Chapter 2
A Brief History of Anaerobic Digestion and "Biogas"

Abstract This chapter briefly traces the history of anaerobic digestion from the time the existence of this phenomenon was first recorded four centuries ago to its rapidly increasing popularity at present. The extent of adaptation of biogas technology across the world is also briefly reviewed. Whereas China and India lead the initiative from among developing countries, the thrust of the developed world is mainly coming from Western Europe.

2.1 Introduction: Discovery of Biogas

It has been known from several centuries that combustible gas is generated when organic waste is allowed to rot in huge piles. For example in the seventeenth century, Van Helmont recorded that decaying organic material produced flammable gases. In 1776, Volta resolved that there was a direct connection between how much organic material was used and how much gas the material produced. That this combustible gas is methane was established by the work conducted independently by John Dalton and Humphrey Davy during 1804–1808 (Tietjen 1975).

Bechamp, in 1868, reported that the formation of methane during the decomposition of organic matter was through a microbiological process. Omelianski, in the 1890s, isolated microbes responsible for the release of hydrogen, acetic acid, and butyric acid during methane fermentation of cellulose. He also reported that methane perhaps formed due to micro-organism-mediated reaction between hydrogen and carbon dioxide (McCarty et al. 1982). Later, in 1910, Sohngen seconded Omelianski's findings. He also reported that fermentation of complex materials occurs through oxidation-reduction reactions to form hydrogen, carbon dioxide, and acetic acid. He demonstrated that hydrogen then reacts with carbon dioxide to form methane. He also assumed that acetic acid through decarboxylation forms methane. This assumption remained highly controversial for decades but is now known to be essentially correct (McCarty et al. 1982).

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2.2 Development of Anaerobic Digestion as a Wastewater Treatment Process

A Frenchman, Mouras, applied anaerobic digestion for the first time to treat wastewater, in his invention of a crude version of a septic tank in 1881, named by him "automatic scavanger" (McCarty et al. 1982). Subsequently an Englishman, Cameron, constructed a tank in 1895 which was similar to Mouras's "automatic scavenger" but had better treatment efficiency, and termed it "septic tank." Because of the successful results achieved in using these tanks, the local government of Exeter in 1897 approved the treatment of the entire city's wastewater by these septic tanks. Moreover, the value of the methane gas which was generated during sludge decomposition in the septic tanks was recognized by Cameron and some of the gas was used for heating and lighting purposes at the disposal works (Chawla 1986).

During most of the following century, the development of anaerobic digestion technology remained exclusively linked to the stabilization of the putrescible solids from domestic wastewaters. This led to the design of heated, fully mixed, reactors of the type widely used even today for the digestion of sewage sludges and animal manures. Application of anaerobic digestion systems to industrial wastewater depollution was stimulated by the sharp rise in fossil fuel prices in the early 1970s and by the increasingly stringent pollution control regulations. The unsuitability of the conventional mixed digester for the treatment of industrial wastewaters of low-strength and of largely soluble organic composition, led to the concept of biological solids recycling and to the retention of active biomass within the digester. These developments in reactor designs, described in Chap. 6, have considerably enhanced the use of anaerobic digestion as a wastewater treatment process.

2.3 Biogas and Developing Countries

In developing countries, where energy is in short supply and expensive (on *per capita* and purchasing power basis, respectively), unlike the West, anaerobic digestion has a far greater relevance than it has to developed countries. Thus, anaerobic digestion in these countries has been primarily focused on energy production via biogas plants (Figs. 2.1 and 2.2). The thrust has been particularly strong in India and China; these two countries have, in a way, provided the lead for several other countries, especially in South-east Asia.

2.3.1 India

India is credited for having built the first-ever anaerobic digester, in 1897, when the Matunga Leper Asylum in Bombay (Mumbai) utilized human waste to generate gas to meet its lighting needs (Khanal 2008).

Fig. 2.1 Biogas use in Nepal (picture courtesy: SNV, Netherland Development Organization)

Fig. 2.2 Biogas use in Rwanda (photo courtesy: SNV, Netherland Development Organization)

The first-ever attempt to build a plant to produce biogas from manure was also made in India, at Bombay, in 1900, but it was not very successful. The first successful attempt came in 1937, when S.V. Desai – a microbiologist of the Indian Agricultural Research Institute (IARI), (then the Imperial Agricultural Research

Institute) – conducted studies leading to the commissioning of a plant which worked satisfactorily for several years.

Intensive research into the technology began only in the 1950s when several plant designs were developed. The most noteworthy of these, known as "Grama Laxmi III" was developed by Joshbai Patel (a Gandhian worker from Gujarat). It became the prototype for the later day's Khadi and Village Industry Commission (KVIC) floating-dome model (Venkata Ramana 1991). After a lull, interest in biogas was renewed in the early 1960s when KVIC implemented and developed standard biogas plant designs for capacities varying from 3 to 14 m^3d^{-1} of gas output. During the same period, the government of Uttar Pradesh, India, established a "Gobar Gas Research Station" at Ajitmel. This station has introduced the "Chinese" design under the name "Janata biogas plant," which is dome-shaped and is drumless. The Structural Engineering Research Centre, Roorkee, has developed and introduced ferro-cement gas holders instead of steel drums. This type of gas holder is believed to be cheaper, and with a longer life. It is also claimed to have lesser maintenance costs.

KVIC has also adopted the ferro-cement gas holders in some of its installations (Venkata Ramana 1991). In addition to the household biogas plants, community level biogas installations have been established to supply gas to families who did not own cattle. Encouraged by the promise of the technology, the Government of India had envisaged setting up one million family-sized plants and hundreds of community plants during the sixth five year plan. The thrust has continued through to the present (eleventh five year plan) and to-date close to four million biogas plants have been installed in India (MNRE 2011). The National Biogas and Manure Management Programme (NBMMP) had planned to set up 150,000 "family-type" biogas plants during 2009–2010. Several grass-root level voluntary agencies and self-employed trained workers are being involved in promoting and constructing these biogas plants, as well as providing maintenance services.

Public toilets incorporating biogas units has been an attractive option, especially in semi-urban areas and small towns in India which are not covered by proper waste treatment facilities and where extra energy in the form of biogas is welcome. But only about 150 community toilet complexes exist which have a biogas digester. This is mainly because the civic bodies that provide funding are either not aware of the importance of biogas systems or opt for the supposedly more "tried and tasted" septic tank alternative.

2.3.2 China

China has the largest biogas programme in the world. Over twenty five million households in China are using biogas by now, which accounts for over 10% of all rural households. By the end of 2005 there were 2,492 medium and large-scale biogas digesters in livestock and poultry farms, while 137,000 biogas digesters had been constructed for the purification of household wastewater.

In Sichuan Province alone, close to five million domestic biogas plants have been constructed by 2010. There is substantial government subsidy on biogas plants.

In order to help the growth of renewable energy sources, the Chinese government has established by law five systems to support the development of renewable energy resources – market fostering and protection, resource exploitation and planning, technical and industrial support, price support and cost sharing, and financial support and economic stimulation. These systems have been extended to support biogas energy as well, and various steps are being taken to industrialize the construction of biogas plants. For example the Shenzhen Puxin Science and Technology Company has developed a plant which is equipped with a glass-fibre-reinforced plastic gas holder to shorten the construction period and to avoid possible gas leakages through brick or concrete domes. Another private sector player, the Anhui Chizhou Xingye Natural Energy Developmental Company in Anhui Province, is producing a prefabricated fibreglass biogas plant in six pieces. It began production in 2002 and now claims to have a manufacturing capacity of 35,000 units per year.

Several stories of spectacular success have been reported. A few are recapitulated below.

Tianguan Alcohol Factory uses the dregs of the distiller to produce biogas in a 30,000 m^3 digester, supplying more than 20,000 households or 20% of the population.

Meili village of Zhejiang Province produces 28,000 pigs, 10,000 ducks, one million ducklings and 100,000 chickens each year. In 2001, it installed digesters to treat 30 tonne of livestock and poultry wastes and night soil. This produces enough biogas for more than 300 households plus 7,200 tonne of organic fertilizer each year.

Hongzhi Alcohol Corporation Limited, which is the largest alcohol factory in south-western China, runs a service using industrial organic wastewater, sewage, and dregs to produce biogas. The service is paid for by the industry and the residents in cities, but is provided free to the farmers. The company has also built a biogas power plant generating seven million kilowatts per hour.

The city of Mianzhu treats 98% of municipal sewage including wastewater from hospitals through digesters with a total capacity of 10,000 m^3. The treated water reaches national discharge standards, greatly improving the environment.

2.3.3 Nepal

In Nepal during 2004–2005, 17,803 domestic biogas plants were installed, bringing the total number installed since 1992 to over 140,000.

In recent years, as many as 62 biogas construction companies have been established in Nepal, along with 15 workshops for the manufacturing of biogas appliances. About 140 micro-finance institutes are involved in financing biogas plants in rural areas. These units have improved the social and environmental conditions of about 800,000 people.

The annual benefits for the average biogas household in Nepal have been estimated as savings of the use of firewood (2 tonne), agricultural residues (1 tonne), dried dung (250 kg), kerosene (70 kg), and chemical fertilizer (39 kg of nitrogen, 19 kg of phosphorous, and 39 kg of potassium). In addition, health benefits are realized through reduced indoor air pollution and attachment of a toilet to the biogas plant in

72% of all biogas households. The biogas support programme is generating direct employment for 11,000 persons and is believed to be particularly beneficial to women as it reduces drudgery (average of 3 h per day per household work) besides reducing deforestation and greenhouse gas emissions.

2.3.4 Vietnam

Vietnam has a large and expanding animal husbandry sector with high potential of biogas generation.

In Vietnam, as in other developing countries Colombia, Ethiopia, Tanzania, Cambodia, and Bangladesh the polyethylene tubular digester was promoted to reduce production cost by using local materials and simplifying installation and operation. The resulting low-cost digester has been well received by poor farmers, especially when farmers participate fully in the necessary maintenance and repair work. Within 10 years, more than 20,000 polyethylene digesters were installed and mainly paid by the farmers themselves. However, the digesters are still not fully integrated into the farming system, as there is only limited use of the effluent as fertilizer for fish and crops. There is also potential for improving the digester efficiency, ease of maintenance, and durability.

From 2003, the Vietnamese and the Netherlands governments are jointly implementing a domestic biogas dissemination project in 10 of Vietnam's 64 provinces. The project combines Vietnam's technical knowledge on plant design and construction with the Dutch experience with large-scale dissemination of domestic biogas. By the end of January 2006, 18,000 biogas plants had been installed.

The project is currently supporting construction of 180,000 domestic biogas plants in 58 provinces of Vietnam (Fig. 2.3).

2.3.5 Bangladesh

Dissemination of biogas technology in Bangladesh has been done mainly by the Bangladesh Council of Scientific and Industrial Research (BCSIR) and the Local Government Engineering Department (LGED). About 24,000 domestic biogas plants of different designs have been installed throughout the country. The fixed dome model has become the most popular of the models. Over 36,000 plants are expected to have been installed by 2010. About 75% of the existing plants are said to be functioning well while about 10% are defunct.

2.3.6 Sri Lanka

Although biogas digesters have been introduced in Sri Lanka in the 1970s, poor design, lack of maintenance skills and insufficient capacity to deal with the problems

Fig. 2.3 Biogas plants being put up in Vietnam (photo courtesy: SNV, Netherland Development Organization)

meant that only a third of the 5,000 installed units have functioned properly. The Intermediate Technology Development Group (ITDG) started a project in 1996 to improve the success rate of the units on a national level by setting up demonstration units to help spread information, restore abandoned units and train users to operate and maintain them. In addition, individual farmers get help to install biogas units on their farms to make use of the manure from their cows.

2.3.7 *Other Developing Countries*

All other developing countries are striving to enhance methane capture and use via biogas plants. Livestock rearing and manure generation is always plentiful in developing countries but is also, almost always, highly dispersed unlike in developed countries. This facet generates major challenges and impediments.

2.4 Use of Anaerobic Digestion Elsewhere

Elsewhere in the world anaerobic digestion was used but primarily as a process for treating high-COD waste rather than as a means of generating energy (biogas). By the mid-1950s, France had over 1,000 anaerobic installations in various farm operations, which varied from simple covered tanks to complex digestion systems (Lesage and Abiet 1952). In West Germany, this technology reached its peak in 1944–1945; the press gave wide coverage to the idea of using agricultural wastes in this process as feed and also about the development of different types of anaerobic plants. According to Van Brakel (1980), a large number of digesters began to be installed in countries such as Nepal, Pakistan, Bangladesh, Thailand, Malaysia, Indonesia, Papua New Guinea, the Philippines, Fiji Islands, Egypt, Uganda, Tanzania, Ethiopia, Zambia, Nigeria, Mexico, Brazil, and many others. Since 1975, a number of these countries, in particular South-east Asian countries, have begun to give a thrust at the government level to exploit the potential of anaerobic digestion.

In Japan, anaerobic digestion has received considerable attention during the last few years from the point of view of pollution control, and for the treatment of livestock, industrial, and urban waste. Japan is the only country in the region which has adopted thermophilic (high temperature; see Chap. 1) digestion of some wastes.

In the USA, Canada, and Western Europe anaerobic digestion has been used mainly for processing animal manure till the mid-1970s. The advancements in high-rate anaerobic digesters began with the introduction of anaerobic filter in 1967. It was followed by the introduction, one after another, of several other forms of anaerobic digesters capable of treating a wide variety of biodegradable wastewaters. These aspects have been detailed in Chap. 6. Developed countries have given the initial thrust towards waste water treatment using anaerobic digesters and it is being increasingly followed all over the world. These reactors do not, normally, generate *net* energy; in other words the biogas they generate does not provide more energy than is invested in running the digesters but they do significantly reduce net energy *consumption* relative to aerobic processes. Anaerobic digesters also generate lesser quantities of sludge which is easier to dispose than aerobic sludge.

Anaerobic digestion and aerobic composting of waste originating from kitchens, food processing units, and gardens is well established in Europe. By the end of 2006, there were some 124 anaerobic digestion plants with capacity greater than 3,000 tonne/year treating feedstock composed of at least 10% MSW. The combined capacity was about four million tonne per year which is 4 times and 15 times the

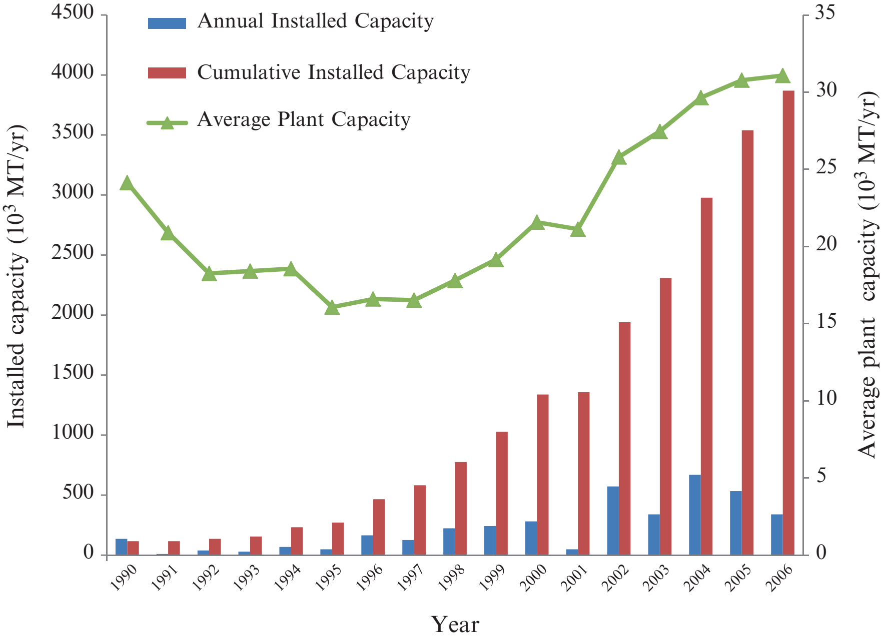

Fig. 2.4 Growth of anaerobic digestion capacity in Europe (adopted from De Baere 2006)

capacity that existed in 2000 and 1990, respectively (Fig. 2.4). This reflects the sharply rising trend in the use of anaerobic digestion in Europe.

Yet, despite the dramatically increased use of anaerobic digestion, only about 3% of biodegradable solid waste in Europe is being treated anaerobically. This points to the enormous potential that is lying untapped. Spain, Belgium, Holland, Switzerland, and Germany have the largest *per capita* anaerobic digestion capacities among the larger European countries. Spain treats about 10% of its organic waste using anaerobic digesters (Fig. 2.5). It must be clarified that whereas Germany has the largest anaerobic digestion plant installed capacity, Spain leads in terms of capacity:population ratio.

At present, Germany has over 4,000 biogas plants with about 1.5 GW of biogas-based electricity production (Fig. 2.6). Most of the new biogas plants have an electrical capacity between 400–800 kW. The first industrial biogas energy park, Klarsee, with 40 biogas plants (total capacity 20 MW) has come into operation. Maize, corn, and wheat are the main substrates (Fig. 2.7); manure constitutes less than 50%. This has given rise to the criticism that food crops are being diverted to energy production in developed countries even as millions in the developing world do not have adequate food to eat.

Currently, there are quite a few large biogas digesters at wastewater treatment plants, MSW treatment plants, landfill gas installations, and industrial bio-waste processing facilities throughout Europe, and more are under construction. Biogas is being increasingly used to generate electricity (Fig. 2.8) or in space heating

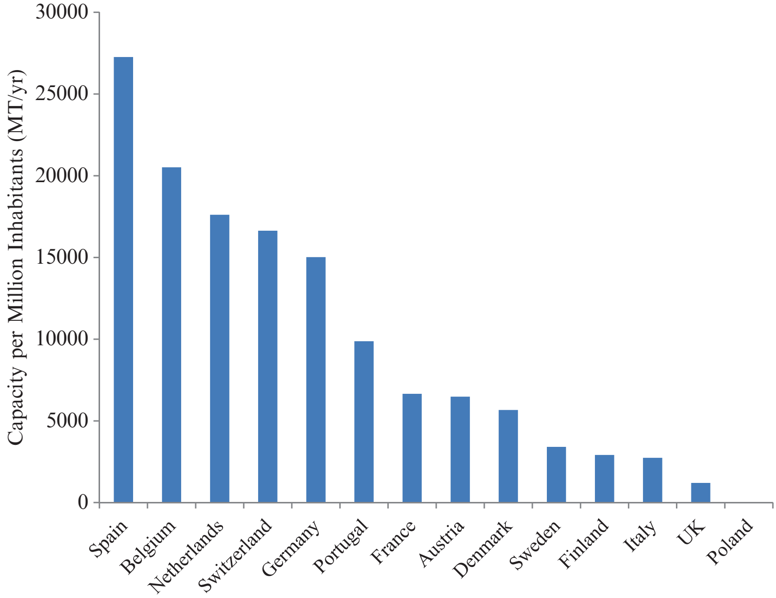

Fig. 2.5 Use of anaerobic digestion per million inhabitants in European countries (adopted from De Baere 2006)

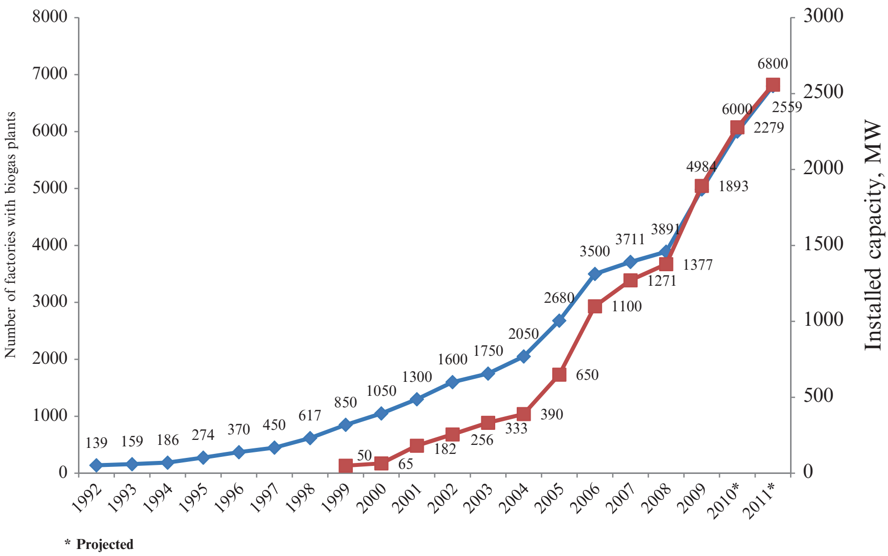

Fig. 2.6 Biogas plants in Germany (dx) and the rise in biogas-based power generation (dx) (adopted from Stolpp 2010)

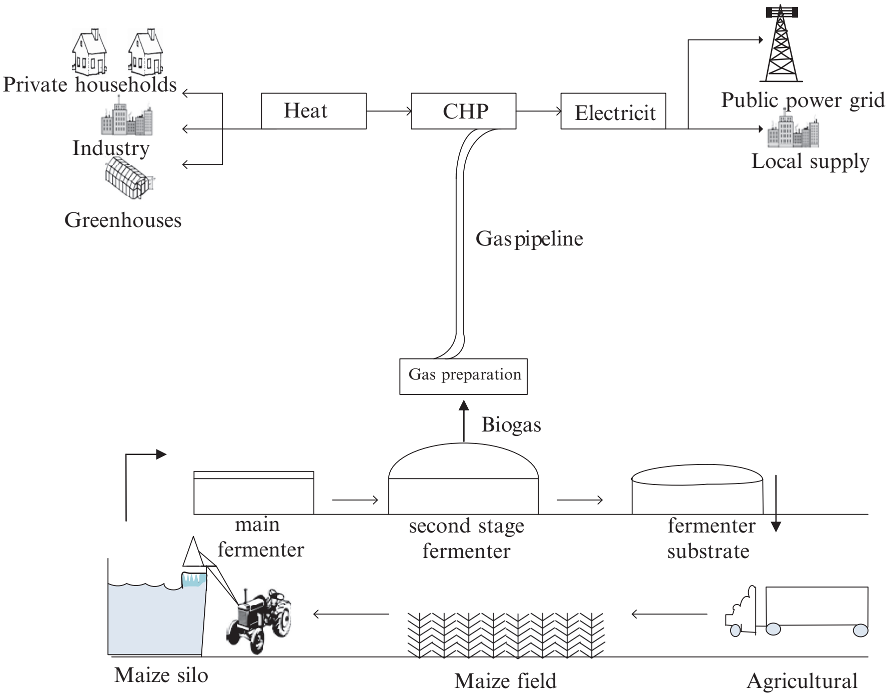

Fig. 2.7 A typical maize-based biogas plant in Germany

Fig. 2.8 Generator set utilizes biogas, for generating electricity (photo courtesy: AgSTAR)

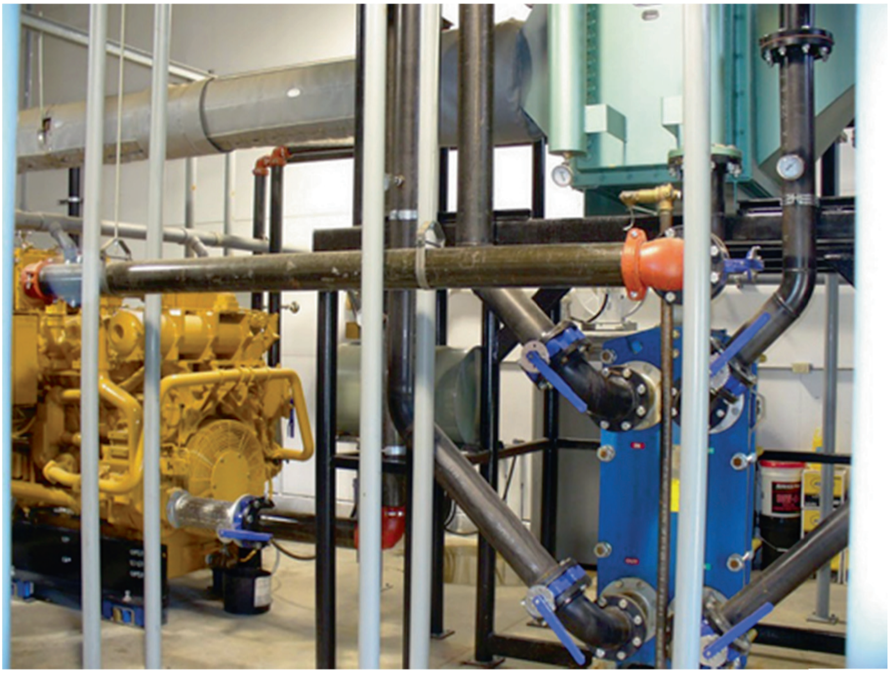

Fig. 2.9 A heat exchanger working with a biogas-fed engine-generator set to utilize heat for space and water heating (photo courtesy: AgSTAR)

(Fig. 2.9). It has been predicted that by 2020, the largest volume of produced biogas will come from farms and large co-digestion biogas plants, integrated into the farming and food-processing structures. These aspects have been covered in greater detail in Chaps. 5–8.

References

AgSTAR (2011) AD 101 Biogas recovery systems. US EPA. http://www.epa.gov/agstar/anaerobic/ad101/index.html. Accessed 1 May 2011

Chawla OP (1986) Advances in biogas technology. Publications and Information Division, Indian Council of Agricultural Research, New Delhi

De Baere L (2006) Will anaerobic digestion of solid waste survive in the future? Water Sci Technol 53(8):187–194. doi:10.2166/wst.2006.249

Khanal SK (2008) Anaerobic biotechnology for bioenergy production: principles and applications. Wiley-Blackwell, Ames

Lesage E, Abiet P (1952) Gaz de fumier: dernières techniques de production et d'utilisation (Gas from manure – the latest production techniques and use) (in French). Diffusion nouvelle du livre (The diffusion of new books), Soissons, France

McCarty PL (1982) One hundred years of anaerobic treatment. In: Hughes DE, Stafford DA, Wheatley BI et al (eds) Anaerobic digestion, 1981: proceedings of the second international symposium on anaerobic digestion. Elsevier Biomedical, Amsterdam, pp 3–22

Ministry of New and Renewable Energy (2011) Booklets on renewable energy. MNRE. http://mnre.gov.in/re-booklets.htm. Accessed 4 May 2011

SNV (Personal communication) (2009) Seeking permission to publish. SNV Netherland Development Organization, Netherlands

Stolpp S (2010) Biogas market in Germany. German Biogas Association. http://www.crossborder-bioenergy.eu/fileadmin/user_upload/Stolpp.pdf. Accessed 1 May 2011

Tietjen C (1975) From biodung to biogas-a historical review of the European experience. In: Jewell WJ (ed) Energy, agriculture, and waste management: proceedings of the 1975 Cornell Agricultural Waste Management Conference. Ann Arbor Science, Ann Arbor, pp 207–260

van Brakel J (1980) The ignis fatuus of biogas: small-scale anaerobic digesters (“ biogas plants”): a critical review of the pre-1970 literature. Delft University Press, Delft, The Netherlands

Venkata Ramana P (1991) Biogas programme in India. TIDE 1(3):1–18

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