Anaerobic Digestion of Waste

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Abstract All sustainable development closely links to the context of energy and to appropriate solutions to cope with challenges arising from trends of increasing urbanisation, by at the same time allowing for development of rural areas. Biogas production through anaerobic digestion of biomass, including the organic fraction of waste materials and residues, is a particularly promising choice and experiences increasing interest worldwide. It does not only supply a clean and versatile energy carrier, but is well suited to contribute towards appropriate waste management schemes in urban areas and in agriculture. Biogas production has high potential worldwide, and in this chapter special focus is given to its implementation in countries with economies in development or transition. China and India are countries where biogas production is already well-known and often adapted, and more widespread implementation is to be expected. This book chapter also highlights the topic anaerobic digestion in countries in Latin America and Africa.

1 General Aspects of Anaerobic Digestion

Biomass is a renewable resource. Its use for energy generation releases no (or only few) additional carbon dioxide into the environment, which is favorable against the background of the climate debate.

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Especially for organic wastes from households, local industry or agriculture, which have a high water content, anaerobic digestion (AD) is a good way to tap the energy content. While generating energy for covering demands in heat, electricity or gas, a valuable fertilizer is generated simultaneously, given that the input materials have a low content of impurities and pollutants.

Anaerobic digestion was practiced 2,000 years ago in Mesopotamia. Today it is widely applied throughout the world. In Europe alone, currently more than 5 million tons of bio-waste per year are treated anaerobically. Globally, a sharp increase of biogas production from agricultural wastes is to be expected especially in India and China. In both countries there are efforts to increase the share of renewable energies. In China, a potential of 200 million biogas plants [17], and in India, a capacity of 15,000 MW within the next 15 years are expected [13].

In addition to production of renewable energy and valuable digestate, anaerobic digestion has further benefits. The amount of organic waste destined for landfills is thus reduced significantly. According to the EU Landfill Directive and some state laws this is necessary to avoid harmful emissions (gas, leachate).

In developing countries AD also has social and societal impact. Especially in rural areas, self-sufficient supply with fuel for cooking and heating purposes can be partially achieved. The often very time consuming and exhausting collection of firewood can be omitted, which would have positive effects on the environment, but above all, have a positive influence on housework and cooking. Considering the fact that in most cases women carry out these activities, AD may also contribute to improve work conditions of women.

2 Basics of the Anaerobic Process

2.1 Biochemistry and Microbiology

Anaerobic digestion (or anaerobic fermentation) is a biological process in which organic material in liquid or solid phase is biodegraded by several groups of microorganisms in absence of free oxygen. Outputs of this process are (1) biogas, which is a mixture of methane, carbon dioxide and trace elements and which has a high calorific value, and (2) a stabilized residue, which in most cases can be used as organic fertilizer. In some process types waste water can also be an effluent.

The general biochemical reaction follows the Eq. 1 [5]:

$$C_cH_hO_oN_nS_s + xH_2O \rightarrow yCH_4 + (c-y)CO_2 + nNH_3 + sH_2S \tag{1}$$

with

$$x = \frac{1}{4}(4c - h - 2o + 3n + 2s)$$
$$y = \frac{1}{8}(4c + h - 2o - 3n + 2s)$$

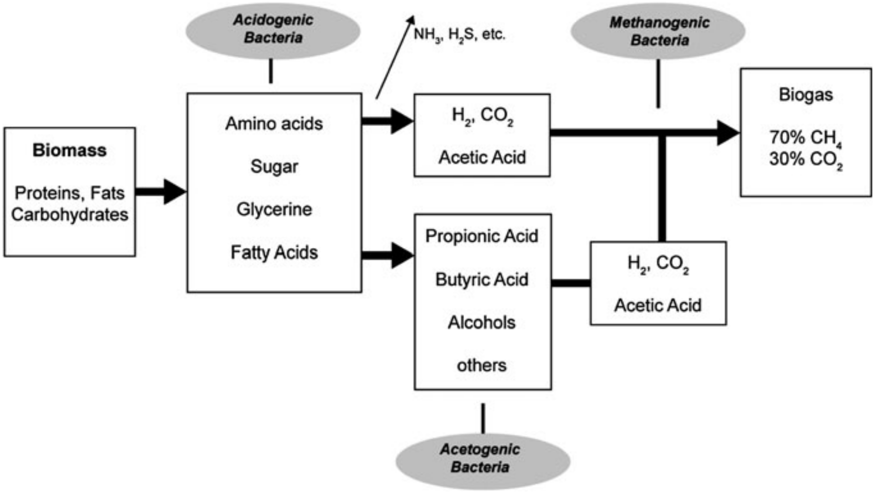


Fig. 1 Reaction chain of anaerobic digestion

As an example the anaerobic biodegradation of glucose (carbohydrate) [24] is:

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$$
$$\Delta G_f' = -420\,kJ/mol$$

By combustion of biogas CO_2 and H_2O are produced:

$$3CH_4 + 6O_2 \rightarrow 3CO_2 + 6H_2O$$
$$\Delta G_f' = -2448\,kJ/mol$$

If glucose is fully oxidized into carbon dioxide and water, a free energy of 2,868 kJ/mol is released (which is equal to the energy contained in glucose after having been formed in the photosynthesis pathway). Burning of methane in the reaction mentioned above leads to a free energy of 2,448 kJ/mol glucose, which is equivalent to 85% of the energy content.

The anaerobic reaction chain includes several steps, each involving specific groups of microorganisms (Fig. 1) [6, 9, 27].

Hydrolysis: In this first stage the substrate, which consists of complex organic structures (carbohydrates, proteins, fats) is hydrolysed into monomeric components (monosaccharides, amino-acids, long chain fatty acids).

Acidification: In this second stage the monomers are transformed into alcohols and volatile fatty acids by acidification bacteria. Hydrogen and carbon dioxide are released as well.

Acetogenesis: In this stage the volatile fatty acids are transformed by acetogenic bacteria in acetic and formic acid by releasing also hydrogen and carbon dioxide.

Methanogenesis: In this forth stage acetic acids, hydrogen and partly carbon dioxide are metabolized by methanogenic bacteria, which releases methane and carbon dioxide. This requires strictly anaerobic conditions (no oxygen) and in general is the limiting kinetic step, as these organisms have a slower growth rate than other groups involved in the steps mentioned above.

In the reaction chain hydrogen producing and hydrogen consuming bacteria are working in synergy and are dependent of each other (interspecies hydrogen transfer). To allow both reactions to be possible, hydrogen partial pressure must be in a small range from 10^{-6} to 10^{-3} bar [28].

2.2 Process Parameters and Factors

Many parameters and factors are influencing the microbial metabolism process. In order to ensure process stability and to optimize the process, some of these parameters have to be controlled [4, 11, 25, 26]. One of the challenges is that optimum conditions for hydrolysis and acidification differ from requirements of methanogenesis. This, among other factors, has to be taken into account when designing and operating AD plants. Most important parameters are shown as follows.

2.2.1 Substrate

The process itself, optimal choice of process technology and plant operation is determined by the type of substrate. The substrate must provide all vital components and should not have limiting or inhibiting substances. Micronutrients as nickel, vanadium, iron, sodium, potassium etc. are necessary, normally given in the substrate [6, 9].

Inhibitory and toxic effects can occur during the digestion process, some examples are as follows: high concentration of ammonia in basic milieu ($pH > 8$) [6], presence of sulphur (competition between sulphur reducing and methanogenic bacteria, undissociated H_2S concentrations >50 mg/L, heavy metals in high concentrations (depending on pH), antibiotics and aromatic compounds (e.g. phenol) [9]. It should also be avoided, that intermediate metabolic products limit the process (for example accumulation of volatile fatty acids). The biodegradability determining the retention time is shown in Fig. 2.

C:N ratio (based on dry mass) should be in a range of 16:1–25:1, at too high C:N ratio nitrogen is deficient (metabolism is malfunctioning). The ratio N:P:S should be about 100:20:20 [6].

Fig. 2 Biodegradability of organic substances in anaerobic digestion processes

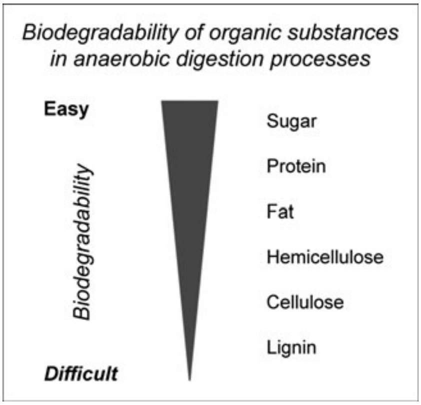
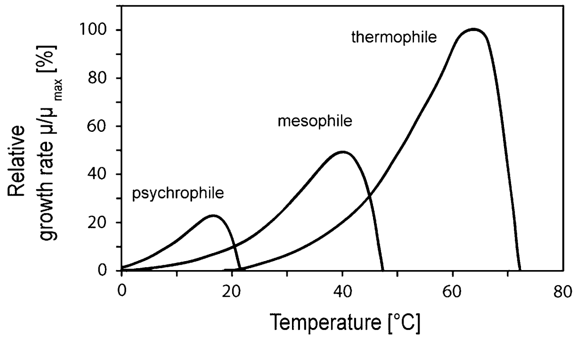


Fig. 3 Effect of temperature on the reaction rate of methanogenic bacteria [4, 31]



2.2.2 Temperature

Temperature range for microorganisms in anaerobic processes is between 0 and 65°C. Enzymatic and bacterial activity increase with temperature (*Arrhenius equation*). Depending on the bacteria three optima can be mentioned. In technical processes for acidogenic and acetogenic bacteria high microbiological activities can be found at 35 and 55°C [6]. Compared to methanogenic bacteria the sensitivity to temperature changes is lower because of the high growth rates. For methanogenic bacteria the optima are in a small range, the intervals are smaller (mesophilic 30–40°C, thermophilic 55–65°C) [36] (Fig. 3).

2.2.3 pH

pH is influencing the enzymatic systems and indirectly the process, because the dissociation equilibrium of the acids is shifted (volatile fatty acids in undissociated form penetrate cell membranes) [10]. Hydrolysing and acidifying bacteria prefer a pH around 6, methane forming bacteria a pH of 6.7–7.5. A pH < 6 has to be avoided, pH > 10 lead to serious damage of the microbial system.

2.2.4 Other Factors

Additional factors, which influence the microbial metabolism processes are as follows [13]:

- buffer capacity (ammonia, carbonate)
- redox-potential
- mechanical factors (stirring, mixing)
- concentration of microorganisms
- specific surface area of substrate
- disintegration
- light.

2.3 Biogas Characteristics

Biogas consists of methane and carbon dioxide; in addition it contains impurities which can affect its use, emissions, and operation and life time of the technical equipment. Gas composition and gas production rate are depending of the substrate (see also Sect. 2 in chapter "Planning Tools and Procedures for Rational-Municipal Solid Wastes Management"). Table 1 shows typical parameters of biogas.

2.4 Substrates for Biogas Production

Biomass of different types can be used as input material for anaerobic digestion. Considering the specific demands of the AD process (described above) a mixture of substrates is advantageous to allow optimum conditions for the microorganisms concerning biodegradable substances, micronutrients, water and avoiding harmful and inhibiting substances.

It has to be mentioned, that lignified biomass (e.g. in wood) and synthetic organic polymers (plastic) are not or very slowly biodegradable. In general theoretical biogas yield can be calculated based on organic compounds (Table 2).

Examples for substrate from waste and residues for anaerobic digestion are: organic waste from households and gastronomy, municipal solid waste, organic waste from industry/commercial waste, sludge and excreta, agricultural residues. Table 3 shows typical biogas yields and composition of selected substrates.

Table 1 Components and characteristics of biogas [6, 13, 15, 27]

Parameter	Data
Methane	50–75% by volume
Carbon dioxide	25–45% by volume
Water (vapor)	2–7% (saturated) by volume
Nitrogen	0–2% by volume
Hydrogen	0–1% by volume
Oxygen	0–2% by volume
Ammonia	0–0.05% by volume
Hydrogen sulfide	10–30,000 mg/m^{3a}
Siloxanes	0–50 mg/m^{3a}
Calorific value (60% CH_4)	21 MJ/m^{3a}
Range	6.0–6.5 kWh/m^{3a}
Density	1.2 kg/m^{3a}
Explosion limits	6–12% (in air)

[a] Standard reference conditions

Table 2 Biogas yields of organic compounds [6]

Lignin	0 L/kg VS
Starch	830 L/kg VS
Protein	890 L/kg VS
Cellulose	960 L/kg VS
Fat	1,420 L/kg VS

3 Planning and Successful Operation of Biogas Plants

Successful operation and economic viability of biogas plants highly depend on adequate planning of the project, skills of the plant operator and knowledge about the biological process.

3.1 Biogas Plant Types

Many different biogas plant types have been developed and are to be found in full-scale for various applications and in different regions. The following overview is restricted on types typically implemented for digestion of solid waste materials, agricultural substrates and household wastes. It needs to be pointed out that a wide variety of additional plant types exists related to waste water treatment, especially for digestion of sewage sludge and industrial liquid wastes rich in COD, e.g. the upflow anaerobic sludge blanket reactor (UASB), the anaerobic baffled digester, the anaerobic contact digester, the fixed film digester, the upflow fixed film

Table 3 Biogas yields and composition of selected substrates [2, 12, 13, 15], (Kranert et al. 2010, Waste analyses of the laboratory of solid waste management. Institute of Sanitary Engineering, Water Quality and Solid Waste Management, "Unpublished")

Substrate	TS (% FM)	VS (% TS)	Biogas (m^3/kg VS)	Methane (% by Vol.)
Municipal solid waste				
Bio waste	30–65	45–70	0.15–0.6	58–65
Market waste	35–60	75–90	0.4–0.6	60–65
Leftovers	10–35	80–98	0.2–0.5	45–60
Green waste	35–70	45–90	0.5–0.65	55–65
Grass	9–13	80–90	0.2–0.7	50–56
Solid waste	65–75	55–65	0.15–0.5	55–65
Fat (fat separator)	2–70	75–90	0.6–0.7	60–70
Food and beverage industry				
Spent fruits	25–45	90–95	0.4–0.7	55–65
Apple mash	2–3	95	0.5	55–65
Potato mash	6–18	85–96	0.3–0.9	55–60
Oilseed				
Residuals	92	97	0.9–1.0	60–68
Rumen	11–19	80–90	0.2–0.4	58–62
Sludge and excreta				
Human excreta				
Without urine	25–30	72	0.2–0.4	45–65
With urine	5	63	0.2–0.4	55–75
Sewage sludge	2–10	50–80	0.3–0.6	40–75
Agricultural residues				
Liquid manure				
Cattle, cow	7,5–13	75–82	0.15–0.6	53–62
Pig	2,3–11	75–86	0.3–0.88	47–68
Poultry	10–29	67–77	0.3–0.8	55–63
Solid manure				
Cattle, cow	24–26	68–76	0.15–0.55	42–68
Pig	15–25	75–80	0.27–0.45	55–62
Poultry	35–86	60–80	0.25–0.45	51–60

TS total solids (dry mass), *FM* fresh mass, *VS* volatile solids (organic mass)

digester, the anaerobic filter digester. Some of the mentioned concepts are occasionally found as one element in hybrid systems when digesting wastes or agricultural materials, but they are not to be considered as a standard in anaerobic digestion outside the waste water treatment branch.

The following table provides an overview on different technology concepts applied for anaerobic digestion (Table 4). In batch systems digestion and methane production start anew with each filling of the reactor and biogas supply therefore is not continuous. For commercial operation it is in general necessary to have several reactors run off-set (alternative loading and unloading), at least three reactors should be operated. A continuous system in most cases is judged to be better suited

Table 4 Types of digesters

Operation of mode: batch/fed-batch or continuous	In *batch systems* substrate is digested over a pre-defined period. Once digestion is complete material is removed and the process is started with a fresh load of substrate In *fed-batch mode* material is added to the digester by and by until the space is used up. Then the digester is emptied to provide new reactor volume In a *continuous* system (or more precise semi-continuous) substrate is regularly fed into the reactor, there is no interruption of either loading the fresh material or unloading the effluent
Transport of material and homogenisation in reactor	The most common types of AD plants are based on the concept *continuously stirred tank reactor* (CSTR). Those plants are equipped with facilities for stirring the digester content (continuously, or in most cases semi-continuously), resulting in homogenization of reactor content but also in differing retention times for different particles, with part of the material leaving the reactor after very short digestion time *Plug flow digesters* are long narrow tanks (typically 5 times as long as the width) with no internal agitation. Inlet and outlet are at opposite ends, feeding is carried out semi-continuously and typically with a thick substrate of 11–15% total solids. In theory, reactor content in this type of digester does not mix longitudinally on its way through the reactor, advancing towards the outlet whenever new manure is added (but actually material does not remain as a plug and portions flow through the digester faster than others–but minimum retention time is assured far better than in CSTR concepts, thus allowing for better hygienisation)
Total solids content (TS)	So-called *wet digestion plants* are most common in agricultural biogas production, they are operated at TS $<$ 15%. When digesting higher amounts of solid materials in this process type, water content needs to be adjusted (addition of liquid substrates, water or recirculation of digester effluent) For digestion of organic materials available mainly in solid form, implementation of technical processes designed to be able to cope with higher TS contents was a logical step (solid municipal bio waste, solid agricultural substrates, etc.). So-called *dry digestion plants* are typically operated at TS $>$ 20%, water content often is not adjusted to a specific value but is a result of the digesting substrates
One-, or two-stage (multi-stage) AD systems	By far the most AD plants are *one-stage processes*, with one single reactor for the digestion process (in general followed by a storage tank). In *two-stage systems* (or multi-stage systems, which however are very rare) process conditions can be optimized for the different groups of microorganisms in order to improve overall efficiency of biogas production. While during the first phase conditions can be optimized in order to achieve a rapid liquefaction, the second phase converts soluble matter into biogas. Compared to single-stage systems the process is more rapid and more stable, but investment and maintenance costs are considerably higher

for large-scale operations [35], drastic changes of input composition should be avoided.

A batch digester is the least expensive to build and easiest to operate. Single-stage batch digesters (often operated in fed-batch mode) need little skills, little familiarity and are often preferred in rural areas due to simplicity of operation. Batch dry digestion is particularly attractive, this is the simplest process where operation involves merely charging solid waste in an air-tight digester, seeding with inoculum and in some cases adding alkali in order to maintain pH. The most successful biogas programme using the batch system is conducted in the Philippines [35]. When operating several reactors off-set, biogas production can be equalized, and batch dry AD plants have now also become a standard in industrialized countries such as Germany (e.g. system Bekon), operating with digestion times of 4–6 weeks (while in developing countries batch reactors are often loaded only a few times per year).

Different variants of continuous digesters mainly implemented in developing countries include the following systems [30, 35]:

1. *Floating dome digester.* This type is of Indian origin and was promoted back in the 1950s by Khadi and Village Industries Commission (KVIC). Digesters of this design are now being used extensively throughout the world. Biogas produced in the digester is trapped under a floating cover. The volume of the gas cover is around 50% of the total daily gas production. The system was originally made of mild steel until fiberglass reinforced plastic gas holders were introduced. Historically, cattle manure was fed for AD of night soil; typical feedstock is cattle dung, agricultural residues, night soil, aquatic plants. Cattle dung is diluted to 10% TS before feeding as inoculum. The system has undergone many efforts to optimize efficiency (heating, mixing, insulation, modifications in geometric configuration, inlets/outlets). In case of a high height:diameter ratio of the digester, a central baffle is included to prevent short circuiting in mixing.
2. *Janata model digester.* This digester was introduced by an Indian non-governmental organization to be 20–30% cheaper than the floating dome model. Most common capacities are 2–6 m^3 biogas/day. The system is well suited for domestic operation or for community size digesters e.g. used in rural/hilly areas.
3. *Fixed dome digester* (*Chinese model*). This type is by far the most commonly used in developing countries. The unit consists of a gas-tight chamber constructed of bricks, stone, or poured concrete. The inside is applied with many thin layers of mortar to make it gas-tight. Level of digestion material is at 95% of total reactor volume at ambient pressure, the digester is fed semi-continuously. Biogas is stored under the dome and displaces some of the contents in the effluent chamber.
4. *Bag design digester* (*Taiwanese model*). The reactor is a long cylinder (length:diameter 14:3), made of PVC or neoprene coated nylon fabric, and acting as plug flow digester (unmixed). Digester walls are thin, which facilitates heating, heating with solar energy might offer additional potential for increasing performance.

Dissemination of technology types has experienced different success in different countries. Even when applying the same technology, often different results were obtained in different countries, and even in different regions [1], which highlights that besides technology other factors have decisive influence on successful implementation of AD projects.

In addition to further potential for installation of AD plants at household levels, biogas facilities at large scale gain importance in countries with economies in development or transition. The need of sustainable waste management schemes, trends of massive urbanisation, industrialisation of agriculture branches (such as animal breeding) are some of the associated factors. In China for example, where pig manure is the traditional substrate for biogas plants, household swine production experiences significant decrease, while industrial pig farming is on the rise and has already taken over 30% of China's pork supply [22]. Such facilities experience problems to dispose the huge amounts of pig wastes, and environmental risks are generally high (waste leakages, foul water flowing into rivers), which makes a biogas plant particularly interesting.

In Brazil and the Philippines large-scale crop-based digesters using sugar-cane residues as feedstock are most common.

India is highly aware of the potential of biogas, and in search of solutions to deal with air pollution from transport (one of its major problems) the country is also planning to use compressed biogas as automotive fuel. AD has been assessed to be a suitable technology to treat organic household waste in urban and peri-urban areas. Based on research, development and implementation activities now much knowledge and experience in AD of kitchen/market waste and organic household waste is already available e.g. in South India, and a range of plants have been developed and implemented by Indian institutions specifically designed to treat organic solid waste rather than manure [37]. Large-scale facilities with capacities up to 100 tonnes per day exist. Main motivation of developers and operators is the need to find waste treatment solutions, generation of biogas is often perceived as an added value. Though not yet fully implemented, the existent innovative legal framework (city authorities are liable to promote waste segregation at source to avoid landfilling of biodegradable waste) can significantly contribute to further dissemination of AD in the country.

Technology is not directly transferable from household scale to large scale at municipal level, specialised expertise is required. The need for hygienisation, additional infrastructure including reception areas, required pre-treatment equipment, management of digestates, safety issues are some points to be considered.

3.2 Dimensioning of AD Plants

Main parameter for dimensioning a biogas plant is the retention time. The retention time can only be accurately defined in batch-type plants. For continuously operated facilities the mean retention time (hydraulic retention time HRT) is

Fig. 4 Hydraulic retention time and organic loading rate

$$HRT = \frac{V_R}{\dot{V}}$$

HRT hydraulic retention time [d]
V_R reactor volume [m^3]
$\dot{V}$ daily influent rate [m^3/d]

$$OLR = \frac{\dot{m} * c}{V_R}$$

OLR organic loading rate [kg VS/(m^3*d)]
c concentration organic matter [kg VS/kg]
$\dot{m}$ daily influent substrate mass flow [kg/d]

VS: volatile solids = organic matter

approximated by dividing the digester volume by the daily influent rate, and this dependency can be applied when deciding about the necessary plant volume (Fig. 4). It needs to be considered that each additional m^3 of reactor volume results in higher investment costs, and therefore the cost-optimum in biogas production is in general below the biological optimum.

The organic loading rate (OLR) is limited by the biological conversion capacity of the AD system, and depends on the plant type, the mode of operation and the digested substrates. When feeding the system above its sustainable OLR gas yield will decrease due to accumulation of inhibitory substances such as fatty acids. OLR is one of the key control parameters in continuous systems, it is closely linked with HRT.

Typical organic loading rates are as follows [12]:

- Stirred reactor run on sludge, manure: 2.0–4.5 kg VS/(m^3*d)
- Stirred reactor with co-fermentation of bio-waste: 0.5–3.5 kg VS/(m^3*d)
- Plug-flow reactor operated with source-segregated biowaste: 7–9 kg VS/(m^3*d)
- AD plant at house-hold scale run on waste, excreta: 0.8–1.2 kg VS/(m^3*d)

For digestion of liquid manure in the mesophilic temperature range the following approximate values apply for choice of HRT [18]:

- Liquid cow manure: 20–30 days
- Liquid pig manure: 15–25 days
- Liquid chicken manure: 20–40 days
- Animal manure mixed with plant material: 50–80 days

Too short retention times can result in a situation where microorganisms are "washed out" faster than they can be reproduced, which means that biogas production comes to a standstill. While this rarely occurs in agricultural plants run on slurry/manure, it can be a problem when treating plant material or industrial wastes.

Retention times are highly dependent of process temperature and digested substrates. Typical HRT for agricultural plants run on slurry are 15–20 days for thermophilic operation (48–55°C), 30–40 days for mesophilic plants (30–42°C) and 70–80 days for psychrophilic digestion (<20°C) [11]. Those retention times refer to a degree of biodegradation of around 50%. Higher degrees are possible but not common due to economic reasons.

In biowaste plants typical retention time is between 20 and 30 days [12, 27], in waste water treatment plants around 20–30 days, in some cases high reactor volume is available, so that retention time is increased up to 60 days [23]. Intensive thermophilic degradation processes are also found with HRT of 10–15 days [6]. For rural biogas plants in developing countries retention time is normally around 150–200 days, sometimes more than a year.

Climatic conditions need to be taken into account especially when planning a facility without heating equipment. It is not suitable to fully rely on general literature data. Large areas in developing countries are highlands or have a continental climate characterised by warm summers but cold winters. Low ambient temperatures decrease microbiological activity in the digester and consequently the rate of biogas production. This can be overcome by increasing either digester volume or digestion temperature. As an example, in India the typical retention time of the feedstock in the tropical south is around 30 days, while in the north material is typically digested for 50–55 days, resulting in a digester volume which is around 1.8 times larger (= 55/30). This works well at an average temperature of 15°C, at lower temperatures heating is required [10].

3.3 *Planning Phase*

The planning phase is most important in each biogas project. Many failures in biogas production are caused by planning errors and unsuitable decisions. General points to be considered are [32]:

- Siting of the biogas plant and layout of the facility is as important as the construction itself. A well-planned AD plant will be a useless facility when installed at the wrong place.
- Substrates need to be appropriate for the installed AD technology. Filling a plant with unsuitable material will result in an unproductive unit (and may also cause technical problems).
- Careless planning of the site may unnecessarily require additional equipment or may cause further labour input.

Knowledge about technology and biological processes is essential for the future biogas plant operator. Literature, biogas seminars and training courses, biogas study tours, individual visits to existing AD plants and direct contact of plant operators are most suitable. Problems to overcome in developing countries are also related to availability of such opportunities (and quality of seminars, courses), costs implicated, high degrees of illiteracy, availability of knowledge and advice at local/regional level.

Among the most important factors when planning an AD plant is a careful and realistic assessment of available substrates and their potential biogas yield.

Labour requirement to run the digester and manage the material flows needs be taken into account. It can vary very much from one site to another, depending on design, general management, knowledge and skills of the operator, the characteristics of available substrates, weather conditions, biogas utilisation paths, etc. Some of the activities are as follows: inspect the digester and all pipes regularly, management of substrates, shredding and pre-composting of farm residues, control of water content and addition of manure/liquid, management of effluent/digestate, control of mixing, monitoring of the biological process, and management of problems.

A survey in southwest China revealed that 61% of the members of a rural community did not believe to have enough labour to run a household digester [22]. Main labourers leaving the village for wage jobs in the city, is one crucial factor. Emigrant labourers often are the young and well educated, who would have been the most likely to adopt biogas technology. It is not only labour requirement for the biogas unit which needs to be considered. Technically it would need more than four pigs to run a household biogas plant in rural China, so that it can meet the household's need for cooking and lighting. Even among skillful pig farmers many villagers are unable to raise more than two pigs [22].

A biogas plant is a long-term fixed investment. When looking at domestic biogas plants in developing countries, investment requirements of some hundred dollar ($) are a significant investment barrier. It is this investment barrier which needs to be decreased, and among possible solutions the following are to be mentioned [10]:

- Investment subsidies. Different programmes exist in different countries. In Cambodia for example, $150 are refunded from the total investment of a family size biogas plant (funds are provided by donors).
- Micro financing. This can be attractive if it allows for an affordable credit for the biodigester.
- Income generation activities. Programmes to enhance and commercialize agricultural products and/or bio-slurry extension programmes can help to encourage uptake of AD.

3.4 Operation of Biogas Plants

Effective management is essential for successful operation of an anaerobic digestion plant and therefore biogas production. In order to operate a biogas plant safely and highly efficient, every plant operator must have detailed knowledge about the technical equipment and the biogas process. This helps to avoid feeding errors and to correctly react in case of problems. Problems can be manifold and include interruption of gas production, insufficient gas quality, formation of scum, feeding problems or problems at the outlet, blocking of piping, and breakdown of equipment. Digestion of energy-rich and easily hydrolysable substrates in general requires more attention, while AD processes run on manure and slurry are more robust and less susceptible to failure.

Operating a biogas plant requires regular and multiple activities in different intervals (ranging from daily routine inspection, to cleaning of reactor e.g. once per year), a continuous process needs more regular attention than a batch process. The operator must be aware of the fact that in case of illness another well-informed person must be able to ensure at least the basic regular biogas plant operation.

In many cases plant operators lack knowledge and put unsuitable substrates in their digesters. Limited and expensive access to training also discourages villagers from utilising biogas, and courses sometimes are perceived as waste of money due to poor quality [22]. In particular materials containing pesticides, disinfectants, antibiotics need to be excluded from the biological process. When digesting waste materials such as food waste knowledge about necessary pre-treatment including hygienisation is imperative.

Repairs will occasionally be necessary and AD plant operators should consider repair costs when calculating economic viability of their facility. Easily available and reliable repair support can be a decisive element for trust in the technology and dissemination in a region, but this is not always the case (especially in rural areas). Often no insurance policy is available, which means that operators need to use their income to pay for repairs [22].

A Chinese adage says "A good message hardly goes beyond the gate, while bad news spreads far and wide" [22]. Failed biogas projects and bad digesters have far more impact on general perception of reliability and economic viability of the technology than good ones. This stresses the importance of a good management of a biogas plant not only for the individual operator but on more general scale. It is not sufficient to build as many AD plants as possible. It is knowledge about adequate operation, individual skills, and availability of reliable support which are crucial.

3.5 Safety Issues

Biogas from any type of digester and from any size of digestion facility is flammable, explosive (in certain mixtures with air/oxygen) and corrosive. Components exposed to AD liquids or to biogas condensation water will be subject to rapid corrosion if unsuitable materials were chosen (this includes the digester itself with various components such as stirring equipment, but also wiring systems and piping in and around digesters).

Carbon dioxide and hydrogen sulfide are both heavier than air, while methane and ammonia are lighter. Heavier components can settle and accumulate at the bottom of tanks and pits. Lighter components can accumulate especially under roofs and ceilings.

By displacing ambient air, biogas can create an environment which is oxygen deficient. Deficiency in oxygen will particularly target brain cells, resulting in judgement and coordination being hindered. At lower oxygen levels (<10%) loss of consciousness will occur and deadly incidents are possible.

- Accumulating methane can create a fire or explosion.
- Ammonia typically causes irritation of eyes and the respiratory tract.
- Hydrogen sulfide is a deadly poisonous gas. In lower concentrations hydrogen sulphide can be perceived by its typical smell (rotten egg smell), which however is not the case anymore at higher concentrations (>150 ppm).

3.6 Ecological and Social Aspects of Decentralized Biogas Digesters

Biogas technology is conducive for maintaining stable power supply with renewable energy, saving fuel and protecting the environment. Through the application of biogas, most of, or even all of the traditional fuel such as fossil fuel, firewood, and straw, will be saved. If the digester produces 400 m^3 of biogas a year, 0.7 tonnes of coal or 1.2 tonnes of firewood can be saved, which is equivalent 2,100 m^2 forest area.

The CO_2 and methane air pollution due to the burning of biomass or coal could be eliminated. In the year 1991 in China more than 2 million tons of greenhouse gas has been reduced as a result of the utilization of biogas. Due to the higher number of digesters in 2010, reduction of greenhouse gas increased to 30 million tons per year [39].

Utilization of biogas offers economic, environmental as well as social benefits. Additionally working cost is substantially cut down in activities such as collecting firewood or raising crops. The time saved in the process of lighting a fire or adding firewood is also significant. It takes about 700 working hours per year in the rural areas to sustain the traditional way of life, while in the case of biogas application only about 200 working hours are needed in activities such as collecting animal manure and applying the sludge-turned fertilizer to agricultural farmland. The comparison shows that 500 working hours are saved in the case of biogas user as against the non-biogas user [7].

Application of biogas provides a solution to problems such as human and animal feces and existing parasite on the site, which together contributes to the improvement of rural sanitation. According to results of relevant tests, most biogas slurries meet the sanitary standard of China for non-hazardous treatment of night soil (96.08% of 426 biogas slurry samples) [34]. Testing further revealed that the retention rate of the total amount of nitrogen in biogas sludge has increased by 46%, while that of amino acid nitrogen has increased by more than 20%. There is almost no loss of the contents of phosphorus, potassium or other nutrients in the sludge. As a result of applying biogas slurry as the fertilizer to the soil, it has been observed that soil porosity, organic substances and pH value have increased respectively. In opposite to large scale fermentation plants, no bad odours can be recognized in the neighborhood of small scale biogas digesters.

Furthermore the fermentation process in the production of biogas is proved to be effective in eradicating parasites' eggs, which contributes to the prevention of infectious diseases and safeguard of the peasants' health. It can also effectively reduce eye syndrome, asthma or other diseases, which are caused by the smoke of traditional cooking style.

4 Utilisation of Products

Anaerobic digestion (AD) contributes to the establishment of environmentally sound waste management. It is currently the most promising way to tackle gaseous emissions from agricultural activity (climate gas emissions: CH_4, N_2O; odour nuisances). In addition, it generates digestate with improved fertiliser value, which results in better nutrient uptake by plants and fewer leaching losses. At the same time the generated energy has the potential to displace other energy sources such as fossil energy. This reduces greenhouse gas emissions and contributes towards a more sustainable energy concept.

4.1 Biogas Utilisation

Biogas has a wide variety of possible applications, the most common ones are:

- Direct use for cooking and lighting (small-scale AD plants at household level usually provide fuel to cover the demand of the household and the agricultural site; biogas burns very cleanly and causes less air pollution than other biomass fuels)
- Utilisation for heat generation
- Generation of electricity (several engine types can be fuelled with biogas; electricity generation is often accompanied by heat generation in combined heat and power plants/CHP)
- Fuel for cars/vehicles
- Feeding into the natural gas grid (after upgrading to natural gas quality; now one standard in industrialized countries when produced at large scale; different upgrading technologies exist)

Biogas can also be used to provide cooling (agricultural storage facilities, pig stables, nearby hospitals or other buildings).

When used to heat and light greenhouses, biogas will significantly increase the level of carbon dioxide, which can result in better plant growth (simple form of CO2 farming).

It is not necessary to make use of biogas directly at the production site. Local biogas grids can be an intelligent solution to provide biogas to where it can be used at highest efficiency [29].

Compared to other renewable energies, it is one advantage of the energy carrier biogas that it can be stored to be used according to fluctuating demands or to availability of alternative energies. Biogas can be a particularly advantageous choice e.g. in hybrid power systems for electricity supply in remote areas or islands [8].

4.2 Digestate

In the organic form, nitrogen must be first mineralised. Ammonia can be converted to nitrate for plant uptake, while some plants may use ammonia directly. The extent of nutrient uptake by plants depends on the time of application and there is always the possibility that nutrients will be leached from the soil when plants are unable to take them up. AD converts much of the organic N into ammonia, yielding a digestate with 60–80% of the total nitrogen content in the form of ammonia [3]. This makes it highly predictable, minimises leaching losses and is in line with the development of good agricultural practices.

The improved fertilizer value of AD digestate is to be considered as economic advantage of the AD unit. Other fertilizers are displaced and higher biomass yields are possible, as reported for napa cabbage, cauliflower [22].

Compared to granular fertiliser, digestate has the drawback that it is a pre-determined blend and its constituents cannot be altered. Once the soil requirement of the first nutrient has been met then no more should be applied to the soil. In a closely monitored agricultural system following rules of good practice other fertiliser is therefore likely to be required to top up the nutrient needs of the soil.

Since most of the nitrogen in digestate is available in the form of ammonia, digestate spreading technologies should be given special attention and priority should be given to techniques minimising ammonia losses.

Biogas can mitigate fecal-borne and parasitic diseases. Agricultural use of untreated human and animal waste is among the main pathways for transmission of serious diseases. In addition, odour emissions are significantly reduced through the anaerobic process and the system attracts less flies.

Digestate which is not fit for landspreading (e.g. due to contamination with heavy metals) must be disposed of.

5 Decentralized Biogas Technology

5.1 General

Climatic condition in most areas of Latin America and Africa is optimal for biogas plants, especially in the Caribbean and the tropical countries. The amount of available substrates for biogas digesters is very high. Nevertheless, in all of Latin

America and Africa there are only a few thousands of such plants. Biogas plants which were built in the 1980s or 1990s are almost all out of order.

Reasons for inadequate dissemination are certainly lack of support from government and lower population density. The causes for failures of existing biogas plants resulted from quite a few aspects, such as inadequate training of users, material errors, technical defects, reduced animal holdings or water problems etc.

At the present some organizations have established and started series of national and international biogas programs so as to promote development of biogas technologies as a solution to the environmental problems and covering the energy gap in Latin America and in Africa.

5.2 Biogas Technology in China

5.2.1 Overview

China is the biggest biogas producer and consumer in the world. The popularization and scientific research of biogas in China began around 1970. After more than 3 decades of development, by the end of 2007, around 26 million household biogas digesters had been counted all over the country. In China, the most basic applied type of household digester is the hydro-pressure digester with 6–10 m^3, also known as fixed-dome type digester. A large number of biogas digesters are set up in various geographic landforms and climatic areas, either in the areas of plateau in western China, or in plain areas of central China, and both in the cold climatic conditions of northern China and in the subtropical and tropical regions of southern China. Large and medium-sized farm biogas projects have increased in number from ca. 800 in 2000 to ca. 8,500 by the end of 2007, and annual biogas production has reached 10.4 billion m^3.

The Chinese Government has always attached great importance and provided strong support for rural biogas development. The biogas development enjoys a very good policy and legal environment, a relatively complete and efficient work net, which covers marketing of biogas application, technical support and maintenance outlets all together. According to the biogas development plan in 2020 it is planned that 10,000 large-scale biogas projects on livestock farms and 6,000 biogas projects utilizing industrial organic effluent will be built. About 80 million rural households (300 million people) will use biogas as their main fuel.

A relatively complete and efficient network has been developed, which covers the adoption of marketing biogas application, technical support and maintenance all together. More than 8,000 rural energy offices have been established in more than 1,900 counties and towns with 40,000 full-time staff members, who are responsible for the administration of biogas in rural areas.

The Ministry of Agriculture has also focused on education, advocacy and training: they have not only published brochures of biogas training materials,

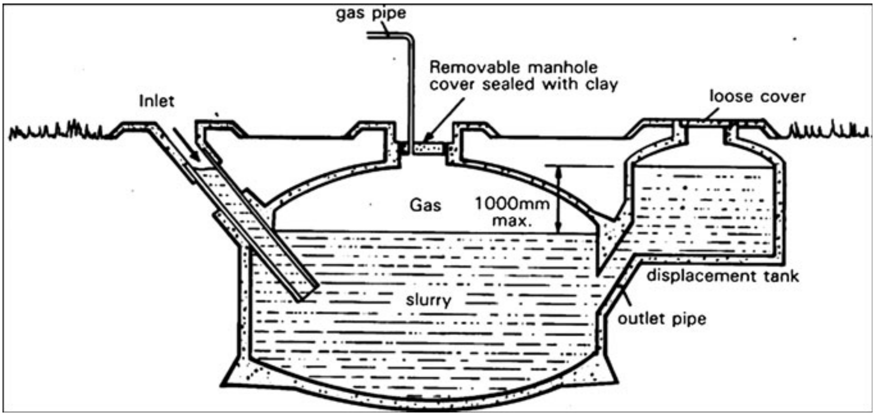


Fig. 5 Construction of fixed-dome biogas digester [17]

television and radio programs, but also organized many training courses, so that the technicians and farmers can access the knowledge of biogas technology.

5.2.2 Typical Household Biogas Plants and its Maintenance

In China, the most basic applied type of digesters is the hydro-pressure digester, which is usually an underground, circular and shallow facility with a domed top, so it is also called as fixed-dome type digester (Fig. 5). The volume of these household digesters is ca. 6–10 m^3, and the life expectance of the digester is 15 years [38].

The dynamic system is adopted for the facility, i.e., when the gas is produced and stored in the upper part of the digester, the gas pressure will increase to push manure and slurry at the bottom of the pit to flow up into the compensating tank. When the gas is used up, the gas pressure will reduce and the slurry will flow back into the digester chamber to push the gas up for usage. As a result of the constant circle of gas consumption and gas generation, the pressure is always maintained in a balanced state between the compensating tank and the fermentation room.

Construction of the reactors is carried out by trained technicians and members of the household. The construction is carried out in the following stages:

- Site selection: at least 10 ~ 15 m away from the shallow well, max. 25 m between the digester site and the biogas appliances.
- Preparation of the material (for example: brick, cement, sand etc…). The basic construction materials are concrete and bricks, which are easily available and commonly used in rural China.
- Positioning and excavation according to the layer construction
- Construction of the digester body, including bottom, walls, roof and sealed layers, as well as brushing starch to prevent leakage

- Construction of the gas transfer pipes for the biogas usage
- Quality control to ensure the construction quality and a normal gas production

These biogas plants are particularly simple to operate and maintain. Waste from the animals and toilet flows directly into the reactor. Sometimes manual fed works are also required in order to maintain the frequent input and output within the biogas digester, otherwise the gas production would drop if fresh material could not be supplied in time. About 20 kg fresh materials have to be fed into the digester and 20 kg slurry to be taken out of the plants on a daily basis. Some harmful substances are not allowed to put into the digester, which include all kinds of toxic pesticide or the crop stems with that pesticide, heavy metal compound and industrial waste water containing toxic substances etc. A regular check over pipes, joints, switches, cover of entrance, exit pipes and water column pressure is necessary. When the pressure in the digester is too high, the gas must be released immediately to protect the gas box or prevent the digester cover from bursting open, which could result in an accident.

The winter temperature in northern of China is relatively low, which is unfavorable for biogas production. A review of the development of household biogas in China shows that one of the key factors which impeded the utilization of biogas in northern China was: how a biogas digester lives through the winter. Therefore measures must be taken for rural biogas digesters to overwinter before the arrival of winter, so as to ensure a normal gas production, and insulation should be adopted such as covering plastic layer or material stack, annular ditch, pouring of hot water or integration of solar cell.

Some interrelated experiment shows that, use of solar radiation, combining with heat-proof shed, building annular ditch, covering with corn and straw could give a significant temperature raise for the biogas plant, and a long time heat preservation guarantee a normal gas production for the biogas plant even in winter.

5.2.3 Economical Assessment of Household Biogas Plants in China

The cost for a small household biogas digester is around 220 € and for a larger model (with pigpen, greenhouse, toilet, and the biogas digester) around 550 €.

After the completion of biogas plants, yearly, a total 900 € in cost-cutting and income increasing can be realized, which includes,

- 45 € for the replacement of coal and saving the cost of fuel and electricity though the application of biogas lamps
- 260 € for the saving of fertilizer application, feeds for livestock
- 610 € for the increased yield of crops and livestock

Therefore, in the first year after starting up a digester, the investment cost can be recovered.

5.3 *Biogas Technology in Latin America*

Climatic condition in most areas of Latin America and Africa is optimal for biogas plants, especially in the Caribbean and the tropical countries.

5.3.1 Colombia

Colombia has ideal conditions for implementation and continuation of biogas technology. It is located in northwestern South America. Colombia has 42 million inhabitants, 74% of which live in urban areas and cities. Depending on the altitude, Columbia can be divided into several climatic zones. In the lowlands the average annual temperatures is over 24°C. The amount of available substrates (the livestock and the agricultural) is enormous, which are suitable for biogas plants. There are 2.5 million pigs and more than 25 million cattle in Columbia.

Main incentive to introduce biogas technology is the severe pollution of surface waters and thus the water resources through the deposits from animal husbandry. The first project for the construction of biogas plants started in the middle of the 80s, with the assistance of a German consulting company. Between 1985 and 1992 altogether 25 biogas plants had been built. The types of biogas plants and their sizes were very varied: a floating-drum plant, a tunnel plant, an upflow anaerobic sludge blanket and some fixed-dome plants with the size from 14 to 115 m^3. Some of the plants are equipped with plastic balloons to include biogas equipment. These plants were designed for medium and large pig and cattle breeders who had between 20 and 2,000 animals [19].

5.3.2 Jamaica

Jamaica is the third largest island in the Greater Antilles. The main island has an area of 10,991 km^2. Climate in Jamaica is tropical and temperature differences are very small throughout the year. In Kingston, the mean monthly temperature in January is 25 and 27°C in July, in the central plateau it is about three degrees lower. In Jamaica, approximately half of the 3 million inhabitants live in rural areas and 30% of the working population is employed in the agricultural sector. The history of agricultural biogas plants dates back to end of 1970s.

Back in 1978 The Scientific Research Council (SRC) started research and development activities in the area of biogas. It has always been regarded as the first and most important advocator of biogas technology in Jamaica. In the phase from 1988 to 1992, 89 biogas plants were built, mostly by Chinese fixed—dome digester type. At the end of 1992 there were only 15 of the 89 plants in operation. A new phase of the biogas plants began in 1993. In the new plants, all the manure and waste water flow by gravity into the plant. Domestic waste water, toilet effluents in particular garden and kitchen waste can be treated by the new plants. 120 biogas plants have been built in this phase.

5.3.3 Bolivia

Bolivia lies in west-central South America and has a total area of 1,098,580 km^2, of which 14,190 km^2 is water. The average annual temperatures are depending on the location and height in a range from 6°C to about 27°C. Bolivia has a population of about 7 million inhabitants, but the most of the population live on an area with only 30% of the total area of the country. Bolivia has extensive oil and gas reserves. One important motivation for biogas plants is to use the fermenters for the production of fertilizers from organic materials. Therefore the government decided to develop biogas technology as part of agricultural production, to prevent ecosystems from being destroyed by agricultural activities.

In 1986, a biogas cooperation project was started by GTZ and the Universidad Mayor de San Simon (UMSS) in Cochabamba. A total of 27 plants were constructed but in 1988 there was only one still functioning. From 1989 to 1992, around 35 plants were constructed [33].

Because of the low temperatures, operation of biogas plants at high altitude is the theoretical limit of biogas technology. In 2002 a draft of biogas digesters for the regions above 2,000 m in Bolivia was developed. In 2003 a tubular biogas digester was installed in the Altiplano, 4,100 m over sea level, with ambient temperatures under 0°C (Fig. 6). From 2002 to 2006 about 250 tubular biogas digesters were installed by departments Cochabamba and La Paz. Until now more than 1,000 biogas digesters are working in Bolivia. Most of them are the type of tubular plastic biogas digester [21].

5.3.4 Cuba

The republic of Cuba is an island country in Caribbean Sea. About 11 million people live in Cuba, of which about two million live in the capital, Havana. Cuba has rich materials, which is fit for the biogas plants:: about 75 million cubic meters of organic waste per year is available, excrement of cattle and pig and from sugar cane, remaining sugar scraps after filtering the pressed sugar juices. In Cuba, the NGO Cubasolar and church-based organization KATE are the powerhouse for the development of biogas technology, with strong support from the government. The history of biogas in Cuba dates back to 1940s, with the introduction and promotion of floating drum digesters and fixed dome digesters, the 1980s witnessed a boom in the development of biogas technologies in Cuba. In the 1980s, about 400 biogas plants were built as small plants in agriculture in Cuba. In 2000 only 50–60 plants were in operation.

At present there are 700 biogas plants in Cuba; the largest one, located in Havana, was jointly developed with United Nations Industrial Development

Fig. 6 Biogas digester in the Altiplano, 4,100 m above mean sea level; gas tank (**1**), digester (**2**)

Organization (UNIDO). Many of these plants now need an overhaul. Thus, in 2007, the repair and modernization of these systems began. From 2008, about 450 new biogas plants will be built gradually.

5.4 Biogas Technology in Africa

5.4.1 Ethiopia

Covering an area of 1,097 million square kilometers, Ethiopia is a country in northeastern Africa. The differences in climate in Ethiopia are primarily due to the altitude. Ethiopia has a population of 79.1 million, but only 16% of them are living in urban area. Ethiopia has the largest livestock population in Africa (approximately 61.5 million in 2001). Most of the households use crop residue, dung, kerosene or fire wood as fuel, but only a few people use electricity. Consequently, there is a large gap in the energy supply system and the market of biogas is enormous.

The first introduction of the biogas technology dates back to as early as 1979, with the first batch type digester being constructed at Ambo Agricultural College. Since then, around 1,000 biogas plants have been built up all over the country, sizes of which ranging from 2.5 to 200 m^3 in households, community, and governmental institutions. At present, approximately 40% of the biogas digesters are out of function. Therefore, an increasing number of people are skeptical about the development potential of biogas in Ethiopia, and the benefits for the farmers. World Vision Ethiopia has recently introduced the application of biogas under its Appropriate Agricultural Technology Promotion Initiative (AATPI) and some 150 plants have been built. As such, the total number of completed biogas plants in Ethiopia would reach 600–700 [14]. In 2007, with the help of Netherlands Development organization (SNV) a national biogas program was started in Ethiopia to build on and to further develop existing institutions and organizations for biogas technology.

5.4.2 Lesotho

The Kingdom of Lesotho has a total area of 30,000 km^2 and a population of almost 1.8 Million people. The average annual temperature in the capital Maseru is 15°C. About 84% of Lesotho's total population lives in rural areas. In Lesotho, sheep, goats, cows, oxen, and other animals are common in even the most rural areas. In rural areas, Paraffin fuel is mainly used for cooking and heating, and also biomass and dried animal dung.

Biogas technology has been used in Lesotho since the 1980s. About 80 household-size biogas digesters constructed in Lesotho were built between 1980 and 1990. But in 2002 none of them were operational. In 2004, "Technologies for Economic Development" (TED) was established with the main focus on renewable energies, sustainable sanitation and climate protection. So far, more than 300 household biogas digesters have been constructed by TED. At the beginning, the digester was used as storage tanks for the untreated wastewater to solve the sanitation problem and from this resulting high costs of operation. But now some of these digesters are also fed with organic solid waste or animal dung.

5.4.3 Tanzania

Tanzania is a country in East Africa with 945,000 km^2. There are around 41 million inhabitants. The average daily temperatures amount to 26.5–30°C. Livestock production by small farmers in the region is used to meet their own demand, as well as for commercial purposes. According to a date research, there are totally 886,500 cows, 699,300 goats and 47,500 pigs in the region of Kagera. They produce 4.3 million tons fresh cow dung and 21,400 tons pig dung per year. Considering water supply, 34% of households have an adequate water supply in the vicinity to ensure the operation of a biogas plant. Therefore it results in a plant's requirement of about 132,000 small biogas digesters in the region of Kagera.

In the early 90s several small biogas plants were constructed by the Tanzanian church in collaboration with its Danish partner organization in this region. During that period, most of the biogas plants were equipped with either domed digesters or tubular plastic digesters. Up to 2007, there were altogether 2,821 built biogas plants in Tanzania, among which 2,444 were fixed dome digester and 429 were tubular plastic digesters. However, in 2007 there were only 1900 biogas plants still in operation due to their limited service life [20]. Since 2008 Berlin regional group of Engineers Without Borders Germany and Mavuno from Tanzania work together on the project "Biogas support for Tanzania (BiogaST)" for the development and construction of decentralized small biogas plants to use of biogas as an energy source for cooking and other energy applications.

5.5 Assessment of Dissemination of Biogas Technology in Latin America and Africa

One reason for the low dissemination of biogas technologies in Latin American and Africa countries is certainly the lack of support from the government. The lower population density compared to China and India makes the environmental problems seem not quite so urgent. The other constraints for the widespread biogas technology include:

- High investment costs
- Lack of legal framework

The causes for the failure or failures of existing biogas plants are listed as follows:

- The operators/users were not sufficiently trained (information about handling and maintenance was inadequate)
- Lack of motivation of the operator/user
- Material errors and technical defects
- Reduced animal holdings
- Evacuation of ownership and water problems etc.

6 Outlook

Anaerobic digestion has potential for more widespread dissemination especially in developing countries and countries in transition. Though implementation at household level remains important, scale of operation at large-scale and municipal level will gain importance, which is closely linked to improved waste management schemes, industrialization of agriculture, and increasing energy demands.

Biogas technology qualifies as a CDM project (avoiding uncontrolled methane emissions from dumped waste or landfills). According to the Kyoto Protocol CDM allows industrialised countries with a greenhouse gas reduction commitment to invest in projects that reduce emissions in developing countries as an alternative to more expensive emission reduction in their home countries. This may further boost implementation of AD in developing countries [37].

Among the most pressing issues related to advancing sustainable dissemination of AD technology are solutions to overcome the investment barriers, educational issues, availability of help and advice (calculations on economic viability, repair services, advice on plant operation/biological process) and implementation of schemes allowing for reliable income generation via biogas (e.g. remuneration for biogas energy, digestate management schemes and programmes, favourable legal frameworks).

At the present some organizations have established and started a series of the national and international biogas programs to facilitate the biogas development in Latin-America and in Ethiopia. The "Biogas for better life" project has the goal: until 2020 there will be 2 million biogas plants installed in Africa. "IGNIS"—project committed for the waste management in Addis Ababa, Ethiopia, in which the biogas development is also an important task. GTZ, UTEC, SNV, Swiss contact, SEQUA and RELUX have initiated some cooperation with local partners in Latin-American and Africa to use and dissemination of biogas technology. They use their experience in biogas programs in a number of countries to support the setting up of biogas plants, to train more technical personnel and promote the general publicity of biogas technology. In this way, more and more people will understand the benefits of biogas and can thus be motivated to develop and disseminate the biogas technology, mobilize the enthusiasms to dissemination and development of biogas technology, so as to realize a feasible model in the rural areas of Africa and Latin America featuring stable gas supply, minimized environmental pollution and sustainable supply of resources and energy.

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