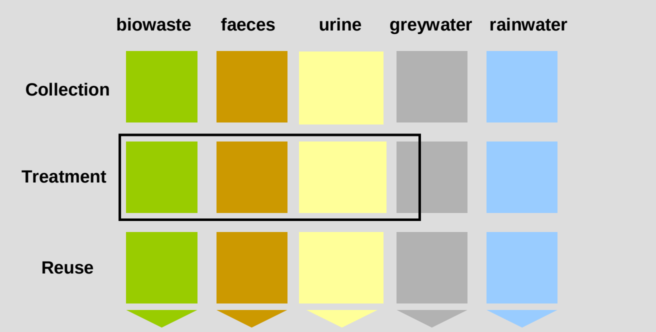
Biogas sanitation for black water or brown water, or excreta treatment and reuse in developing countries

Draft version



Preface and acknowledgements

Dear Reader,

The work on this document began in 2004 and was progressed by various staff members and consultants of the GTZ “sustainable sanitation – ecosan” team and some CIM integrated experts over the years. The main purpose of this document is to provide an overview and introduction on biogas santation for blackwater or for brown water, or excreta treatment for reuse in developing countries, and to point you in the right direction for further reading.

Colleagues who have contributed to an earlier version of this document include Susanne Kimmich, Florian Klingel, Ina Patricia Jurga, Hagen von Bloh, Elisabeth-Maria Huba and Christopher Kellner. This current version was written mainly by Heinz-Peter Mang and Prof. Dr.-Ing. Zifu Li (both Beijing University of Science and Technology and China Node for Sustainable Sanitation).

If you spot omissions, errors or confusing statements, please e-mail us your feedback at ecosan@gtz.de and to heinz-peter@worldtoilet.org.

We hope that you find this publication useful for your own ecosan projects and dissemination activities.

Kind regards,

Dr. Elisabeth von Münch

Leader of GTZ program „Sustainable sanitation – ecosan“

Lead authors: Heinz-Peter Mang and Zifu Li
Edited by: Dr. Elisabeth von Münch

Please send feedback and comments to the e-mail address given below. We look forward to hearing from you.

Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH

ecosan program

Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Germany
T +49 6196 79-4220
F +49 6196 79-7458
E **ecosan@gtz.de**
I www.gtz.de/ecosan

partner of
sustainable sanitation alliance

Contents

1 Summary

Anaerobic treatment units, as part of an on-site, decentralised or semi-decentralised wastewater treatment system, are a competitive alternative to centralised wastewater treatment plant systems due to their energy and soil conditioner production capacity, low-tech components and adaptability.

Sanitation has a strong link to agriculture, as the nutrients such as nitrogen and phosphorus contained in human excreta are needed as fertilizer, and the organics as soil conditioner. Excreta are a rich source of inorganic plant nutrients such as nitrogen, phosphorus and potassium, and of organic matter. Each day, one adult humans excrete in the order of 30 g of carbon (90 g of organic matter), 10-12 g of nitrogen, 2 g of phosphorus and 3 g of potassium. Most of the organic matter is contained in the faeces, while most of the nitrogen (70-80%) and potassium are contained in urine. Phosphorus is equally distributed between urine and faeces. It has been calculated that the fertilising equivalent of excreta is nearly sufficient for a person to grow its own food (Drangert 1998). In reality, part of this potential is lost, during storage and treatment (e.g. nitrogen loss through ammonia volatilisation).

Excreta is not only a fertiliser. Its organic matter content, which serves as a soil conditioner and humus replenisher – an asset not shared by chemical fertilisers – is of equal importance. The traditional practices of recycling faecal sludges to agriculture or aquaculture (e.g. in Southeast Asia) have for centuries made use of this resource. For the same reason, urban farmers in arid or semi-arid zones or during dry seasons, in addition to procuring water for irrigation are endeavouring to get access to wastewater, raw or treated. This allows them to renounce or minimize the purchase of chemical fertiliser. It is now being postulated that sanitation systems should, whenever feasible, be conceived and managed such as to enable and maximise the recycling of organic matter and nutrients contained in human excreta (Winblad 1997; Esrey et al. 1998). A change in the sanitation management paradigm from flush-and-discharge to recycling of urine and faeces is gaining ground in Europe (Larsen and Guyer 1996; Otterpohl et al. 1997 and 1999; Otterpohl 2000).[1]

The main advantages of anaerobic treatment systems are the generation of biogas and about 80% less sludge production compared to aerobic treatment processes.[2] The fact that the plant nutrients nitrogen and phosphorus are not removed is an advantage as well if the effluent is applied in agriculture to replace chemical fertilizer. The phosphorous compounds remain a potential phosphate supplier, as phosphorus is removed with the bacteria mass in form of settled sludge. Therefore the here described sanitation concept for brown or black water of fecal sludge (excreta) based on anaerobic technology has major advantages in terms of nutrient recycling, energy balance and CO_2-emissions reduction compared to conventional aerobic wastewater treatment systems.

The traditional high flush toilet generates an end product which is not suitable for on-site use in a small-scale biogas plant. It fails to produce an interesting amount of biogas. One way out of this dilemma is to add organic kitchen waste to the biogas unit. Therefore access to the waste water from an existing sink (via modifications under the sink), or the addition of a special sink, used only for kitchen garbage, may be a better answer. (A organic garbage disposal, if carefully used to avoid introduction of excess water, is a definite plus.)[3]

In decentralized or semi-centralised wastewater treatment systems, biogas sanitation units are often designed as primary treatment of wastewater to reduce large particles and some organic matter (i.e. by settling and digestion).[4]

The specific local circumstances must be taken into consideration when planning a biogas sanitation system; parameters are e.g. how much excreta, black or brown water has to be treated; the dillution factor of the influent with flush water or urine; adding of other organic feedstock; the settleable sludge content in the influent; the climate and soil temperatures; how much area is available; and the intended reuse or disposal pathway.

Four types of biogas sanitation units are briefly described in this fact sheet: (a) the biogas settler (BS) or biogas septic tank (BST); (b) the anaerobic baffled reactor (ABR); (c) the anaerobic filter (AF); (d) the upflow anaerobic sludge blanket reactor (UASB); and combinations of these units.

An understanding of financial and economic returns are key ingredients in the decision-making process towards biogas sanitation. Financial analysis of costs and benefits provides insight into consumer willingness to invest in combined biogas and sanitation technologies by capturing potential net returns to the household. A discussion paper prepared by Winrock International for the Dutch Ministry of Foreign Affairs presents as result for selected African countries that biogas sanitation could yield benefit-cost ratios (BCRs) ranging from 1.22 to 1.35 and financial internal rates of return (FIRRs) from 7.5% to 10.3%.[5]

Pure biogas sanitation systems are in operation in many countries (e.g. Barbados, Bangladesh, Bolivia, Burundi, Buthan, Cameroon, China, Democratic People's Republic of Korea, Ethiopia, Georgia, India, Indonesia, Jamaica, Kenya, Laos, Lesotho, Marrocco, Mozambique, Nepal, Nicaragua, Philippines, Republic of Korea, Rwanda, South Africa, Tanzania, Thailand, Uganda, Vietnam, Zambia and others); the technology is becoming more and more known and accepted. This publication intends to contribute to spread awareness about this technology.

2 Introduction

2.1 Target audience of this publication

To understand this document only a basic technical background is needed. The target audience for this publication are people who:

[1] Martin Strauss, Human Waste (Excreta and Wastewater) Reuse, EAWAG/SANDEC, Switzerland, August 2000,

[2] W.W. Eckenfelder, J.B. Patozka and G.W. Pulliam, Anaerobic Versus Aerobic Treatment in the USA, 5th International Symposium of Anerobic Digestion, proceedings pp 105-114, IWA Publishing, 1988

[3] David House, Biogas Handbook, Alternative House Information, USA, ISBN 0-915238-47-0AACR2, 2006

[4] Ludwig Sasse, DEWATS - Decentralised Wastewater Treatment Systems in Developing Countries, BORDA, Germany, 1998

[5] Mary Renwick, Prem Sagar Subedi and Guy Hutton, A Cost-Benefit Analysis of National and regional Integrated Biogas and Sanitation Programs in sub-Saharan Africa, Winrock international, The Netherlands, April 2007

- want to get an overview of biogas sanitation, their different designs, their application, maintenance, efficiency and technical components;
- want to know the most important documents written in this field for further reading
- may have a particular interest in developing countries, especially from the perspective of the poor.

2.2 Scope of this document

Biogas sanitation systems can purify a wide range of wastewater, but this publication focuses on treating black or brown water, excreta, feacal sludge, wastewater from low or no flush toilets and the kitchen-outlet. Such treatment concept can easily be combined with urine diversion systems treating anaerobically only the brown water which consists of wastewater mixed with feces, but without urine.

This document deals with biogas sanitation treating mainly black and brown water, or excreta (also called night soil). The construction of biogas sanitation units is the same as for completely mixed wastewater treatment but it can be smaller if designed for black- or brown water, excreta or feacal sludge only, depending on the treatment target: (a) optimised energy output, or (b) optimised hygienisation.

2.3 Definition of biogas sanitation systems

Biogas sanitation systems are defined as ‘‘engineered systems designed and constructed to utilize biological processes which break down solids and liquids by bacterial action in treating organically loaded sludge, excreta or wastewater’’. Purification is the result of the breakdown which occurs in the absence of oxygen (anaerobic conditions). Synonymous terms to biogas sanitation system include biogas septic tank in which the anaerobic conditions are referred to as "septic" giving the tank its name.

Compared to a proper designed, operated and maintained biogas sanitation system, a typical septic tank system consists of a (baffled) tank and a soak-away drain without any reuse of the pre-treated effluent and the biogas produced. Therefore, depending on soil conditions and ground water level, the effluent of a septic tank can transport bacteria, viruses, household chemicals, and other contaminants into the groundwater causing serious problems [6] and the climate will be affected by vented methane emissions.

2.4 Historical development of biogas sanitation systems

Anaerobic digestion is one of the oldest technologies applied for wastewater treatment. Historically, Louis Mouras of Vesoul, France, was given a septic tank patent in 1881 and credited with the invention. Baffles, which regulate the flow, were added in 1905 to make the septic tank more efficient. The first baffles were made of oak boards. [7] It is reported that the septic tank was first introduced in the USA in 1883, in England in 1895 and in South Africa in 1898.

The first biogas septic tank unit usually referred to in literature is the biogas sanitation unit at the Mantunga Homeless Lepers Asylum near to Mumbai, built in 1859. Its primary function seems to have been sewage treatment, but the biogas was also used. The first sewage treatment plant designed as biogas plant was installed in 1938 in Mumbai-Dadar. [8] In 1978, an experimental community sanitation biogas plants with support of UNICEF had been implemented in Uttar Pradesh.[9] Since then community biogas sanitation systems have been promoted by various stakeholders throughout India.

In 1895, the technology concept of a biogas septic tank was developed in Exeter, England, where a septic tank was used to generate biogas for the sewer gas destructor lamp, a type of street gas lighting. Also in England, in 1904, the first dual purpose tank for both sedimentation and sludge treatment (biogas settler) was installed in Hampton.

In China, the small scale agricultural biogas plant had been developed in Taiwan in 1920, based on urban household septic tanks.[10] As a standard, the toilet and the pigsties have been connected to the same underground digester.[11] In order to treat collected feacal sludge and excreta (nightsoil), the city of Qingdao started the operation of the first large scale biogas sanitation digester in July 1978. At the same time, the Zhangzhou College of Education developed a kind of small scale 3-step biogas digester for anerobic treatment of excrements from household dry toilets.[12] A major increase in the number of pure biogas sanitation systems took place in 1984, as the application expanded with the development of the "Purifying Domestic Sewage Biogas Tank" developed by the Chinese Chengdu Biogas Research and Development Centre. [13] Since then many public toilets have been connected with biogas septic tanks, composed by biogas settler and anaerobic filters.

The first national biogas program supported by German Economic Development Cooperation considering toilet wastewater and human excreta as feedstock, was conducted under the lead of the Ministry for Energy and Mining in Burundi. The project was initiated as GTZ-Biogas Dissemination Programme in 1984 in the region of Cankuzo; it became part of a "Special Energy Programme" in 1988 and was stopped due to civil war in 1992. After first experiences with family sized biogas septic tanks, the project started in 1987 to build middle and large scale biogas sanitation systems connected to the toilets of boarding schools and other institutions. Private contractors were commissioned for larger plants. The training of craftsmen, the establishment of a service system and the set-up of material credit funds were to provide the basis for a self-reliant dissemination concept. By 1992, 206 small-scale biogas plants, and 84 institutional biogas

---

[6] www.waterencyclopedia.com/Re-St/Septic-System-Impacts.html
[7] http://www.fcs.uga.edu/pubs/current/C819-2.html

[8] Gerhard Eggeling, Götz Mackensen, Luwig Sasse, Production and Utilization of Biogas in Rural Areas of Industrialized and Dveloping Countries, GTZ, ISBN 3-88085-274-X, Germany 1985
[9] http://www.unicef.org/india/overview_4457.htm
[10] Cao Guo-Qiang, Chengdu Biogas Scientific Reseach Institute of the Ministry of Agricuture,GTZ-BORDA Biogas Forum 1992/I No.48
[11] Ariane van Buren, A Chinese Biogas Manual, Science Publishing House, China, 1976, Intermediate Technology Publications, ISBN 978-1-60322-039-2, July 1979
[12] Yao Yongfu, Qian Yibo, Gu Yunxuan, Zhang Hui, Xu Yuansheng, Xiong Chengyong, Fang Guoyuan, Xu Jiequan, and Zhang Taiming, The Biogas Technology in China, Agricultural Publishing House, China, ISBN 7-109-01777-X, 1992
[13] Lai Cheng and Lai Yao-Fu, Chengdu Biogas Resreach and Training Centre, GTZ-BORDA Biogas Forum 1991/III No. 46

sanitation plants with digester volumes of up to 250m^3 had been constructed. [14]

Standards for on-site household based "biodigester septic tanks and biolatrines" had been firstly developed in 2000 by the GTZ & DED[15] supported Ethiopian Project LUPO (Land-Use Planning Oromiya) and later were improved in Lesotho by the NGO Technology for Economic Development (TED). [16]

A document on the Biodigester Septic Tank (BST) was prepared in 2000 by the Scientific Research Council of Jamaica and presented to the Ministry of Commerce and Technology, Ministry of Health, and the Ministry of Land & Environment/Ministry of Water & Housing for approval to be used as the system for future on-site sewage treatment for housing developments. In the following years a wide range of request was received from housing developers to utilize the biogas technology (the Biodigester Septic System) for the on-site treatment of domestic sewage, thus replacing septic tanks and soak–away pits.[17]

Biogas sanitation systems have been used for excreta treatment for more than 100 years, thus improving water quality and sanitation in many regions of the world.

2.5 Characteristics and definitions, following Eawag's Compendium of Sanitation Systems and Technologies[18]

Anal cleansing water is water collected after it has been used to cleanse oneself after defecating and/or urinating. It is only the water generated by the user for anal cleansing and does not include dry materials. The volume of water collected during anal cleansing ranges from 0.5 L to 3 L per cleaning.

Biogas is the common name for the mixture of gases released from anaerobic digestion. Typically biogas is composed of methane (50–75%), carbon dioxide (25–50%) and varying quantities of nitrogen, hydrogen sulphide and other components. In conventional septic tanks, Imhoff tanks and anaerobic lagoons this biogas is vented out, creating climate critical emissions due to its methane content. The rate of methane production depends on the rate of removed COD and the temperature. It is also common to relate the production to the dry matter (TS) or organic dry matter (OTS) of the input material. In human feaces organic matter makes up 86% of dry matter. About 40 % to 60 % of organic matter is converted to biogas. Average daily production of fresh human manure (only feces): 0.12-0.6 kg/person (depending on age, diet and climate), with average composition of 71% water and 29% dry matter.[19]

1 kg TS human excreta produces up to 478 l of biogas in 60 days HRT. Also depending on the fermentation temperature 1 kg TS human excreta produces 430 l at 35^{o}C or 300 l at 25^{o}C. (Yao Yongfu 1992)

Black water is the mixture of urine, feces and flushwater along with anal cleansing water (if anal cleansing is practiced) and/or dry cleansing material (e.g. toilet paper). Blackwater contains all of the pathogens of feces and all of the nutrients of urine, but diluted in flush- or anal cleansing water.

Brown water consists of feces and flushwater (although in actual practice there is always some urine, as only 70–85% of the urine is diverted). Brownwater is generated by urine-diverting flush toilets and therefore, the volume depends on the volume of the flushwater used. The pathogen and nutrient load of feces is not reduced, only diluted by the flush- and anal cleansing water.

Effluent is the general term for liquid that has undergone some level of treatment and/or separation from solids. It originates from either a collection, storage and treatment or a (semi-) centralized treatment technology. Depending on the type of treatment, the effluent may be completely sanitized or may require further treatment before it can be used or disposed of.

Excreta (nightsoil) consists of urine and feces that are not mixed with any (flushing) water. Excreta is small in volume, but concentrated in nutrients and pathogens. Depending on the feces it is solid, soft or runny.

Fecal Sludge is the general term for the raw (or partially digested) slurry or solid that results from the storage of black water or excreta. The composition of fecal sludge varies significantly depending on the location, the water content, and the storage. For example, ammonium (NH4-N) can range from 300–3000 mg/L while Helminth eggs can reach up to 60,000 eggs/L. The composition will determine the appropriate type of treatment, and the recommended end-use.

Feces refers to (semi-solid) excrement without urine or water. Each person produces per year approximately 50 L of fecal matter. Of the total nutrients excreted, feces contain about 10% N, 30% P, 12% K and have 10^7–10^9 fecal coliforms /100 mL.

Flushwater is the water that is used to transport excreta from the user interface to the storage or treatment point. Freshwater, rainwater, recycled greywater, or any combination of the three can be used as flushwater source.

Organics refers here to biodegradable organic material that could also be called biomass or green organic waste (including kitchen sink waste). Organic degradable material could include leaves,grass and market wastes.

Treated Sludge is the general term for partially digested or fully stabilized fecal sludge. The USA Environmental Protection Agency has strict criteria to differentiate between degrees of treatment and consequently, how those different types of sludges can be used. 'Treated Sludge' is used as a general term to indicate that the sludge has undergone some level of treatment, although it should not be assumed that 'treated sludge' is fully treated or that it is automatically safe. It is meant to indicate that the sludge has undergone some degree of treatment and is no longer raw. It is the responsibility of the user to inquire about the composition, quality and therefore safety of the local sludge.

---

[14] Werner Kossmann, Uta Pönitz, Stefan Habermehl, Thomas Hoerz, Pedro Krämer, Barbara Klingler, Christopher Kellner, Thomas Wittur, F. v. Klopotek, Andreas Krieg, and Hartlieb Euler, Biogas Digest Volume I - IV, Biogas – Country Reports, GTZ, Germany, 1996

[15] DED = German Development Service

[16] Christopher Kellner, Biodigester Septic Tank and Biolatrine, LUPO Project, Ethiopia, 2000

[17] Ministry of Land & Environment, Jamaica National Environmental Action Plan (JaNEAP) Status Report 2002

[18] Elizabeth Tilley, Christoph Lüthi, Antoine Morel, Chris Zurbrügg and Roland Schertenleib. Compendium of Sanitation Systems and Technologies, EAWAG, Switzerland, ISBN 978-3-906484-44-0, 2008

[19] Tiziana Pipoli, Feasibility of biomass-based fuel cells for manned space exploration, Seventh European Space Power Conference, Stresa, Italy, ESA proceedings, SP-589,May 2005

2.6 Basic principles of biogas sanitation

Biogas sanitation systems are typically used as part of a on-site household based, decentralised or semi-decentralised wastewater treatment processes.

They have been used to treat:
1. Domestic wastewater
2. Brown water
3. Black water
4. Excreta (nightsoil)
5. Feces
6. Fecal sludge
7. Organic waste

This publication focuses on options 2 to 6 as they can easily be incorporated into an ecosan system, leading to safe reuse of treated effluent.

The concentration of nitrogen in the black water could increase very much, thus interrupting the digestion process. Urea from the urine will be transformed by enzymes in ammonia, carbon dioxide and ammoniac. Urea will be toxic to the bacteria (self-intoxification). This problem could be avoided by solid/liquid separation (AQUATRON[20], filter bag[21], settler) or urine diversion toilet bowls and pans, and only the "solid" part (fecal sludge) is digested; or organic waste (kitchen waste) is added as carbon rich material. In practice, it is important to maintain, by weight, a Carbon/Nitrogen (C/N) ratio between 20-30:1 for achieving an optimum rate of digestion. The C/N ratio can be manipulated by combining materials low in carbon with those that are high in nitrogen, and vice versa.[22] If C/N ratio is very high the gas production will be low; if the C/N ratio is very low, the pH value will increase, and will have a toxic effect on bacteria.

Biogas sanitation systems are usually designed as a primary treatment for removal of settleable and digestable solids and organic matter (Biogas settler, biogas septic tank) and secondary (advanced) treatment for nutrient removal (nitrogen), hygienization and COD-, BOD-reduction (anaerobic filter, upflow anaerobic sludge blanket). Secondary and tertiary treatment normally occurs with natural aerated trickling filters, constructed wetlands or aerobic pond systems.

Anaerobic digestion is a complex physical-chemical and biological process that takes place in absence of air. Due to the biological conditions these decompostion process is possible under anoxic and anaerobic conditions:

a) **Anoxic decomposition or respiration**: oxygen comes from other substances within the wastewater, for example NO_3, and a bio-chemical degradation through bacteria is initiated:

$$C_6H_{12}O_6 + 4NO_3 \rightarrow 6CO_2 + 6\ H_2O + 2\ N_2$$

b) **Anaerobic decomposition or fermentation**: no additional oxygen – substances are split by bacteria into components and components are re-arranged; bio-chemical degradation is originated by bacteria:

$$C_6H_{12}O_6 \rightarrow 3CH_4 + 3\ CO_2$$

The digestion is a multi-stages process (hydrolysis, acid formation stage, methanogenesis) performed by different bacteria. In biogas sanitation systems, the different degrading reactions take place in one digester. The digestion process starts with hydrolysis of the input materials caused by bacteria in order to break down insoluble organic polymers such as carbohydrates. Acidogenic bacteria then convert sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids; followed by acetogenic bacteria converting the resulting organic acids into acetic acid, along with additional ammonia, hydrogen, and carbon dioxide. At the end of the process, methanogens convert these products into methane and carbon dioxide.

a) **Hydrolysis and fermentation**: (1) the organic matter is enzymolyzed by extracellular enzymes; (2) bacteria decompose the long chains of complex to simpler substances, for example polysaccharide to monosaccharide

b) **Acidification**: (1) acid producing bacteria convert intermediate fermenting bacteria into acetic acid, H_2 and CO_2; (2) acid producing bacteria create anaerobic conditions for CH_4 (methane) producing bacteria

c) **Methane formation**: methanogens, methane producing bacteria, reduce low molecular weight components into alcohols, organic acids, amino acids, CO_2, H_2S and traces of CH_4

The organisms that are responsible for digestion are sensitive to the environmental conditions; some facilitating and inhibiting factors that play an important role in the process are described below. Any material, at some concentration level, can be inhibitory or toxic to the anaerobic digestion process. The following seven groups of materials have such an impact already at low presence level: (1) ammonia, (2) heavy metals, (3) light metal cat-ions, (4) oxygen, (5) short chain organic acids, (6) other organic acids, and (7) sulfides.

Important parameters for monitoring anaerobic processes are: organic dry substance, pH value, C/N ratio, Redox potential, volatile fatty acids, moisture content, acidity and alcalinity, and substrate structure. *For further reading please refer to: Bernd Gutterer, Thilo Panzerbieter et. al., Decentralised Wastewater Treatment and Sanitation in Developing Countries, BORDA, Water, Engineering and Development Centre, Germany, 2009.*

2.7 Advantages of biogas sanitation systems

The advantages of biogas sanitation systems compared to conventional or pure aerobic wastewater treatment systems are:

- Cost effective: biogas sanitation systems can be less expensive to build than other treatment options. Biogas septic tanks having at least the same investment as a conventional septic tanks, and capture the biogas for further use. Operation and maintenance expenses (energy and supplies) are low. Operation and maintenance require only low skilled labour.
- 'Natural' low-tech system: Anaerob technology is a natural system of wastewater treatment which normally does not rely on complex machines and processes. Low-tech systems as the anaerobic pre-treatment units of a DEWATS require low but adequate maintenance.

[20] www.berger-biotechnik.com/downloads/aquatronhybridtoiletsystem.pdf
[21] B. Vinnerås,and H. Jönsson, Faecal separation for nutrient management—evaluation of different separation techniques, Urban Water Volume 4, Issue 4, Pages 321-329 December 2002
[22] www.unu.edu/unupress/unupbooks/80434e/80434E0k.htm

- Providing habitat value: well designed gravity flow do not need any pumping and its underground construction does not occupy valuable space specially in urban areas; only 0,5-1m^2/m^3 daily flow are needed, compared to 25–30m^2/m^3 flow in aerobic ponds and constructed wetlands.[23]
- Can be large or small: is suitable to be designed at small (decentralised), medium-sized (community level) or large scale.
- Treatment capability for a wide variety of domestic and industrial effluents.
- Decentralised wastewater treatment, saving a large amount of investment into the sewerage system. Low energy and maintenance cost, low total lifetime cost.
- If well designed, constructed and operated, 5-times less sewage sludge production compared to aerobic systems are expected. The sludge yield from anaerobic treatment is approximately 0.1 kg VSS/kg COD removed; by contrast aerobic activated sludge treatment performs in order of 0.5 kg VSS/kg COD removced. The operation of a biogas sanitation system combined with aerobic post-treatment can reduce the specific sludge production by 40%.[24]

2.8 Limitations of biogas sanitation systems

There are limitations in the use of biogas sanitation systems:

- Organic material degrades more rapidly at higher temperatures because the full range of bacteria are at work. The three ranges of temperature in which methane bacteria work are called *psychrophilic* (8-25ºC) *mesophilic* (35-45ºC) and *thermophilic* (53-65ºC). Biogas sanitation is often applied in countries where the ambient average temperature ranges above 15℃. In temperatures below 8ºC no much digestion will take place. The process is also sensible to temperature changes, which have to be avoided in order to ensure a steady biogas production. To improve biogas sanitation systems also isolation, active and passive heating and other solutions could be applied, depending on available design, funds and micro-location.
- Performance may be less consistent than in conventional treatment, if no reuse of effluent is designed a biogas sanitation is mainly a primary or secondary treatment step. The biological components are sensitive to toxic chemicals, such as ammonia and pesticides. Flushed pollutants or surges in water flow may temporarily reduce treatment effectiveness. Therefore sometimes buffer tanks for wastewater flow equalization should be built and maintained.
- As effluents from human excreta are contaminated with all kind of pathogens a reliable technology is necessary for their inactivation. It is known that during anaerobic digestion an inactivation of most animal and plant pathogens is obtained under long period thermophillic conditions (>50℃ for several days). However several studies on wet fermentation report that also mesophilic and lower temperature operation inactivates pathogens, and there are findings that reactors with retention times of 60 days and more produce pathogen reduced effluents. Chinese, and Dutch as well as German studies showed that there is a complete inactivation of the pathogenic test organisms through aerobic post composting process.

Table 1: Effects of anaerobic sanitization on selected pathogens and parasitic ova as well as on E-Coli indicator (source: Zhang Wudi, BRTC, China 1985)

Pathogens & parasitic ova	Thermophilic fermentation (53-55℃)		Mesophilic fermentation (35-37℃)		Ambient temperature fermentation (8-25℃)	
	Days	Fatality (100%)	Days	Fatality (100%)	Days	Fatality (100%)
Salmonella	1 – 2	100	7	100	44	100
Shigella	1	100	5	100	30	100
Poliviruses			9	100		
E-Coli titre	2	$10^{-1} – 10^{-2}$	21	10^{-4}	40 - 60	$10^{-4} – 10^{-5}$
Schistosoma ova	Several hours	100	7	100	7 – 22	100
Hookworm ova	1	100	10	100	30	90
Ascaris ova	2	100	36	98.8	100	53

2.9 Classification of biogas sanitation systems

Biogas sanitation systems can be classified according to various parameters; the three most important design criteria are (1) hydraulic retention time (HRT), (2) volumetric load, and (3) sludge retention time (SRT).

The *hydraulic retention time* (HRT) of the substrate in the digester depends on the process temperature and the type and concentration of substrate itself. This will then determine the volume of the digester. Digesters are designed for an optimum economic balance between gas yield and volume (HRT). Therefore the retention time is chosen as the total time required to produce a maximum of the total gas (to obtain the remaining is not economic). A minimum of 20 days of HRT is recommended due to bacterial reproduction time, but from a health point of view the HRT should be extended.

A *sludge retention time* (SRT) of at least 10 days is necessary to promote methanogenesis in the anaerobic treatment of primary sludge at a process temperature of 25℃ (Miron et al. (2000) while a SRT of 15 days is necessary for sufficient hydrolysis and acidification of lipids. For temperatures as low as 15℃, an SRT of a t least 75 days has to be considered to achieve methanogenic conditions (Zeeman et al., 2000).[25]

Different types of biogas sanitation units may be combined with each other (so called combined systems or DEWATS-pre-treatment) in order to benefit from the specific advantages of the different systems. The quality of the final effluent from the systems improves with the complexity of the treatment facility. Design information of the recommended four design variations are available through many websites and literature. Local design and engineering adaptations respecting human's diet (organic load & biogas potential), hygienisation need (household or community) and effluent reuse (energy cropping, tree nursery, grasland, vegetable, grain) are always nessesary,

[23] Bernd Gutterer, Thilo Panzerbieter et. al., Decentralised Wastewater Treatment and Sanitation in Developing Countries, BORDA, Water, Enginnering and Development Centre, Germany, 2009

[24] E. Gasparikova, S. Kapusta, I. Bodík, J. Derco, and K. Kratochvll, Evaluation of Anaerobic-Aerobic Wastewater Treatment Plant Operations, Polish Journal of Environmental Studies Vol. 14, No.1 pp 29-32, 2005

[25] G. Zeeman and W. Sanders, Potential of anaerobic digestion of complex waste(water), Water Science and Technology Vol. 44 No 8 pp 115–122, IWA Publishing 2001

therefore in the following chapters only a introduction could be given.

3 Biogas settler (BS) or biogas septic tank (BST)

The biogas settler (BS) or biogas septic tank (BST), is mainly applied as on-site household based system with secondary treatment of effluents in compost (solids) and drainages / subsurface irrigation (liquid). The direct effluent from the reactor, a dark slurry, is a nutrient-rich fertilizer for agriculture and aquaculture, due to the conservation of nitrogen during the anaerobic process. Any kind of suitable organic waste (kitchen sink) could be added to increase the biogas productivity. BS are also applied as pre-treatment step in combined anaerobic / aerobic systems (DEWATS) and for constructed wetlands.

Generally, the removal of 65% of solids, 40% of biochemical oxygen demand (BOD) and a 1-log removal of E.coli can be expected in a well designed biogas septic tank although efficiencies vary greatly depending on operation & maintenance, and climatic conditions. Biogas septic tanks can be installed in any type of climate although the efficiency will be affected in cold climates. Even though the biogas tank is gas- and watertight, it should not be constructed in areas with high groundwater tables or where there is frequent flooding, without any coating similar as a fresh water tank or a swimming pool. In a biogas settler, where the separation of the solids retention times (SRT) from the hydraulic retention times (HRT) is done with a baffle or a separation wall, the accumulated sludge must be removed from the biogas tank bottom periodically.

4 Anaerobic baffled reactor (ABR)

The anaerobic baffled reactor (ABR), a series of upflow and downflow baffles, where the baffles are used to direct the flow of wastewater in an upflow mode through a series of sludge blanket reactors. This configuration provides a more intimate contact between anaerobic biomass and wastewater which improves treatment performance. It could be used as primary tretament as well, especially where of toilet effluents are diluted with flush water.

Separation of the solids retention times (SRT) from the hydraulic retention times (HRT) is the key to the successful operation of an ABR. Due to this fact, a baffled reactor is considered as the best alternative to aerobic treatment and/or primary settlement. The treatment efficiency achievable is 70-95% BOD removal, which makes the effluent quality moderate but usually superior to that of a conventional septic tank.

5 Anaerobic filter (AF)

The anaerobic filter (AF) is suitable for those effluents that contains low content of suspended solids for instance from biogas settlers or biogas septic tanks as primary treatment and narrow COD/BOD ratio. The bacteria in the filter are immobile and generally fix themselves to solid particles or to the reactor walls. Filter materials like rocks, cinder, plastic, or gravel provide additional surface area for bacteria to settle. The larger surface area for the bacterial growth helps in the quick digestion of the wastes. A good filter material provides a surface area of 90 to 300 m^2/m^3 reactor volume.[26]

Anaerobic filters are reactors consisting of supporting material layer. On the surface of these material layers or bed fixation of microorganism the development of biofilm takes place. Anaerobic filters can be applied not only for treating concentrated wastewater but also for those wastewaters that have low organic load. However, they function efficiently for diluted sewage. In case of concentrated sewage the risk of blockage of the filter material increases with the concentration of suspended solids. They are best suited for post-treatment. If they are preceded by a biogas settler or a ABR or a UASB that retains settled solids, AF will work better. Biological oxygen demand up to 70% to 90% is removed in a well operated anaerobic filter.

6 Upflow anaerobic sludge blanket reactor (UASB)

The upflow anaerobic sludge blanket reactor (UASB), is a tank filled with anaerobic granular or flocculant sludge with good settling properties (the bacteria may spontaneously agglomerate to form granules). Influent wastewater is distributed at the bottom of the UASB reactor and travels in an upflow mode through the sludge blanket. The anaerobic degradation of organic substrates occurs in this sludge blanket, where biogas is produced. The biogas produced under anaerobic conditions serve to mix the contents of the reactor as they rise to the surface.[27]

The UASB reactor has the potential to produce higher quality effluent than biogas septic tanks, and can do so in a smaller reactor volume. The design of an UASB reactor must provide an adequate sludge zone since most of the biomass is retained there. The sludge zone is completely mixed because the wastewater is fed into the reactor through a number of regularly spaced inlet ports (Shieh and Li 1987).[28] The UASB is also characterised by a much longer SRT in comparison with the HRT.

It is a well-established process for large-scale industrial effluent treatment processes, its application for on-site domestic sewage treatment started in the 1988 in Cali, Columbia under the German Development Cooperation GTZ-biogas advisory service. The treatment efficiency achievable is 55-80% BOD removal. Effluent from the UASB will usually still require further treatment prior to discharge to the environment (similarly to biogas septic tanks).

7 Further References

Ludwig Sasse, Biogas Plants, Deutsches Zentrum für Entwicklungstechnologien - GATE in: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH – 1988

Uli Werner/Ulrich Stöhr/Nicolai Hees, Biogas plants in animal Husbandry, Deutsches Zentrum für Entwicklungstechnologien - GATE in: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH – 1989

[26] http://www.thewatertreatmentplant.com/anaerobic-filters.html
[27] http://www.training.gpa.unep.org/content.html?id=229&ln=6
[28] Adams, Jr., C.E.; Aulenbach, D.B.; et. al., Wastewater Treatment - Environmental Engineer's Handbook, Ed. David H.F. Liu & Bela G. Liptak, Boca Raton: CRC Press LLC, 1999

Ludwig Sasse, Christopher Kellner & Ainea Kimaro, Improved Biogas Unit for Developing Countries, Deutsches Zentrum für Entwicklungstechnologien - GATE in: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH - 1991

Susanne Schroth, Peter Pluschke, Hulshof Pol, Daniel Grohganz and Hartlieb Euler, End-, Status-, Länder-, und Seminarberichte und Datenbank des Sektorprojektes zum internationalen Stand der Anaerobtechnologie, GTZ, 1998 (in German language)

Christian Müller, Anaerobic Digestion of Biodegradable Solid Waste in Low- and Middle-Income Countries, EAWAG/SANDEC, Switzerland, May 2007

Christian Lohri, Evaluation of Biogas Sanitation Sysstems in Nepalese Prisons, IRC & EAWAG, October 2009