, followed by the CSTR and the anaerobic contact (AC) process. The treatment of agricultural waste mainly employs traditional hydraulic digesters, while newer biogas plants use advanced anaerobic processes such as CSTR and UASB as well as upflow solids reactors (USR) and upflow blanket filter (UBF) reactors. Biogas plants for agricultural waste are classified as small, medium, large and super large based on the scale of biogas production and digester volume.

Although small-scale biogas plants are the most common, large-scale biogas plants produce the largest biogas output. With the changes associated with socio-economic development, the growth of household-scale digesters will slow down in the future. As central sewage treatment networks become more widespread, biogas septic tanks will be confined to villages and small towns. The development of biogas plants holds the most growth potential for the future.

1. Introduction

Biogas fermentation, also called biogas technology or anaerobic digestion, is a promising waste treatment alternative because it results in the production of renewable energy sources such as methane while simultaneously removing organic pollutants. China has a long history of utilizing biogas. The 13th-century adventurer Marco Polo believed that covered sewage tanks were used in China probably as far back as 2000–3000 years ago [1]. In the 1880s, a test of biogas production using simple building digesters was carried out in the Chao Mei area of Guangdong Province. Since the early 20th century, anaerobic technology has existed on an industrial scale in China. Guorui Luo built the first modern digester in China in the 1920s It was named the “Chinese Guorui gas vessel”, and used garbage as feedstock to supply cooking and lighting fuel for his home on Xinxing Road, Shantou City, Guangdong. In 1929, he established the Shantou Guorui Biogas Lamp Company. In 1931, Guorui Luo moved the company to Shanghai and changed the name to the Chinese Guorui Biogas Company. He established a number of branches along the Yangtze River and in the southern provinces. The technology spread quickly into the 13 southern provinces around the Yangtze River. The first monograph on biogas in the world, the Chinese Guorui Biogas Digester Practical Lecture Note, was published in 1933. Unfortunately, this first biogas wave died down with the outbreak of the Sino-Japanese war in 1937 [1].

The Chinese government put forward a call to find alternative energy sources to replace oil in 1957, setting off the second biogas wave in China. Development efforts were centered in Wuchang, as biogas scientists worked to exploit the multiple functions of biogas production, simultaneously solving the problems of manure disposal and the

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need for improved sanitation [2]. Jiang Zigang proposed a testing scheme using animal manure to produce biogas, and this was the starting point of the second biogas wave. The Great Leap Forward ended the second biogas movement. Over 100,000 digesters were discarded because of a shortage of scientific programming and practical technical regulation [3].

The third biogas wave occurred between the late 1970s and early 1980s when the Chinese government decided that biogas production could be an effective and rational way to utilize natural resources as an aspect of agricultural modernization, providing benefits such as energy access, environmental protection, and improvements in sanitation. More than 7 million digesters were built during this period, making China one of the leading nations for biogas development. Representatives from developing countries came to China to learn about the technology. Unfortunately, half of the digesters were abandoned in the 1980s owing to various technical barriers, such as gas and liquid leakage, insufficient feedstock of animal manure (and also human feces), difficulty in handling straw as feedstock, and a lack of knowledge regarding maintenance and monitoring [2].

Beginning in 2000, the Chinese government again began promoting rural biogas as a solution to two major problems – the rural energy shortage and widespread environmental pollution. The government provided incentives and financial supports that have spurred growth and development in the application of biogas technology for waste treatment up to the present.

The benefits of biogas extend beyond energy production. Biogas digestate can be used as an organic fertilizer for agriculture, increasing independence from chemical fertilizers, pesticides, and fossil fuels, and resulting in mitigation of greenhouse gas emissions. Biogas technology addressed several rural problems such as a lack of clean cooking fuels (and associated indoor air pollution), help with disease transmission interdiction (human and animal waste are often infection sources), water pollution from waste, and reductions in the biochemical oxygen demand in wastewater [4,5].

2. Application and development of different types of biogas digesters

In China, there are three types of biogas digesters: household-scale digesters, biogas septic tanks, and biogas plants.

2.1. Household-scale digesters

Household-scale digesters are adaptable for the treatment of waste from decentralized livestock and poultry breeding. Some household-scale digesters also use straw as feedstock. A typical household digester has a volume of 6–15 m^3, and can treat waste of 8–20 pigs, 1–2 cows, or 150–200 chickens, producing 0.8–2.0 m^3 of biogas per day.

Most household-scale digesters have a fixed-dome structure, and are also called hydraulic digesters. The fixed-dome digesters were developed in the 1970s and the basic construction and design have not changed. National standard guidelines state that the fixed-dome digester should be assembled using three components: the digester, a human toilet, and an animal house [6]. A typical fixed-dome digester consists of an underground well-like digester, made of bricks, cement, and reinforced concrete, and a dome-shaped roof below ground level. There are two rectangular openings starting near the middle of the digester and coming up to a little above ground level. These two openings face each other and act as the inlet and outlet points for the digester. The outlet also acts as the hydraulic chamber. The dome-shaped roof is fitted with a pipe at the top that is the biogas outlet. The biogas accumulated in the dome exerts pressure on the slurry, thus pressing it from the digester into the inlet and outlet tanks.

Over the past 40 years, technology for the fixed-dome digesters has improved significantly, and many innovative and efficient household-scale digesters have been developed to replace the traditional fixed-dome digesters. Examples of new designs are the hydraulic cylinder digester, meandering stream digester, prefabricated block digester, and spheroidal digester [4,7]. In recent years, due to the increasing labor costs and the tendency of the traditional fixed-domed digesters to leak, alternative construction materials have been introduced, including high-density polyethylene, polyvinyl chloride (PVC), inflatable plastic materials, and glass-fiber-reinforced plastic.

Compared with the floating-dome digester, a design from India [8], the fixed-dome digester is more advanced in the following aspects: lower construction costs, absence of moving parts and rust-prone steel parts, longer life span, more compact, and less temperature variation due to underground construction. However, there are disadvantages to the fixed-dome type digesters. Due to its high gas pressure, even a small crack in the upper brick work will cause substantial biogas leakage. In addition, gas pressure can fluctuate substantially depending on the volume of stored gas. Even though underground construction buffers temperature extremes, digester temperatures are generally low [8].

Biogas technology and agricultural production technologies, such as crop farming and animal breeding, can be integrated to different eco-agriculture systems with the household-scale digester as the link, typically represented as "pig–biogas–fruit" (an integration of pig breeding, biogas production, and fruit-tree planting) in South China [9], and "four-in-one" (with pig breeding, biogas production, toilet and vegetable planting in greenhouses) in North China [10].

The third biogas peak between the late 1970s and early 1980s is clearly shown in Fig. 1. From 1984 to 1994, development of household-scale digesters almost completely stopped. However, starting in 2000, household-scale digesters developed rapidly. By the end of 2014, there were over 41.83 million household-scale digesters in China for the treatment of waste of livestock and poultry and domestic sewage, and the total biogas output was 13.25 billion m^3 in 2014. The development

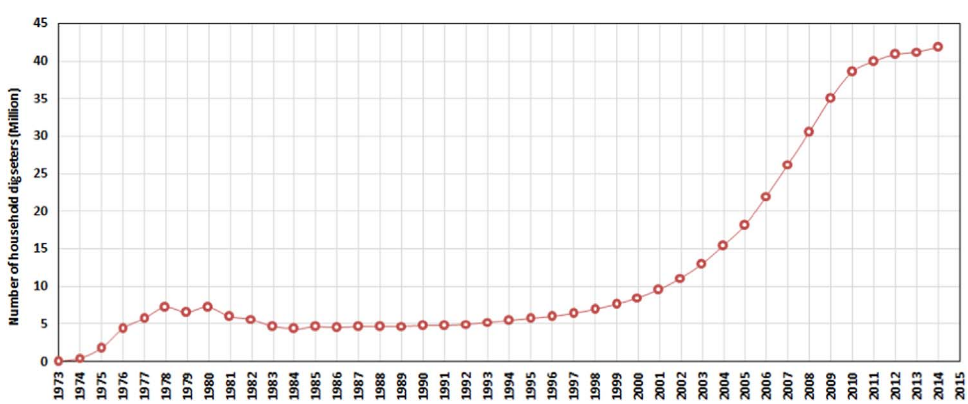

Fig. 1. Development of household digesters in China.