

Anaerobic methods of municipal wastewater treatment

Naturgerechte Technologien, Bau- und Wirtschaftsberatung
 TBW GmbH, Frankfurt
 March 2001

Technical Field:

- Energy / Environment (E)
- Water / Sanitation (W)
- Agriculture (A)
- Foodprocessing (F)
- Manufacturing (M)

This Technical Information is available in:

- English (e)
- French (f)
- German (g)
- Spanish (s)
- Other:.....

1 Introduction

During anaerobic bacterial degradation of organic matter (i.e. in the absence of oxygen), methane gas (CH₄), carbon dioxide (CO₂) and traces of other elements are produced. CH₄ can be utilised as renewable energy source, substituting fossil fuels. Speaking of wastewater treatment, an additional benefit of anaerobic processes is the reduction of total bio-solids volume by 50-80%, which is more than aerobic processes achieve. Moreover, the final sludge is biologically stable and can serve as fertilizer or soil conditioner for agriculture. Some traditionally implemented anaerobic technologies (e.g. septic tanks) are suitable for domestic wastewater treatment at the single household level or for facilities shared between several households. Other technologies, such as the anaerobic sludge digester, being one common part of the activated sludge process (an aerobic wastewater treatment process) and the upflow anaerobic sludge blanket (UASB) reactors (joint anaerobic treatment of wastewater and sludge) are suitable for the treatment of municipal wastewater. Anaerobic sludge digesters have a long tradition primarily in industrial countries. Since 1980, an increasing number of full-scale UASB anaerobic sewage treatment plants have been installed in larger warm climate countries as well.

Municipal wastewater treatment often combines anaerobic and aerobic treatment steps in order to achieve the best possible purification and hygienisation results. Under "real life" conditions in developing countries, typical full scale process combinations (as presented in Fig. 1) are however rarely entirely realised. Instead, often only the main treatment steps (aerobic wastewater treatment without a sludge digestion or anaerobic UASB treatment of sludge and wastewater without a post-treatment of the wastewater) are put in place in order to reduce the most severe environmental effects. Accordingly, post-treatment steps – shown in Fig. 1 below the dotted line – are often not realised in developing countries as yet. Future considerations do however have to be based on more stringent decomposition values, environmental, hygiene and nutrient standards.

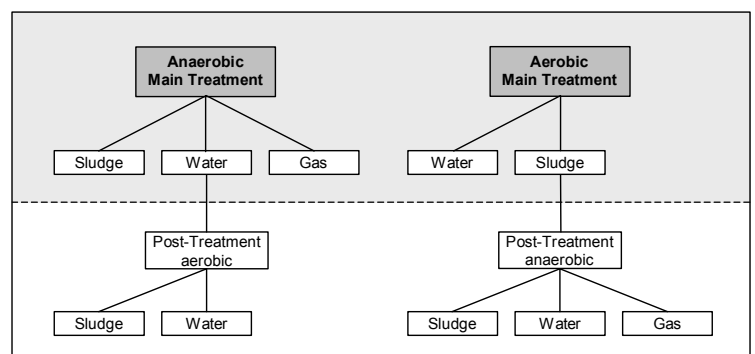


Fig. 1: Principal difference between anaerobic and aerobic intensive wastewater treatment (Source: [11])

2 Main requirements of anaerobic municipal wastewater treatment

The applicability of anaerobic treatment for municipal sewage (mixed sludge and wastewater) depends strongly on the temperature of the sewage. The activity of mesophilic anaerobic bacteria is at its optimum at 35°C. At lower temperatures, bacterial activity decreases, which results in lower treatment performances. This is the reason why in cold climate countries (which are mostly industrialised), only a small separated portion of the sewage, namely the primary (after sedimentation) and secondary sludge (after aeration) are treated anaerobically, however requiring a heavy insulation and heating system, while the bulk of the volume, the wastewater, is treated aerobically mostly with aerators in open or closed ponds.

According to the present technology development combined anaerobic sewage treatment is feasible without heating at sewage temperatures above 15°C. For temperature ranges of 12 to 15°C (for example in the Mediterranean region), anaerobic sewage treatment is also feasible, but more research and development activities are still necessary to assess optimum treatment conditions and reactor concepts for these temperatures. Consequently, anaerobic sewage treatment is primarily of interest for countries with a tropical or sub-tropical climate, which are mostly developing countries.

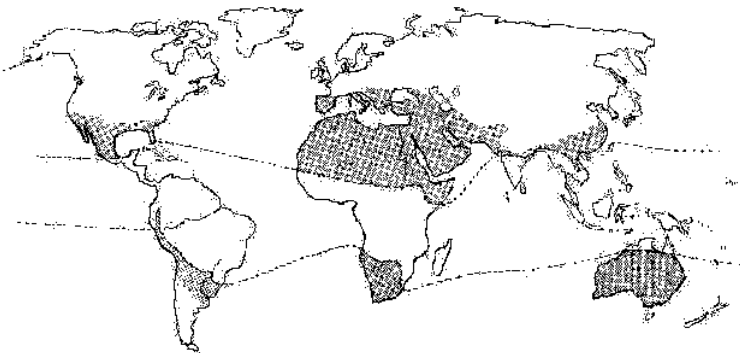


Fig. 2: World temperature zones
grey: 12 – 15°C; enclosed regions:
>15°C (Source: [1])

Fig. 2 illustrates the critical temperature ranges, grey shaded areas indicating sewage temperatures of 12-15°C, the areas between the dotted lines temperatures above 15°C.

Speaking of this type of technology, in addition to appropriate sewage temperatures, a further precondition for effective anaerobic treatment are the organic loading and nutrient content of the wastewater. The initial organic loading rate should be above 250 mg COD_{in}/l (COD = chemical oxygen demand), the optimum loading rate being >400 mg COD_{in} / l. The optimum nutrient ratio given as COD:N:P (N = nitrogen, P = phosphorus) is 190-350:5:1, anaerobic treatment however being feasible up to a ratio of 1000:5:1. The average sewage composition meets these requirements (domestic sewage is very dilute in comparison with most industrial wastewaters).

Although the production of biogas is mostly considered as being of minor importance in the municipal wastewater treatment context, collection, treatment and preferably a valuable utilisation of the gas is necessary in order to avoid the release of CH₄ (which has a high greenhouse gas potential) into the atmosphere and to prevent the emission of bad odour to the neighbourhood. Utilisation is possible in co-generation units for electricity production (either for own demand or for feeding to the public power grid) or for vapour production or heating purposes. From an ecological point of view, the gas should at least be flared and thus transformed into CO₂ and water, if gas utilisation cannot be implemented due to disadvantageous infrastructural and economical frame conditions (lack of financial means, no revenues for submission to the grid).

Anaerobic systems can well be applied on a small scale. This is important for developing countries with a need for decentralised sewage systems, since large-scale centralised treatment is very costly. There may be on-site, community-on-site or off-site treatment. (See also

GATE Technical Information on “Decentralised wastewater treatment methods for developing countries”) In order to comply with the discharge standards regulating COD, BOD (biological oxygen demand), nutrient and pathogen loading rate of the plant effluent for the respective implementation sites, process design usually combines anaerobic treatment with aerobic post-treatment steps, e.g. small facultative ponds for further polishing of the effluent. A comparison of investment and operation costs of different treatment systems shows that, given a high availability of land and thus low land costs, and not considering smell, environmental and climatic effects, pond systems at first appear to be the more economic solution. If however land is scarce and its price exceeds 10 US\$/m² or other environmental effects are considered, then anaerobic treatment becomes even financially the more attractive and sustainable solution. Compared to the activated sludge system, investment (due to the lower amount of machinery and equipment needed) and operation costs (due to the lower amount of energy, spare parts and manpower) are usually about half as high as for the anaerobic UASB process, given sufficient sewage temperatures.

3 Practical performance

Anaerobic digestion processes have already been applied since the end of the 19th century for the stabilisation of primary and secondary sludge from activated sludge processes and the treatment of night soil in septic tanks and simple biogas digesters.

Anaerobic treatment of raw domestic/municipal sewage is, however, a more recent development which has barely found entrance into common know-how and experience, in particular in industrialised countries. Therefore, financing institutions still tend to rather transfer activated sludge systems with anaerobic sludge digestion, which are suitable for cold climates, since the bulk of

the cold wastewater cannot be heated to allow for anaerobic treatment.

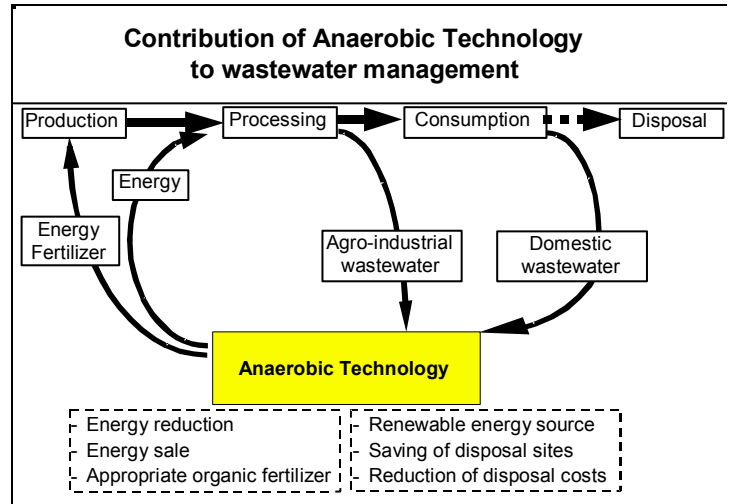


Fig. 3: Anaerobic technology for wastewater management

Anaerobic UASB treatment without post treatment already reach removal efficiencies of 65%, 80% and 70% for COD, BOD and TSS (total suspended solids) respectively. A comparative study done by GTZ/TBW assessing most of the existing anaerobic treatment plants in tropical countries (about 60 full scale plant of this type were in operation in 1998 [11]) shows that it can be a very attractive alternative both cost-wise (with low amounts of foreign exchange needed) and from the environmental point of view.

Generally speaking, joint anaerobic treatment of sludge and wastewater is attractive (given sufficient sewage temperature) due to the following **advantages:**

- Low investment and maintenance costs:
 - No primary clarifier required
 - No sludge digester required (stabilisation of suspended organic matter in anaerobic reactor)
 - Low land requirements
 - Local production of construction material, mechanical plant components, spare parts

- Low demand for process energy (no energy consuming aerators): thus a considerable reduction of CO₂ emissions due to low consumption of fossil energy and simultaneous surplus energy production
- Reduction of CH₄ emissions from uncontrolled disposal/decomposition of wastewater due to the collection of the gas formed during the process
- Low sludge production and high sludge quality (the sludge, if not loaded with pathogens or heavy metals, can readily be applied to agricultural land)

The main **disadvantages** of these treatment systems are:

- Lower treatment efficiencies (about 5-10% less than in activated sludge processes if no post-treatment is installed)
- H₂S content in the gas can lead to problems with bad smell and corrosion
- No nutrients (N, P) are removed without post treatment
- Compared to pond systems, a rather poor pathogen removal if no post-treatment is installed
- Compared to pond systems, a high demand for operational know-how
- Economically not feasible for sewage temperatures below 15 °C

Anaerobic treatment alone will usually be insufficient to meet the officially required effluent discharge standards: If legislation demands compliance with the standards, the treatment systems need to be combined with a post-treatment installation.

The great majority of the anaerobic systems in operation for municipal wastewater treatment belong to the UASB-type (upflow anaerobic sludge blanket; see chapter 5.1), even though other anaerobic high-performance treatment systems may also be applied (i.e. fixed bed systems or floating bed systems, where the bacteria are attached to a fixed or floating carrier material). Most of the world's anaerobic sewage treatment plants of this type have been built in countries with a large internal market like Mexico, Brazil, India, China

and Colombia. Some relevant large sewage treatment plants implementing UASB technology are presently also under construction with German cooperation in Venezuela, Ecuador and Egypt.

3.1 Problems encountered

During years of practical experiences with the implementation of anaerobic technology, the following problems were encountered:

- Poorly designed and constructed reactors or deficiencies in operation led to CH₄ emissions to the atmosphere and odour nuisance in plant neighbourhood
- Floating sludge in UASB reactors caused unwanted sludge wash-out, thus reducing effluent quality (a main reason is the poorly designed three-phase separator or mistakes with the actual or planned loading rate)
- Corrosion of construction material and equipment
- Insufficient knowledge of the process by the implementing, supervising and financing organisations or insufficient task management between these three functions so that responsibilities for weak points cannot be clearly identified
- Insufficient training and know-how of operators and plant management

4 Perspectives

With increasing experience in combined anaerobic sewage treatment for tropical countries, design, construction and operation of these reactors has been optimised, resulting in an improved system reliability.

Due to a lack of investment capital at present and in the very near future, nutrient removal is and will presumably be no focal point of wastewater treatment in most of the developing countries yet: the priority is to remove pathogens and the organic pollutants. For irrigation purposes in agri- or aquaculture, a conservation of nutrient resources (N and P) is even desired. Future considerations do however

have to pay respect to the fact that N- and P-removal will become necessary against the background of an intensified agriculture and increasing eutrophication due to higher loads conveyed to water bodies. The improvement of hygiene and sanitation conditions will also gain in importance and therefore require further attention. Possibilities of biological nutrient removal with the present anaerobic/aerobic systems are not yet sufficiently assessed. Usually, the carbon content is too low so that an additional source of carbon is required. Facultative ponds have shown promising results in N- and P-removal if designed for this purpose. A better removal of pathogens asks for further sludge treatment and a post-treatment of the treated wastewater.

5 Features for joint anaerobic municipal wastewater and sludge treatment

5.1 UASB-technology

The UASB-process (upflow anaerobic sludge blanket) has proven to be the most promising communal or municipal anaerobic low-cost treatment technology. Dutch research in the late 60's developed the basic technology for a beet sugar enterprise up to the commercial level and applied it in selected sugar factories to solve wastewater treatment problems. Since the early 1980s, considerable research and development has been done with respect to anaerobic municipal wastewater treatment systems and, specifically, UASB reactors. It can now be considered feasible for municipal wastewater treatment because of its proven rapid organic removal efficiency, its simplicity and low degree of mechanisation, the low capital and maintenance costs and low land and energy requirements. Fig. 4 shows an example for a full-scale UASB treatment plant for 14,000 m³ of municipal wastewater per day in India.

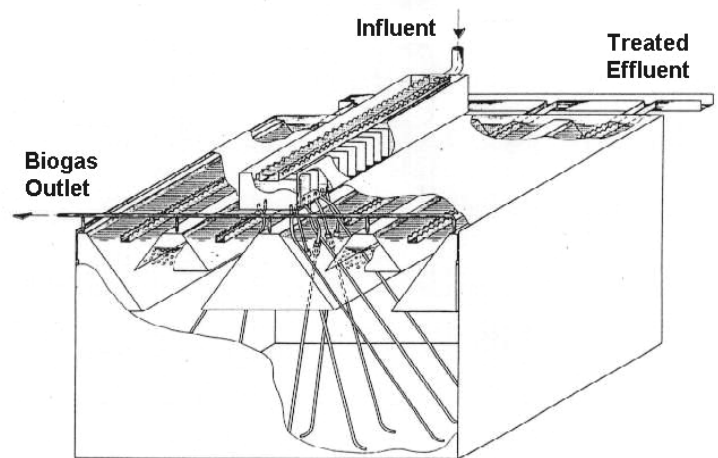


Fig. 4: UASB-reactor for domestic wastewater treatment, Mirzapur, India (Source: [4])

A UASB-reactor (see Fig. 5) is constructed with a specific feeding system consisting of inlet pipes equally delivering influent to the bottom of the unit. The upstream velocity is in equilibrium with the sludge settling speed, so that a suspended sludge (bacterial) blanket is formed. The upstream velocity has to be rather constant in order to guarantee a proper sludge-water contact and to avoid a wash-out of the active bacteria; an external mixing device for this technology is not required.

Besides the distribution system, the most characteristic device is the "gas-liquid-solid-" or "three-phase separator" at the top of the reactor. Its function is to separate the biogas and to retain the solids (bacterial sludge) and the treated liquid phase, thus preventing sludge wash-out. Due to their anaerobic operation, UASB-reactors are characterised by a considerably lower sludge production (the most relevant cost factor in municipal wastewater treatment) and a low energy demand, thus leaving a net energy surplus.

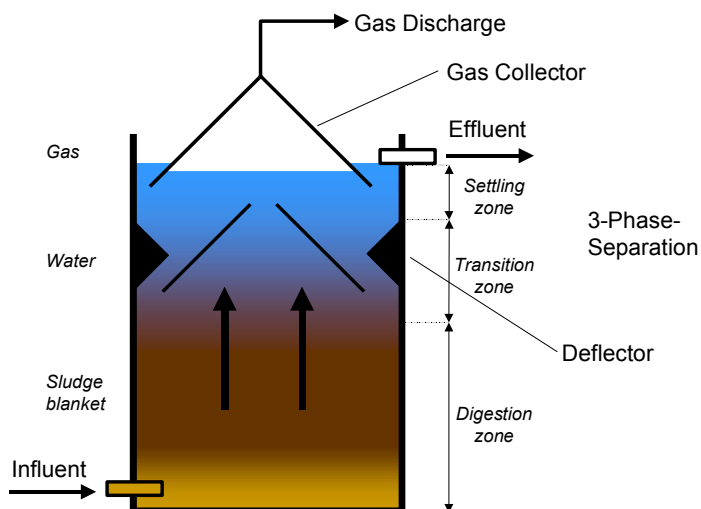


Fig. 5: Principle design features of UASB
(Source: TBW, modified after [3])

In a pilot project in Bucaramanga, Colombia, a combined sewerage system and UASB treatment facility made the city more advanced with respect to sanitation than any other Colombian city. The system was implemented at an investment cost of 17 US\$ per capita (including 30 km of extended sewerage system), it serves 160,000 population equivalents (p.e.) at operation costs of 1.5 US\$/p.e. per annum. Present investment data show that at average temperatures of 20°C or above and with a plant size of at least 40,000 p.e., a UASB-system with wastewater stabilisation ponds (WSP) as post-treatment can be implemented at an investment cost of around 4 US\$/p.e., compared to activated sludge systems at about 8 US\$/p.e..

The pathogen removal efficiency of UASB treatment processes is not considered sufficient if environmental standards from industrial countries are applied, in particular not for the sludge, and must be followed by a post-treatment option to meet the increasingly strict discharge standards. Nevertheless, already now a 90-99% removal of for example helminth eggs in the effluent wastewater is possible with UASB technology alone.

Further treatment options may include composting of digested sludge for final pathogen reduction in the sludge and

wastewater post-treatment in ponds or constructed wetland systems. (For further information, see GATE Technical Information “Anaerobic treatment of municipal wastewater in UASB-reactors”).

5.2 Septic Tank

The septic tank is an appropriate low cost technology and the most common, small scale, decentralised anaerobic treatment plant, however built without any gas collection or utilisation system. It is a simple sedimentation tank with a low requirement for maintenance and a treatment capacity of up to about 50 households.

The system consists of a closed tank where sedimentation takes place and settleable solids are retained (see Fig. 6). Retention time of the liquid is in the order of one day. Sludge is digested anaerobically in the septic tank, resulting in a reduced volume of sludge.

Based on the low removal efficiencies of 30% COD, 50% BOD and 70% TSS respectively and low nutrient removal, the effluent is destined for use in agricultural irrigation. Present research efforts of some German institutions and companies (a.o. BORDA, TBW GmbH, see chapter 7) concentrate on appropriate low-cost collection and utilisation of the gas produced.

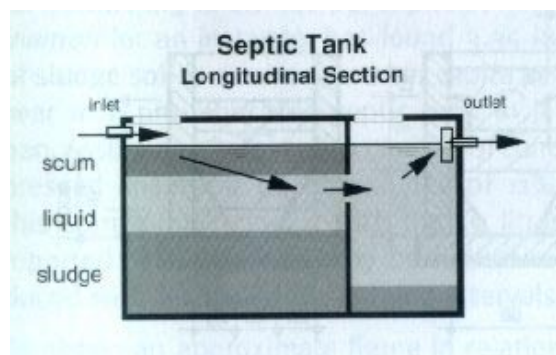


Fig. 6: Principle design features of septic tank
(Source: [9])

6 Features of anaerobic sludge treatment in activated sludge processes

6.1 Sewage sludge digester

Anaerobic treatment of sludge from aerobic wastewater treatment with long retention times has a very long history in some of the central European countries but has improved considerably: These anaerobic systems can be built and operated on various scales in size with a high degree of technical sophistication and automation, but sometimes are technically quite simple as well.

Anaerobic sewage sludge treatment offers several substantial **advantages**:

- Reduction of sludge volumes
- Stabilisation of the sludge
- Production of biogas to be used as process energy
- Valuable nutrients are retained
- Anaerobic sludge can be preserved and easier dewatered

In Central Europe, anaerobic digestion of sewage sludge is presently a routine process implemented in combination with the aerobic activated sludge process, which is the standard technology for municipal wastewater treatment here. Sewage sludge is the total solid material that results from sedimentation and bacterial activity and growth during aerobic wastewater treatment. The floating and sinking layers formed before, during and after a treatment of the wastewater are normally all fed to the sludge digester. Here, anaerobic fermentation takes place at process temperatures of 35°C (mesophilic) to 55°C (thermophilic) and biogas is generated. To generate appropriate reactor temperatures, a heating system is required. Its energy demand can partly, sometimes fully, be covered by utilising the produced gas, which can either be burnt directly or in co-generation units. Fig. 7 shows some typical egg-shaped sludge digesters in Germany.



Fig. 7: Egg-shaped reactors for anaerobic sludge digestion (Source: TBW)

The egg shape has proven to be the best solution as it reduces construction material and is ideal for mixing and heating. So far, it has yielded the best operational results and greater quantities of methane per volume of sludge processed to offset fuel costs. At the same time the technology produces a consistently well-digested stabilised sludge. After a retention time of around 30 days, the treated sludge is mostly dewatered and disposed of in landfills, incinerators or utilised as an agricultural fertilizer and soil conditioner. The composition of biogas generated from sludge digestion differs from that of a digestion of a mix of sludge and wastewater as discussed earlier. Sludge digestion gas normally contains 50 - 60 percent CH₄, 30 - 40 percent CO₂ and small amounts of other residual gases. The thermal energy produced is used to maintain the digester temperatures; surplus electricity, which is not used by internal plant demands, can be fed into the public grid.

7 References and further information

- [1] Alaerts, G.J., Veenstra, S., Bentvelsen, M., van Duijl, L.A. et al.: Feasibility of Anaerobic Sewage Treatment in Sanitation Strategies in Developing Countries. IHE Delft, The Netherlands, 1990.
- [2] Collazos C.J., Hoyos L.F., Schellinkhout, A.: Manual de Diseño Construcción, Operación y Mantenimiento de la PTAR "Río Frío" Bucaramanga. DICOM-DHV. Bucaramanga, Colombia, 1991.
- [3] Haandel, A.C. van; Lettinga, G.: Anaerobic sewage treatment. A practical guide for regions with a hot climate. John Wiley & Sons Ltd, Chichester, England, 1994.
- [4] Haskoning Consulting Engineers and Architects: Evaluation report on process performance. 14 MLD UASB treatment plant, Mirzapur, India. Internal Report. Nijmegen, The Netherlands, 1996.
- [5] Kellner C.: Biogas Technology - Global Overview on the State of the Art, Environmental, Technical and Economical Aspects. CAMARTEC-GTZ-TBW. Arusha, Tansania, 1992.
- [6] Koné S.: Zusätzliche Einsatzmöglichkeiten der Biogastechnologie in der Abfall- und Abwasserbehandlung, Ergebnisse Phase I: notwendige strategische Maßnahmen und Vorschläge zu deren Durchführung. GTZ-TBW. Frankfurt, Germany, 1992.
- [7] Mang, H.-P., Navía G., Jiménez F., Guardia F.: Planta de Tratamiento de Aguas Residuales "CAPINOTA". FIDES-CEINCA-GTZ-BMZ-TBW, Bonn, Germany, 1997
- [8] Peña Romay L.: Empleo de Digestores Anaerobios de Flujo Ascendente "DAFA", en el Tratamiento de Efluentes Domesticos del Area de Santa Cruz. UAGRM. Santa Cruz de la Sierra, Bolivia, 1998.
- [9] Sasse, L.: DEWATS. Decentralised Wastewater Treatment in Developing Countries. Bremen Overseas Research and Development Association (BORDA), Bremen, Germany, 1998.
- [10] Switzenbaum M.S: Anaerobic Treatment Technology for Municipal and Industrial Wastewater. Water Science and Technologies. IAWQ. Pergamon Press. Oxford, UK, 1990.
- [11] GTZ/TBW Supraregional Sector Project "Promotion of anaerobic technology for the

treatment of municipal and industrial sewage and wastes": Status Reports; Final Report. GTZ/TBW, Eschborn/Frankfurt, Germany, 1998.

- [12] Tilche A. and Rozzi A.; 1988: Poster Papers of the Fifth International Symposium on Anaerobic Digestion. Monduzzi Editore. Bologna
- [13] Verink, J.: Manual for Setting Up and Operating Anaerobic Pilot Plants. Scientific Research Council of Jamaica-GTZ-TBW. Kingston, Jamaica, 1998.

7.1 Institutions and Organisations

Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, German Appropriate Technology Exchange GATE Information Service

P.O. Box 5180, 65726 Eschborn, Germany
 Phone: ++49 (0)6196 / 79-3093,
 Fax: ++49 (0)6196 / 79-7352,
 Email: gate-id@gtz.de,
 Internet: <http://www.gtz.de/gate/gateid.afp>

Naturrechte Technologien, Bau- und Wirtschaftsberatung (TBW) GmbH

Baumweg 10, 60316 Frankfurt, Germany
 Phone: ++49 (0)69 / 943507-0
 Fax: ++49 (0)69 / 943507-11
 Email: tbw@tbw-frankfurt.com
 Internet: <http://www.anaerob.com>

Wageningen Agricultural University (WAU)

Department of Environmental Technology
 Bomenweg 2, P.O. Box 8129, 6700 EV
 Wageningen, The Netherlands
 Phone: ++31-317-483339
 Fax: ++31-317-482108
 Email: office@algemeen.mt.wau.nl

International Institute for Hydraulic and Environmental Engineering (IHE)

P.O. Box 3015, 2601 DA Delft,
 The Netherlands
 Phone: ++31-15-788021
 Fax: ++31-15-122921
 Internet: <http://www.ihe.nl>

7.2 Useful Links

<http://www.mwra.state.ma.us/sewer/html/sewdi.tp.htm>

Massachusetts Water Resources Authority (MWRA), Boston. Example of the second

largest sewage treatment plant of the US: Deer Island Sewage Treatment Plant.

<http://www.iwap.co.uk>

International Water Association (IWA), IWA Publishing (IWAP): a non-profit publisher providing information services on all aspects of water and related environmental fields.

<http://www.ihe.nl/shortc/anaerob.htm>

International Institute for Hydraulic and environmental Engineering (IHE Delft). General introduction to anaerobic wastewater treatment.

<http://www.cepis.org.pe>

<http://www.cepis.org.pe/eswww/fulltext/anaerobi.html>

Centro Panamericano de Ingeniería Sanitaria y Ciencias del Ambiente (CEPIS) Environmental technology centre of Panamerican health organisation (Organización Panamericana de la Salud). Papers about different aspects of anaerobic wastewater treatment.

<http://wastewater.net>

Wastewater Net Message Forum: Links to wastewater related issues.