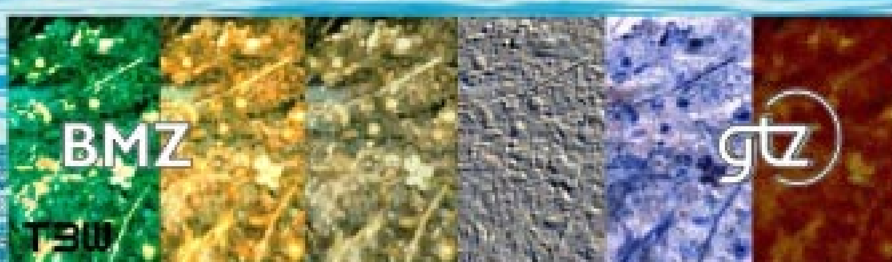
Waste and Waste water

PROJECT

Anaerobic Digestion

Anaerobic Processes
for the Treatment of Municipal and Industrial
Wastewater and Waste

An Overview



Anaerobic Processes for the Treatment of Municipal and Industrial Wastewater and Waste

An Overview

The improvement of wastewater and waste treatment without ~~putting~~ further strain on the environment or hygiene issues but taking into consideration the aims of climate protection are urgently needed and can be realised world-wide.

Regarding an economic and sustainable process handling, wastewater and waste treatment should comprise the utilisation of both material and energy.

To this, anaerobic processes may contribute significantly. They are however still rather unknown, compared to the so far predominantly implemented processes - aerobic sludge and pond systems, disposal sites, compostation and combustion.

Anaerobic processes may be implemented on their own or in combination with other treatment processes as cost efficient treatment alternatives for municipal, industrial and agricultural wastewater, sludge and waste.

The overview on hand is an account of the basic conditions for the implementation and utilisation of anaerobic technologies and mainly aims to serve decision makers in developing countries as source of information.

Postscript of the authors

This summary of final, status, country and seminar reports and evaluation of case studies and databanks of a four-year sectoral project on the international state of anaerobic technology was elaborated by Susanne Schroth, Dr. Peter Pluschke, Dr. Hulshof Pol, Daniel Grohganz, Pedro Kraemer and Hartlieb Euler (TBW GmbH, Frankfurt).

The universities of Wageningen, Hannover, Louvain-La-Neuve, Mexico City, Bogota, Sao Paolo, Bombay and Bangkok as well as numerous other institutions in 16 countries and their staff contributed to the project.

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Preface

Wastewater and wastes are becoming a problem of growing importance for Third-World-Countries. The increasing achievements of civilisation cannot be separated from an increase in the residues of society that do not receive any or only insufficient treatment, resulting in adverse effects on water, soil, climate and human health. Reasons are to be found in a whole syndrome of causes typical for developing countries: the low working efficiency of governmental and municipal communities or systems, the weak financial power, the lack of environmental and hygiene conscience, the lack of know-how, weak institutions and insufficient knowledge about availability and functioning of environmentally sound technologies.

Anaerobic processes can be of advantage in numerous developing countries, as they are working more efficiently at higher ambient temperatures than in cold climates. They should not to be considered as a kind of „miraculous solution" for the entire removal of all wastewater and wastes, but they do have a number of characteristics especially attractive for developing countries which other technical solutions cannot provide. One specific advantage is their energy efficiency: besides reuse of the organic matter, the „re-"utilisation of energy is possible. Anaerobic processes can be implemented in urban as well as in rural areas and in the industrial as well as in the food production sector. They are suitable for almost any kind of wastewater or waste with an organic loading. Depending on the respective conditions, anaerobic treatment can be economically advantageous compared to traditional treatment processes, because resulting products such as soil conditioner, energy and treated water can be utilised or sold.

This brief overview on hand accounts for some of the most important results of a project by the Deutsche Gesellschaft für Technische Zusammenarbeit, GTZ GmbH, promoted by the German Federal Ministry for Economic Cooperation and Development. Herewith, we aim to contribute to a sustainable development on earth.

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Introduction

In the last two decades of the 20th century, cholera and typhus have caused numerous cases of illness and fatalities in Latin America, Asia and Africa. These are the tragic consequences of insufficient water supply, water pollution and years of neglect of the disposal infrastructure in developing and newly developed countries. Hygiene aspects as well as wastewater and waste treatment are given a high priority with respect to sustainable development in accordance with health requirements. In addition to water pollution and the increasing scarcity of drinking water, soil degradation and negative climatic effects of the greenhous gases CO_2 and methane from fossil sources as well as from untreated wastewater and waste are gaining in importance.

Ways of disposal based on the idea of environmentally sound recycling methods open up possibilities for the re-utilisation of wastewater and waste as „raw material", thus substituting scarce natural resources (water, soil nutrients, fossil sources of energy).

The numerous possibilities for the implementation of anaerobic technologies may be beneficial within the frame of supra-sectoral co-operation between the subject-areas of (waste)water, waste, energy, urban and rural development and environmental protection. Based on the guidelines on wastewater and waste policy for development co-operation, the German Federal Ministry for Economic Co-operation and Development (Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung, BMZ) commissioned the sectoral project „Promotion of anaerobic technology for the treatment of municipal and industrial wastewater and wastes" in order to gain clarity about the status quo, the potential and implementation possibilities of anaerobic processes.

Operational data of various plants, experience gained from institutions from more than 20 industrialised and developing countries and their recommendations have been analysed and documented.

In the interest of ensuring a future-oriented disposal management in developing countries, the overview on hand primarily aims to serve political decision makers as information base and tool for the assessment of appropriate technologies and their implementation.

How do anaerobic processes work?

Anaerobic processes utilise the **natural** microbial degradation of organic substances in an environment free of oxygen. The removal efficiency is the result of a complex co-operation of a bacterial compound degrading the organic matter to mineral substances, water, carbon dioxide (about 30-40%) and combustible methane (about 60-70%). The degradation process can be accelerated by suitable technology.

Anaerobic degradation processes are especially efficient at **constantly higher temperatures**.

In developing countries, this temperatures are often naturally given, in industrialised countries they mostly have to be achieved artificially by heating and insulation measures.

What are the areas of implementation for anaerobic processes?

Anaerobic processes can be applied to almost any kind of wastewater, sludge and solid wastes containing biologically degradable organic matter. Increasingly, they are utilised for the treatment of municipal, industrial and agricultural wastewater, sludge and waste in developing and industrialised countries.

Proven implementation areas for anaerobic technology in industrialised countries are sludge treatment, which is standard in larger sewage treatment plants, and the treatment of industrial wastewater and of manure and dung in agriculture. Meanwhile, anaerobic processes are also applied in the municipal wastewater sector – in centralised and decentralised treatment plants mainly in developing countries – and for solid waste treatment, mainly in Middle-European industrialised countries.

WHAT CAN BE TREATED ANAEROBICALLY?

predominantly organic
wastewater, sludge, wastes
from
municipalities, industry, agriculture
in
industrialised, newly industrialised and developing countries

The most varied areas of implementation are to be found in industry, (see Fig. 1): in recent years, especially combined systems for the treatment of substrates of different consistencies and origin have become attractive (co-fermentation). Here, manure and sewage sludge are predominantly used as basic substrate for the co-fermentation of e.g. biowaste, industrial sludge and wastewater.

In the frame of sectoral, environmental and regional programmes for sustainable development, for water protection and energy projects, sanitation measures or activities for the reduction of greenhouse gases, anaerobic processes can be part of a cross-section concept for resource protection.

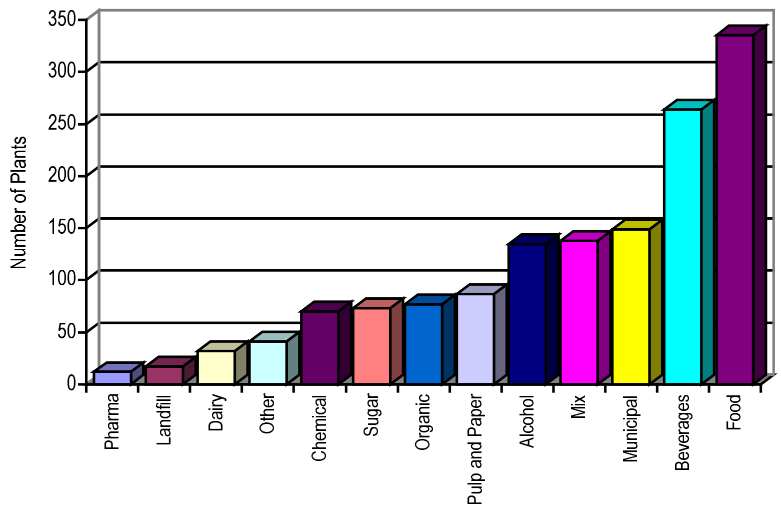


Fig. 1: Implementation of anaerobic plants for different substrates worldwide (agriculture not included) Source: Anaerobic plant data bank of the project, various other sources

Utilisation of Final Products

The final products resulting from anaerobic digestion such as treated wastewater, organic matter, nutrients and biogas can be reused. With respect to both sustainability and economic efficiency, they should be utilised. Regarding climatic aspects, the realisation of gas utilisation – for the production of electricity and thermal energy for heating and cooling purposes and steam production – is very important due to the adverse climatic effect of methane. Sludge and compost can be applied as fertilisers or soil conditioners, purified wastewater can be used for irrigation and substrate moisturising purposes.

Products of Anaerobic Processes			
Solid	Sludge Consistency	Liquid	Gaseous
Post-Treatment			
Compostation	Drying	Post-treatment	Combustion
Utilisation			
Fertilisation Soil conditioning	Fertilisation Soil conditioning	Irrigation Substr. moisturising	Electrical utilisation Thermal utilisation

Favourable frame conditions

The effectiveness of anaerobic or combined anaerobic-aerobic processes for the treatment of wastewater and waste is particularly advantageous if specific frame conditions are given. A clearly defined political will to solve wastewater and waste problems with respect to an ecological and economic view of the entire system is the most important pre-condition for success. Effective legislation, appropriate financing possibilities, a free choice of processes as well as technical know how are all indispensable.

Anaerobic processes are very seldomly implemented as sole systems without a minimum degree of technological knowledge and a reinforcing social and technical environment. Hence, exemplary plants in operation, active institutions and sufficiently trained personnel for design and operation are necessary.

COUNTRY EXAMPLE: FRAME CONDITIONS IN INDIA

India can look back on a long tradition of predominantly agricultural and energy applications of anaerobic processes. In addition, its striving for political and economic independence from the world market played an important role for anaerobic technology in the country.

The most important authority for environmental legislation is the environmental ministry with its regional and local departments. Limits for the discharge of municipal wastewater are set at 30 mg BOD_5/l [1] and 50 g DM/l [2]. A comprehensive and distinct legislation concerning the feeding of energy to the public grid is in place: The possibility of „energy banking" allows feeding of electricity to and – without reference to time – the withdrawal of the corresponding amount of energy from the public grid. What is remarkable in India is that revenues for the feeding of electricity produced from renewable sources of energy are higher than would be costs of purchase.

At present, international financing programmes are promoting the implementation of a broad spectrum of anaerobic technologies for a wide variety of wastewater, municipal and industrial wastes and mass animal agriculture. The "Waste to Energy"-Programme supported by the United Nations Development Programme (UNDP) and the "Ganga-Action-Plan", co-financed by the World Bank, are two examples. In addition to the multi- and bilateral international financing organisations, national institutions in India give financial support to integrated environmental projects, using anaerobic processes.

The Indian Government has set incentives to increase the readiness of private investors to finance projects in the environmental sector:

- Faster deduction (within one year) for specific plant elements that are of use for the control of effects on the environment.
- Lower customs duty for specific plant elements.
- Tax allowances, e.g. for a five year period if the construction site is situated in an underdeveloped region.

Despite the already existing basic know-how developed in India over decades, the long tradition of organic matter recycling and despite water scarcity, an increase in the use of anaerobic processes continues to depend on the existence or creation of advantageous frame conditions. These are mainly control measures for environmental legislation, the improvement of know-how and the availability of sufficient financial means for waste and wastewater treatment.

[1] BOD_5: Biological Oxygen Demand in five days
[2] DM: Dry Matter

Legal Framework

Experience has shown that solutions for wastewater and waste-related questions with respect to health care and the protection of natural resources are only sought if the legal framework is appropriate. Anaerobic processes are rather taken into consideration by the system-oriented decision makers than by those oriented towards specific cases.

Speaking of environmental politics, the realisation of respective aims can be defined by national, regional and local regulations concerning environmental quality (of water, soil and air) and regulations on working conditions as well as on emissions in the energy sector, in agriculture and hygiene. In this context, rules and regulations for e.g. separate collection of wastes, landfills (covering and lining), sewerage systems (separate or mixed) or energy (feeding to the grid) may be decisive factors for the choice of technology.

IMPORTANT REGULATIONS ARE

- Limits for direct and indirect discharge to surface waterbodies
- Technical standards for emission behaviour of treatment plants
- Quality standards for training, plant operation and control
- Legislation for cost-covering feeding of electricity, gas or heat to the public grid
- Tariffs for collection and treatment covering the costs

Interdisciplinary Co-Operation

Close co-operation and networking between political decision makers, licensing and control authorities, research, financing and training institutions, experts and technology companies on the market, between producers of wastewater and waste and users of end-products will support and enforce a successful introduction of the technology as well as sustainable plant operation. Mutual agreements between the responsible decision makers for waste, wastewater, disposal, energy and climate, environment and health as well as between those in charge of urban and rural development are of invaluable advantage.

Costs and Financing

Costs of land, energy, water supply and health services, fees for waste and wastewater and costs of sludge disposal determine the relative and absolute advantage of anaerobic and combined processes.

Compared to *pond systems*, anaerobic processes are e.g. only of economic advantage if land availability is scarce and land prices are above 12 US$/m², or if climate and health-related factors (e.g. mosquitoes) are taken into consideration.

In comparison to *activated sludge systems*, anaerobic or combined processes in most cases perform better with respect to investment cost and operational requirements, independent of the above named cost factors.

For industrial wastewater and liquid manure, the concentration of organic substances in the substrate to be treated and energy prices often gain a decisive role in the resulting profitability.

Costs of anaerobic waste treatment are about as high as those incurred for closed composting plants. In the short-term, they may be more expensive than sanitary landfills – depending on land and compost price – , but less cost intensive than incineration plants.

Motivation for private investment in anaerobic treatment usually results from the higher costs for the current consumption of natural resources due to fees for disposal/discharge or other taxes, or from the higher costs for alternative processes. Returns from disposal fees, sales of energy and compost, own utilisation of the products and resulting cost savings can be put down as profit for an anaerobic plant. The cost relations are a result of the frame conditions, possibly existing investment incentives and the specific situation.

The majority of municipal plants in developing countries is built with public financial means in the context of governmental or municipal disposal duties. These may be financial means from national or international programmes or from multilateral financing. The level of knowledge within the specific financing institutions is very often the decisive factor for the choice of technology. In the past, invitations for tenders did not always sufficiently consider anaerobic processes as an alternative.

In addition to the financing of investments, the financing of plant operation has to be clarified in the planning phase of a project at the latest. It is only in isolated cases that an anaerobic plant is economically viable due to the returns from energy and compost sales alone. While reduction in operational means (e.g. for energy) and the utilisation of products of anaerobic processes facilitate the financing of plant operation, they only seldomly permit profitable treatment costs (incl. of amortisation). The returns may still be of importance since, in developing countries in particular, a high number of treatment plants fail due to insufficient allotment of operational means (among others, for energy consumption and spare parts) and have to be closed down. Decisive for the sustainable operation of public treatment plants is the form of organisation, e.g. to what extent governmental–municipal and the private sector are willing to co-operate concerning plant operation.

Country Example: General Conditions in Brazil

At present, about 90 anaerobic plants are in operation in Brazil for the treatment of industrial and domestic wastewater. Referring to the domestic wastewater sector, this is attributable to a great extent to the governmental wastewater federations and their employees who have specifically promoted the implementation of anaerobic technology.

Several regional wastewater federations can look back on 15 years of experience with anaerobic technology in practice in the domestic sector. The state of Paraná has its own anaerobic industry which developed special plant types (RALF-Reaktor: Reactor Anaerobio de Leito Fluidizado, a modified UASB: Upflow Anaerobic Sludge Blanket). The introduction of the technology was largely realised without the support from international development co-operation. Only recently did the World Bank start financing anaerobic treatment plants, mainly for cost considerations.

The driving force behind activities for the implementation of anaerobic technology in Brazil is the pollution of (surface) waters and the resulting environmental legislation. Standards for direct (different for the specific federal states) and indirect discharge to surface waters exist and are increasingly being controlled. Concerning implementation activities of the RALF-Reactor (mostly without gas collection), energy aspects are not the focal point, so that direct emissions to the atmosphere with adverse effect on the climate are often not reduced by any kind of precautionary measures. The cost-effectiveness is a major argument for implementing the process in Brazil. Preferably, a greater number of smaller decentralised plants (> 100,000 p.e.) of the above described type are constructed rather than large-scale plants in conurbations.

As in almost every one of the 16 countries investigated within the project, one of the major problems for sustainable implementation of anaerobic technology in Brazil is the securing of trouble-free plant operation. Insufficient management, poorly trained personnel and lack of consumption material for operational measures result in a neglect of the necessary maintenance. Increased privatisation of the operation of municipal plants aims to diminish these adverse effects.

Know-How and Training

In a number of developing and newly developed countries (Brazil, Mexico, Colombia, India, China), national know-how in anaerobic technology is available. Practical experience concerning the construction and operation of these plants is mostly concentrated at certain points in both industrialised and developing countries and furthermore based only on limited technology applications.

Speaking of anaerobic treatment of municipal wastewater, industrialised countries do not have a significant lead in know-how and experience compared to developing or newly developed countries, in contrast to the industrial wastewater sector. The reason is that combined anaerobic-aerobic systems are not being implemented in the municipal wastewater sector in temperate climate, due to their specific temperature demand. Experience gained in the meantime is a result and product of joint efforts to further the development and implementation of the technology as cost-effective and simple treatment alternative for application in warm climates.

In the medium term, the demand to catch up on the further development of anaerobic technologies in scientific institutions and universities is considerable.

It is indispensable for practical plant operation to train the technicians and workers who have to guarantee a secure and optimised plant operation in daily routine. With respect to safe and sustainable plant operation, the qualification of personnel presents a focal requirement. So far, existing training institutions meet this demand only to a very limited extent.

In the appendix, a number of institutions providing know-how and training possibilities are listed.

Sensitisation

Public awareness regarding the linked problems between environment, energy and climate as well as regarding the protection of water and the urban environment is often a decisive factor in the introduction of environmentally sound disposal systems.

Key Points for Decision Makers – Clarification of General Conditions

- What are the laws and regulations already in place that support and regulate activities in the wastewater and waste sector concerning material and energy reuse?
- Are development possibilities given on the local level that allow the appropriate outline of disposal fees, of returns granted for feeding of electricity or gas to the public grid, of transport and collection systems (mixed or separate collection of solid waste, mixed or separate sewerage systems for wastewater)?
- To what extent do institutions from different sectors co-operate?
- What are the costs of water, health, energy, land, compost and sludge disposal? How high are labour costs?
- How are cost factors rated with respect to the selection of processes to be implemented?
- What are the national and international promotion and training possibilities that can be used, extended or created?
- What are the general conditions and financial incentives required in order to guarantee an environmentally sound waste management?
- What measures are suitable for the increase in public awareness regarding environmental, climate and hygiene aspects?

Suitability of Different Technologies

The choice of technology requires that numerous aspects be considered, depending, to a great extent, on the given situation, individual features and the effects of alternatives; the present document cannot deal with all these factors for each individual situation. The chapter „Technology Selection“ focuses on the description of the main specific characteristics of anaerobic technology – as far as helpful, comparisons and alternative processes are considered.

Wastewater

Outlines for wastewater treatment often combine anaerobic and aerobic treatment steps in order to achieve the best possible purification results.

Under real life conditions in developing countries, ideal process combinations (as presented in the following diagram) are rarely realised entirely. Rather, only the main treatment steps (aerobic treatment without sludge digestion or anaerobic treatment without post-treatment of the wastewater) are put in place in order to reduce the most severe environmental effects of heavily polluted wastewater. Accordingly, post-treatment steps – shown in the diagram below the dotted line – are often not yet being realised in developing countries. Future considerations do however have to proceed from more stringent environmental and hygiene standards.

MAIN DIFFERENCES BETWEEN INTENSIVE ANAEROBIC AND AEROBIC PROCESSES FOR WASTEWATER TREATMENT

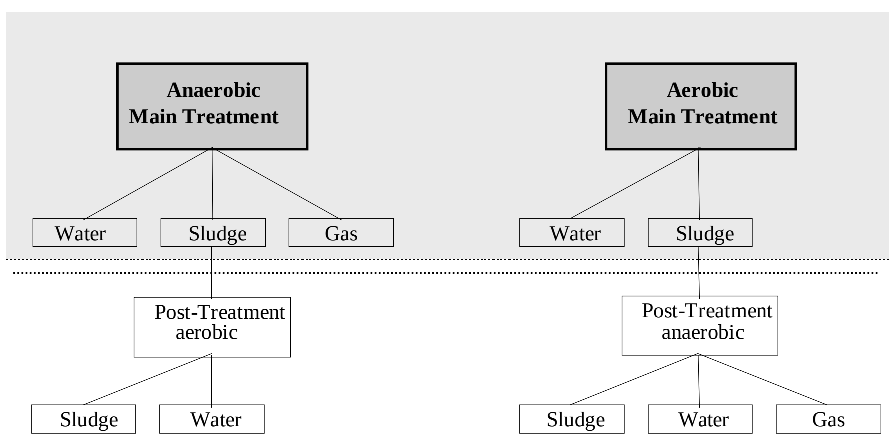


Fig. 2: Difference between anaerobic and aerobic processes

At present, the technical development of anaerobic processes for municipal wastewater treatment aims at the reduction of odours by help of improved gas collection and utilisation, furthermore at the improvement of post-treatment steps for treated wastewater as well as implementation possibilities for lower temperatures in order to extend the geographical range of implementation sites (e.g. for Mediterranean countries).

In the industrial wastewater sector, the range of substrates to be treated is increasingly being extended, the reduction of treatment costs also for medium to small enterprises is continuously being worked on.

Anaerobic Processes – Aerobic Processes

The most important characteristics of aerobic and anaerobic processes can be summarised as follows:

Parameter	Aerobic Digestion	Anaerobic Digestion
Degradation process	Degradation of organic substances to CO_2, H_2O, nitrate, sulphate, phosphate and biomass	Step-by-step degradation of organic substances to CO_2, NH_4^+, methane and biomass, eventually H_2S
Growth of organisms	Very fast growth, low generation span, therefore high biomass production (sludge)	Slow growth (esp. of methanogenic bacteria), great generation span, therefore low biomass production (sludge)
Environment requirements of organisms	Great species diversity, broad degradation spectrum, low degree of specialisation, low sensitivity	Higher number of organism groups, partly opposite environmental requirements, more sensitive against changes in the environment
Operational safety	Higher biological stability than anaerobic process	Biologically more trouble-prone than aerobic process
Energy demand	O_2 needed as hydrogen acceptor, therefore comparably high demand of foreign energy for aeration	No O_2 needed as hydrogen acceptor, therefore low demand of foreign energy (no aeration)
Energy gains	Great energy difference between initial substrate and end-product, self-warming capacity due to exothermal metabolic activity, end-products of no energetic use	Low energy difference between initial substrate and end-product, no/very little self-warming capacity, energetically valuable end-product (methane)

Efficiency Characteristics of Aerobic and Anaerobic Processes

The following tables and diagrams show important efficiency characteristics of anaerobic and aerobic processes.

Table 1 summarises the degradation efficiency and sludge production rates of selected processes.

Table 1: Degradation efficiency and sludge production of different processes

<table>
<tr><th rowspan="2"></th><th rowspan="2">UASB with post-treatment pond</th><th rowspan="2">UASB without post-treatment pond</th><th colspan="2">Activated sludge process</th><th rowspan="2">Pond system</th></tr>
<tr><th>high organic loading</th><th>low organic loading</th></tr>
<tr><td>Degradation BOD_5</td><td>75-90 %</td><td>bis 98 %</td><td>90 %</td><td>95 %</td><td>80-90 %</td></tr>
<tr><td rowspan="2">Sludge production</td><td rowspan="2">0,2-0,4
kg TS/
kg $COD_{removed}$</td><td rowspan="2">0,2-0,4
kg TS/
kg $COD_{removed}$</td><td>0,9-1,0</td><td>0,5-0,7</td><td rowspan="2">0,03-0,08
m^3/p.e.•a</td></tr>
<tr><td colspan="2">kg TS/
kg $COD_{removed}$</td></tr>
</table>

Table 2 shows the electric energy demand of selected treatment options for only weakly polluted wastewater (here: municipal wastewater) in developing countries.

Table 2: Electricity demand of different processes for weakly polluted wastewater

UASB with post-treatment pond	Activated sludge process	Naturally aerated ponds
0,1-0,15 kWh/kg $BOD_{5\ removed}$	0,8 - 1,0 kWh/kg $BOD_{5\ removed}$	ca. 0,1 - 0,15 kWh/kg $BOD_{5\ removed}$

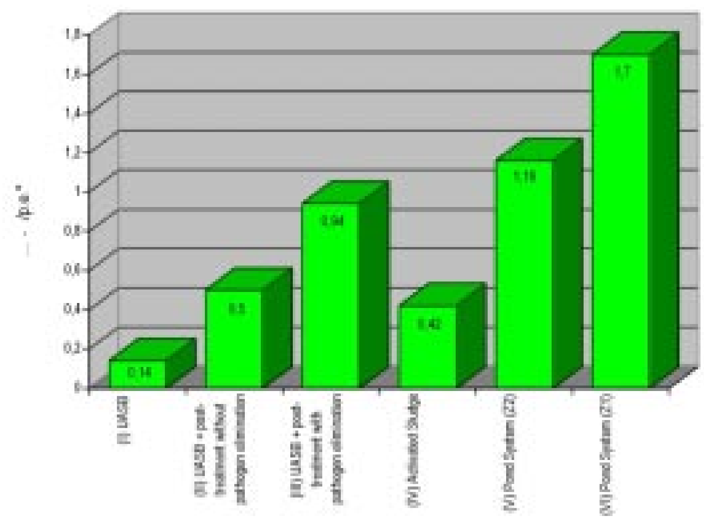
Table 3 gives an overview of a dynamic cost comparison of selected treatment alternatives for municipal wastewater without electrification. It is based on comparable starting conditions, degrees of pollution and degradation efficiencies. For the basic scenarios, Z1 represents a degradation from 250 mg BOD_5/l [1] to 20 mg BOD_5/l, Z2 for a degradation to 50 mg BOD_5/l.

[1] BOD_5: Biological Oxygen Demand in five days

Table 3: Dynamic cost comparison

	UASB with post-treatment pond	UASB without post-treatment pond	Activated sludge with sludge digestion		Pond system	
Basic Scenario	Z 1	Z 2	Z 1	Z 2	Z 1	Z 2
Treatment costs in US$/$m^3_{treated\ wastewater}$	0,081	0,059	0,155	0,143	0,098	0,070

Fig. 3 compares the respective land demands of different anaerobic and aerobic processes on the basis of different effluent values.



* population equivalent

Final loading to be achieved by the processes:

I:	50 mg BOD_5/l (Z 2)	IV:	20 mg BOD_5/l (Z 1)
II:	20 mg BOD_5/l (Z 1)	V:	50 mg BOD_5/l (Z 2)
III:	20 mg BOD_5/l (Z 1)	VI:	20 mg BOD_5/l (Z 1)

Fig. 3: Land demand of ideal wastewater treatment processes (in m^2/p.e.)

The combination of technical and operational requirements of anaerobic technology and the necessary financing result in the following advantages and disadvantages for developing and newly developed countries:

Advantages

In comparison with pond systems:

- low land demand,
- low emissions of climate gases,
- low odour emissions in case of optimum operation,
- hygienic advantages.

In comparison with aerobic processes (e.g. activated sludge):

- lower degree of mechanisation,
- less process steps (sludge and wastewater are treated jointly),
- low sludge production, high sludge quality,
- possible limitation of climatically relevant emissions (CO_2 and CH_4) due to low demand for foreign energy and energy production,
- low demand for foreign exchange due to local production of plant components and spare parts,
- low demand for operational means, control and maintenance,
- correspondingly low investment and operational costs.

Disadvantages

In comparison with pond systems:

- relatively high demand for investment and operational means,
- high demand for know-how,
- demand for co-ordination and co-operation between sectors.

Compared to aerobic processes:

- To date, insufficient standardisation and adaptation: for several implementation possibilities there is only a small number of reference projects,
- necessity of substrate heating in colder climates,
- high methane and odour emissions in case of inappropriate plant design or operation,
- without post-treatment, low degree of pathogen and nutrient removal,
- remaining odour nuisance of end products,
- sensitivity towards toxic substances,
- long start-up phase before steady state operation, if activated sludge is not sufficiently available,
- uncertainties concerning operation and maintenance due to still low availability of know-how and process knowledge.

What are the main components of an anaerobic wastewater treatment plant?

In many cases, an anaerobic treatment plant consists of the following main components:

- *Mechanic pretreatment:*

  Here, coarse and disturbing substances are separated from the influent raw sewage by means of screens, grids, sieves and sedimentation ponds.

- *Main treatment:*

  The anaerobic treatment step. There are numerous types of reactors and varying possibilities for flow management of the substrate, all of them having the absence of oxygen in common.

The most important techniques are:

- *Wastewater distribution:*

  Mostly located at the reactor bottom. A constantly even distribution of the wastewater in the sludge is decisive for the achieved removal rates.

- *3-phase-separation:*

  Allows treated wastewater to flow off, holds back the sludge and collects the produced gas.

- *Post-treatment:*

  Wastewater receives post-treatment especially in order to comply with influent standards, to remove pathogens and reduce nutrient content. Ponds or other aerobic processes are implemented.

- *Sludge treatment:*

  For anaerobic processes, this is in most cases reduced to drying in drying beds.

- *Gas utilisation:*

  If possible, this is realised on-site so that part of the produced electricity, heat and eventually cooling energy can be utilised directly in the treatment steps or for other plant components. As far as possible, surplus electricity is fed to the grid or sold to neighbouring consumers. In case surplus gas is produced that cannot be utilised, it has to be flared.

- *Treated wastewater, sludge, compost produced:*

  These products can be reused in agriculture.

Amounts of wastewater and its characteristics

The knowledge about the amounts of wastewater produced, daily and seasonal fluctuations as well as their chemical and biological characteristics are the starting point for the design and dimensioning of a treatment system.

IMPORTANT WASTEWATER PARAMETERS

COD – Chemical Oxygen Demand. The COD-content describes the concentration of substances in the wastewater that can be oxidised and is expressed in mg/l. The concentration of COD in the wastewater should have a minimum value of 250 mg/l, optimum conditions are > 1.500 mg/l.

BOD_5 – Biological Oxygen Demand. The BOD_5-content describes the concentration of substances in the wastewater that are biologically degradable within 5 days and is expressed in mg/l. Optimum conditions are > 800 mg/l.

Temperature. Wastewater temperature is decisive for its suitability for anaerobic treatment. For combined treatment of municipal wastewater and faecal sludge, substrate heating is normally not economic, so that – according to the present state-of-the-art technology – a minimum temperature of 18 °C of the raw sewage should be given.

Toxic Substances. Toxic substances hinder the microbiological degradation processes and therefore reduce the removal efficiency of a treatment plant. In case their concentration exceeds the tolerable amount of the micro-organisms, biological degradation may come to a halt. Speaking of municipal wastewater, prohibitive concentrations hardly ever occur.

Wastewater production. A continuous wastewater flow is the optimum condition that allows the best possible utilisation of the plant capacity and prevents sludge wash out. Variations in wastewater flow and the guarantee of sufficient buffer capacity have to be considered in plant design.

The determination of the amount of wastewater may be based on the number of inhabitants, reference data, existing studies or actual measurements of the wastewater flow. The composition of municipal wastewater is rather constant – regional and structural differences do, however, have to be considered. Important factors influencing wastewater composition are the state-of-the-art of sanitation (flush toilets), sewerage systems (mixed or separate) and the connection rate to the sewerage system. Moreover, mean, minimum and maximum precipitation, discharging industries (amount and composition of wastewater discharged, branch of industry), sanitary and consumption habits are factors for consideration.

TRENDS

Per capita amounts of wastewater vary between about 100 and 300 l/p.e.•d according to climate conditions and the state of development in the respective country or region. Higher connection rates to the sewerage system and an increased living standard (flush toilets) are expected to result in greater amounts of wastewater. In case of land scarcity, the comparably low investment and operational costs of anaerobic treatment processes will gain importance in the municipal wastewater sector in developing countries.

KEY POINTS FOR DECISION MAKERS – WASTEWATER AMOUNTS AND CHARACTERISTICS

- How much wastewater will have to be treated?
- How strong are the expected variations in wastewater flow
- What is the influent wastewater temperature?
- How high is COD-loading?
- How high are the amounts discharged by the industry? Which industrial branches discharge, which toxic substances are contained?
- Do pathogens and their elimination play a role at the respective plant site?
- How will the amounts of wastewater develop in the future?

Site Selection

Anaerobic treatment plants generally have a comparably low land demand (see Fig. 3). The site selection is determined by geographical and infrastructural conditions:

Topography

Favourable topographical conditions allow the utilisation of gravity for wastewater transport so that there is no or only little demand for pumps. Spatial vicinity to a waterbody makes channeling unnecessary.

Neighbourhood

The type of adjoining buildings or settlement areas has to be considered: Odour nuisance may arise for residential districts in the plant surroundings; possibilities for energy utilisation in industrial surroundings have to be assessed.

Sewerage system

Existing sewerage infrastructure and its dimensioning may be a basis for planning the treatment unit.

Electricity grid

With respect to a sensible economic and ecological use of energy, the provision of possibilities for a connection to the public grid or to electricity consumers site is important.

Reuse of products from wastewater treatment

In order to reduce transport distances, possibilities for the reuse of sludge and purified water should exist close to the plant location.

KEY POINTS FOR DECISION MAKERS – SITE SELECTION

- Can gravity / existing sewerage systems be utilised for charging the plant?
- What kind of neighbourhood relationships characterise the plant surroundings?
- Where and how can end products be utilised?

Process Selection

A thorough decision and choice of the process to be implemented are decisive for successful plant operation. The possible alternatives to be considered for the respective substrate and local conditions should be compared systematically.

The questions formulated so far should be understood as guidelines for aspects to be considered and carefully investigated.

Due to rising environmental awareness and progressive legal regulations, environmental, climate and health issues have to be considered more and more in addition to technical questions concerning the suitability and efficiency of processes involved.

Important processes applied in developing countries are the following:

Anaerobic Processes	Aerobic Processes
Ponds	
Anaerobic ponds Covered anaerobic ponds	Naturally aerated ponds Aerated ponds
Facultative ponds	
Low Maintenance Processes with low Efficiency:	
Septic tank Imhoff tank	Gravel filter Cascades
Intensive and High Rate Processes:	
Sludge bed reactor (UASB) Fluidised bed reactor Fixed bed reactor	Activated sludge process Trickling filter Rotating biological disk

Short description of most important processes

Ponds

Facultative ponds	Ponds with a depth of about 1,5 m, surface loading of about 200 - 350 kg BOD_5/ha•d (for post-treatment after anaerobic treatment step about 400 - 500 kg BOD_5/ha•d) and formation of aerobic layers close to the surface and deeper anaerobic layers over daytime, depending on depth, temperature. Loading rate and algae activity.
Aerated ponds	Ponds with artificial surface aeration, comparable with long-term activated sludge process, were developed in the attempt to prevent odour emissions from overloaded facultative ponds.
Naturally aerated ponds	Ponds with low depth that are exposed to natural air movement in a way that guarantees sufficient supply of oxygen (by wind, movement of water surface) for aerobic conditions.
Improved anaerobic ponds	Ponds with up-flow regime of the substrate and gas collection, showing anaerobic conditions at a depth of 3 – 5 m due to a high surface loading)starting at about 3.000 kg BOD_5/ha•d.

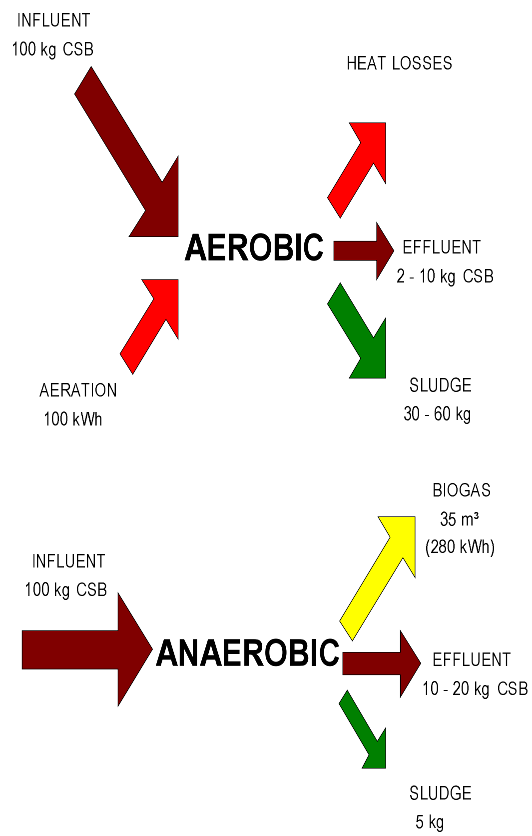
Anaerobic processes

Septic Tank	Simple sedimentation tank that stabilises settled sludge by anaerobic digestion. Dissolved and suspended solids leave the reactor almost without treatment. (Most frequent decentralised wastewater treatment worldwide.)
Imhoff Tank	Sedimentation tank above a digestion tank without gas collection. Suspended and dissolved solids do not have immediate contact to active sludge.
UASB - Upflow Anaerobic Sludge Blanket – Reactor	Anaerobic reactor with up-flow regime, sludge retention and 3-phase separation (the EGSB – *Expanded Granular Sludge Bed Reaktor* - may be used as alternative: this is in principle a high, lean UASB with high upflow velocity).
FB – Fixed bed reactor	Reactor with inert filter medium (for growth of biomass, today mostly plastic material), mostly with external separation and recirculation of biomass.
Fluidised bed reactor	Modern high rate reactors with high volume-time efficiency. Inert filter medium and recirculation for keeping up of fluidised state.
RALF – Reactor Anaerobio de Leito Fluidizado	Modification of UASB reactor developed in Brazil with very small or often no 3-phase separation, resembles a pond with upflow regime.
HUSB - Hydrolysis Upflow Sludge Bed-Reaktor	Anaerobic reactor with upflow regime with the main objective of separation of solid substances. Main difference to UASB is the short HRT of about 2 - 5 h (many applications in China).

Aerobic processes

Activated sludge process	Aerobic biological wastewater treatment using activated sludge in aerated tanks. In Europe, usually combined with anaerobic sludge digestion.
Trickling filter	Percolation process with a highly permeable medium (mineral or plastic) in the reactor that serves for bacterial growth.

MASS FLOW
FOR AEROBIC AND ANAEROBIC WASTEWATER TREATMENT (EXAMPLE)



Among high rate processes, the activated sludge process is predominantly applied. Trickling filters and aerated ponds are also widespread in developing countries.

Speaking of anaerobic wastewater treatment, sludge bed reactors and a number of modifications of this reactor type are the processes predominantly applied. Fixed bed reactors are mainly implemented in industrial wastewater treatment.

Key Points for Decision Makers – Process Selection

- **...concerning technology:**
  - Which process combination complies with legal regulations on removal rates of pathogens and nutrients?
  - Which pre- and post-treatment steps are necessary to achieve these?
  - What kind of future plant extensions should already be considered in the planning stage (extension of capacity, removal efficiency)?
  - Is the wastewater temperature suitable for anaerobic process steps?
  - Is sufficient personnel and know-how available for safe plant operation?
  - What kind of training activities are necessary?
- **...concerning costs:**
  - How much space is available? How high are the land costs? Should space-saving processes be preferred?
  - How high is the demand for foreign exchange, what kind of customs duties will arise for plant components?
  - What influence do energy and sludge disposal costs have?
  - Can the financing of sustainable operation of a high rate plant be guaranteed? Do low maintenance processes have to be preferred?
  - Can energy, sludge and treated wastewater be utilised efficiently?

In addition to water quality requirements (quality of the discharged wastewater and of the receiving water body), advantageous effects on climate and soil have to be considered.

An advantage of anaerobic technology is its potentially positive effect on the climate: In addition to avoiding emissions from e.g. wastewater dumps, greenhouse gas emissions can be prevented in house and at external sites of energy utilisation by substituting fossil fuels.

Regarding soil quality, it has to be taken into account that the deposition of polluting substances e.g. from „wild“ wastewater dumps can be prevented or reduced. In addition, nutrients can be recirculated and the soil structure can be built up by utilising the digested sludge.

Health and hygiene effects of successful municipal wastewater treatment are obvious. The necessary sewerage system does already have the effect of keeping away critical wastewater flows from the population.

Both the anaerobic and aerobic treatment processes reduce the pathogen content in wastewater, purely anaerobic processes, however, to a lesser degree than combined processes. Depending on the objective, a thorough elimination of pathogens (viruses, intestinal bacteria) is a point of concern, especially if the treated wastewater and the sludge are utilised in agriculture. From the hygiene point of view, the best removal efficiencies can be achieved by a combination of anaerobic and aerobic treatment steps if sufficiently long retention times are applied. Plant layouts with anaerobic treatment and post-treatment ponds can achieve pathogen removal rates of up to 99,9%.

Solid Waste

Anaerobic Processes – Aerobic Processes

Anaerobic technology for the treatment of solid waste is still comparably young (only within the last 5 years has a greater number of plants been built, mostly in Central Europe) and is at present mainly implemented

- for treatment of biowaste,
- as part of mechanical-biological treatment of un-sorted and separately collected municipal waste,
- in co-fermentation plants for co-digestion of sewage sludge, dry manure or industrial waste and
- for the collection of landfill gas, which in most cases only allows an energetic reuse of wastes (and is therefore not considered in the following).

Anaerobic processes for biowaste in most cases integrate an aerobic post-treatment step (composting) after anaerobic digestion. Due to the high organic matter content in most municipal solid wastes (50-85%) and other factors, the technology is particularly interesting for being implemented in developing countries. The first pilot plants for anaerobic waste treatment and cofermentation only now start to be adapted to the conditions in these countries.

Suitability of Organic Waste for Anaerobic Digestion or Composting

ANAEROBIC DIGESTION	COMPOSTATION
Liquid manure/sewage sludge	
Slaughterhouse waste	
Table scraps	
Kitchen scraps	
Organic industrial	
Biowaste (rural / urban)	
	Lawn mowings / leaves
	Yard waste / hedge trimmings

→ **Decreasing moisture**

Fig. 4: Suitability of organic waste for anaerobic digestion or compostation

Waste Characteristics

Almost all organic solid waste can be degraded anaerobically. In the context of treatment of solid biowaste, anaerobic technology is especially suitable for the treatment of substrates which have a high moisture content and are therefore less suitable for compostation. Predominantly dry substrates with a high share of structure and lignin material (wood) that are good for compostation, are less suitable for anaerobic digestion

Given a sufficient moisture content, the substrate characteristics of municipal and agro-industrial organic waste generally allow anaerobic digestion. Concerning monosubstrates from industries, a balanced nutrient content and the absence of harmful concentrations of toxic substances have to be considered.

IMPORTANT WASTE PARAMETERS

Dry solid matter (DM) content. The dry solid matter content describes the amount of substrate after the withdrawal of water until constant weight is reached. Solid waste is suitable for anaerobic digestion within a range of about 10 and 40% DM. Below 10% DM content, the substrate consistency turns towards sludge.

Organic dry solid matter content. The organic dry solid matter content describes the organic share of the dry matter; for anaerobic digestion, it should exceed 50%.

Structure material. Structure material are substrates with a high content of lignin (wood, shrub/tree cut offs). A low content of structure material is advantageous for anaerobic digestion, a high one for composting.

Temperature. Anaerobic digestion plants for solid waste are operated either under mesophilic (around 35°C) or thermophilic (around 55°C) conditions. In the majority of cases, the digestion substrate is heated, the heat produced in the co-digestion unit is however mostly sufficient.

Toxic substances. Toxic substances hinder microbiological degradation processes. Therefore, their concentration in the waste must not reach a prohibitive level. Regarding household waste, this is generally not given.

C/N-ratio. Describes the ratio of carbon to nitrogen content in the substrate. The C/N-ratio should exceed 10/1, a value of about 20/1 should be tried to be achieved.

Protein content. The protein share in the organic dry solid matter should not exceed 50%.

The advantages and disadvantages of anaerobic technology for solid waste treatment mostly resemble those identified for wastewater. Compared to the most important treatment alternatives (composting, landfills, incineration) however, a number of additional ones can be named:

Advantages

- the material and energetic re-use possibilities,
- the comparably high share of surplus energy (about 2/3),
- the low land demand compared to compostation and landfilling (correct also if wastes are disposed of in a landfill or incinerated after digestion),
- the prevention of leachate and methane emissions from uncontrolled dumping,
- the reduction of operational costs due to possible returns from sales of the end products compost, gas, heat/cooling,
- lower emissions compared to landfilling, compostation and incineration, mainly due to closed plant construction.

Disadvantages

- the relatively high level of technological sophistication (not true for comparison with incineration plants),
- the still low number of specific examples and demonstration plants for different wastes in developing countries,
- non-separation of (bio-) waste in the municipal sector that makes material reuse difficult.

What are the main components of an anaerobic solid waste treatment plant?

In simplified terms, the anaerobic treatment of biowaste in industrialised countries basically consists of the following main components:

- In the *dry preparation step*, the wastes are subdivided into different fractions by sieves, disturbing substances are separated (e.g. by magnetic separation or manual sorting of the coarse fraction), part of the waste is crushed.
- The pre-sorted waste is forwarded to the *moist preparation step*: Here, the waste, as far as necessary, is diluted in pulping tanks and heavy substances are separated in sedimentation tanks. After further crushing, the substrate is hygienated and heated either by surplus heat from the co-generation units or by steam from steam producers.

- The *fermentation* or *digestion*, the actual anaerobic treatment, is either mesophilic (at 35°C) or thermophilic (55°C) and involves one or two treatment steps. After sufficient retention time, the substrate is transferred to the post-digestion tank.
- In most cases, the digested sludge is dewatered and *composted* together with the shredded coarse fraction. The separated water is recirculated for substrate dilution, the surplus water has to be treated prior to discharge.
- *Utilisation of end products:* Electricity and heat are produced in co-generation units. The thermal energy is used to heat the substrate as well as the digestion and hygienisation tanks, the electricity is used within the treatment plant (about 1/3), surplus electricity is fed to the public grid. *Compost* from aerobic treatment can be applied in gardening and landscaping.

Co-Digestion

Recent developments in the waste sector combine the anaerobic digestion of industrial and municipal solid waste, sludge and agricultural residues (co-digestion, co-fermentation). These processes reduce requirements for transport, allow a better utilisation of existing capacities and may improve direct recirculation of organic substances into agricultural production.

Combined Processes

Anaerobic waste treatment is often combined with composting plants, landfills (with or without gas collection) and incineration of residues. To optimise thermal and electric energy utilisation beyond its application as process energy, the energy produced can be used for aeration and sludge drying purposes in wastewater treatment plants or as substitute fuel in incineration plants.

Site Selection

Similar to wastewater, anaerobic treatment plants for solid waste have a comparably low land demand. The following factors have to be considered in the process of site selection in particular:

- Odour problem (also due to transport activities) in residential areas.
- Possibilities for energy utilisation in plant surroundings (industry, residential areas).
- Possibilities for a connection to the electricity grid should be given, or energy consumers should be located nearby.
- Reduction of distances and costs of transport due to vicinity to the municipalities connected and to landfill sites (for disturbing substances) and/or to sites for the application of the sludge or compost.
- Vicinity to a wastewater treatment plant for joint treatment of produced surplus water.

KEY POINTS FOR DECISION MAKERS – SITE SELECTION

- What type of building areas are located in the vicinity of the possible plant site?
- How far are transport distances?
- Are separate wastewater treatment facilities required?
- Possibilities for material and energetic utilisation of end products?
- Is a municipal waste management scheme for organic waste disposal in place?
- Can industrial waste be opened up/integrated into the concept?
- Can a continuous delivery of waste be secured?

Process Selection

Characteristics of important types of processes

1. Dry fermentation

- Simple pre-treatment
- Solids content > 25% (slight moisturising necessary)
- Extensive requirements for feeding and emptying
- Good utilisation of volumetric capacity of the reactor
- Extensive requirements for substrate mixing in the reactor
- Incomplete circulation

2. Wet fermentation

- Extensive requirements for pre-treatment
- Solids content < 15 %
- Comminution and homogensiation are necessary
- Substrate is mixed completely, therefore intensively degraded at an even level
- Separation of inert substances by flotation and sedimentation
- Dewatering and wastewater treatment are necessary

3. One step processes

- Simple process technology
- Mesophilic (30-40°C) or thermophilic (50 65°C) operation
- Additional hygienisation effect at thermophilic operation
- Lower values for degradation and gas productivity
- Longer retention times

4. Two step processes

- Separation of hydrolisation and methanisation
- Shorter retention times
- Increased requirements for process equipment
- Trouble-prone to a greater extent
- Improved degradation efficiency

5. Batch and storage processes

- One step, discontinued processes
- Simple construction method, but high volumetric requirements of reactors
- Processes can hardly be automised
- No constant gas production over time
- Compensation by operation of several tanks at different process stages
- Extensive requirements for feeding and emptying

Key Points for Decision Makers – Process Selection

- **...concerning technology:**
  - Which process is suitable for what type and amount of waste?
  - Which pre-treatment steps are necessary?
  - Is the digested substrate subject to post-treatment?
  - Can plant extensions be anticipated (extension of capacity, substrates)?
  - Is land available and at what costs?
  - Where does the wastewater receive treatment?
- **...concerning plant operation:**
  - Is sufficient know-how available? Are training activities necessary?
  - Are secured disposal fees in place?
  - To what extent can energy and fertiliser add to operational costs (revenues or savings)?
- **...concerning investment costs:**
  - How high are land costs?
  - How high is the demand for foreign exchange, what kind of customs duties will arise?
  - Which plant components can be produced or are available locally?

Environment and Health

Due to the large amount of surplus energy produced in the form of biogas during anaerobic digestion of solid waste, considerable amounts of fossil fuels can be substituted, greenhouse gas emissions can be avoided on site as well as at external consumption sites. In addition, methane emissions from uncontrolled landfills are avoided, emissions of harmful substances into the soil, to ground and surface waters are reduced.

Emissions and health risks, especially arising from open dumping and simple incineration facilities, are diminished due to the closed construction of anaerobic waste treatment plants.

An improvement of the hygienic working conditions for the „informal sector“, whose members are active in small-scale recycling in numerous developing countries, can be achieved if this sector is integrated in programmes and projects.

Plant Design and Construction

Extensive know-how for plant design and sufficient experience for each design phase in detail have to be available. Good plant design will facilitate start-up and operation of the plant and will reduce necessary technological adaptations to a minimum.

Plant design has to integrate the specific site conditions and requirements of the chosen technology.

The following design parameters have proved to be central points of consideration:

Wastewater

- *Plant influent*:

  The influent has to be dimensioned according to the average flow of wastewater, taking into consideration the frequency of heavy precipitation and other great flow variations, if necessary, buffer capacities are to be considered.

- *Distribution of wastewater:*

  The piping has to be dimensioned sufficiently large so that the risk of clogging is minimised.

- *Reactor size:*

  The necessary volume of the digestion reactor has to be determined according to the amount of wastewater to be treated and the estimated retention time (desired/necessary degradation rate).

- *3-phase-separation:*

  The 3-phase-separation (for UASB-plants) has to be dimensioned in a way that allows the produced gas to be extracted entirely and that avoids odour emissions by uncontrolled gas release. Sludge wash out due to overloading of the reactor has to be prevented.

- *Gas utilisation:*

  The gas has to be purified prior to its utilisation in gas appliances (desulphurisation) in order to avoid corrosion. The gas storage capacity and the number of appliances should take into account times of plant standstill. Future utilisation of the entire gas produced should already be secured in the design phase.

- *Post-treatment:*

  The post-treatment process has to guarantee compliance with respective discharge standards and should allow the maximum use of the „by-products“ gas, purified water and sludge.

- *Process optimisation*:

  Especially for industrial wastewater, the type of treatment plants and their desired efficiencies have to be chosen specifically and adapted to the respective branches.

Solid Waste

- *Pre-treatment:*

  An early removal of disturbing substances saves subsequent aggregates and piping. The conditioning of the waste prior to or after the digestion step has to be adjusted to the substrate characteristics, strong variations have to be buffered.

- *Process optimisation:*

  Especially for industrial solid waste, the treatment processes are adapted specifically to the respective branches. Increasingly, partial standardisation, plant examples and modular construction are available.

- *Gas utilisation:*

  The gas has to be purified (desulphurisation) prior to further application in order to avoid corrosion damages.

- *Wastewater treatment*:

  For the treatment of surplus water, a sewerage system allowing wastewater discharge to a municipal or industrial wastewater treatment plant contributes to a limitation of own requirements for treatment and purification.

KEY POINTS FOR DECISION MAKERS – PLANT CONSTRUCTION

- Are qualified construction companies available with experience in the respective technology?
- Is qualified and experienced personnel available?
- Are independent construction supervision and quality control secured?
- Does the planner have sufficient interest in successful plant construction, does he share responsibility for reliable plant operation?

Plant Operation

Operational problems are often caused by a lack in operational management and in organisational structure, especially in developing countries. Maintenance programmes, strategies for plant control and preconditions for a comprehensive and permanent operational control should therefore be developed parallel to plant design and construction.

For smaller decentralised or household plants these requirements are reduced.

Wastewater

The following points guarantee optimum conditions for plant operation:

- *Plant documentation and operational diary:*

  The documentation should contain survey and locational plans with influent channels and water bodies for discharge as well as licensing documents. The operational diary has to demonstrate the technical state of the plant and operational changes at regular intervals or according to necessity.

- *Maintenance programmes and examination protocols:*

  These have to be kept for all plant components.

- *Control measurements and optimisation steps for the anaerobic process:*

  - *daily:*
  pH-value, conductivity, redox potential, COD content, settleable/non-settleable solids, nitrogen content, temperature (water, air) and weather (precipitation)
  - *weekly:*
  BOD_5, phosphorus
  - *continuously:*
  production of biogas, CH_4 content in the biogas
  - *as required and according to legal (water) regulations:*
  other parameters with defined discharge standards; content of toxic substances (for process and ecosystem).

In order to assess possible causes and links in case of operational problems, more frequent examinations may become necessary.

Test plants operated in parallel are suitable for determination of loading limits and optimum long-term loading rates.

- *Purification, utilisation of gas:*

  The produced amount of gas is an indication for process efficiency and stability. Therefore, it should be measured and documented at regular intervals (determination of methane and CO_2 content).

  Gas purification is normally necessary in order to minimise deposits on and wear out of gas use appliances, especially for a utilisation of the biogas in motors (concerning standard motors, already small amounts of sulphur quickly result in damage and shorten intervals for oil change). Maintenance and operational requirements increase with sophisticated gas utilisation and with inferior gas quality.

  In case of thermal gas utilisation for cooking, cooling and heating purposes, appliances should be checked occasionally concerning their proper functioning, wear out and deposits due to gas impurities.

  The functioning of gas flares has to be controlled as daily routine, they should be operated automatically.

- *Post-treatment:*

  The higher the technology level of the chosen post-treatment process, the higher are the requirements for operation and maintenance and the necessary level of know-how. Facultative ponds for example are characterised by only very little regular requirements for operation and maintenance.

- *Sludge treatment:*

  Operational requirements for the treatment of sludge from anaerobic plants are small. Here, normally sludge drying and composting are sufficient. Further process steps on a higher technological level like e.g. sludge dewatering (thickener, press etc.) and separate sludge digestion are not necessary.

  The sludge should be examined regularly with respect to parameters crucial for its further disposal or utilisation (e.g. content of nutrients or harmful substances).

Waste

The following points guarantee optimum conditions for plant operation:

- *Plant documentation and operational diary:*

  see wastewater

- *Maintenance programmes and examination protocols:*

  see wastewater

- *Control measurements and optimisation steps for the anaerobic process:*
  - *daily:*
  pH-value, organic acids, temperature, conductivity, nitrogen
  - *weekly:*
  TS content
  - *continuously:*
  production of biogas, CH_4 content in the biogas
  - *as required:*
  content of toxic substances (for process/ecosystem)

- *Purification, utilisation of gas:*

  see wastewater

- *Composting:*

  During composting of the digested substrate, the course of temperature should be controlled, sufficient aeration and turning of the compost piles has to be secured in order to prevent the formation of anaerobic layers and to secure a constant degradation within the compostation process. As with sludge, the compost should also be examined regularly with respect to parameters crucial for its further disposal or utilisation (e.g. content of nutrients or harmful substances).

- *Wastewater:*

  Not every treatment plant for solid waste has its own wastewater treatment facilities. Possibilities for utilising wastewater in the process (moisturising, composting) have priority and have to be checked regularly.

KEY POINTS FOR DECISION MAKES – PLANT OPERATION

- Is the necessary equipment for plant monitoring in place (measuring equipment, electronic data processing equipment)?
- Are operation and maintenance plans being observed?
- Is the continuous documentation of plant operation realised?

Training

Sufficient know-how for plant operation has to be secured or otherwise to be established by suitable training measures already in the construction stage. Training of technical operational staff should also promote the understanding of environmental aims and the economic context.

The utilisation of surplus energy outside the plant requires specific plant management and external organisation structures that are not common for any other treatment technology. In developing countries, examples for anaerobic sludge digestion and gas utilisation are still rare, therefore additional training measures for gas technology are necessary.

Training and educational concepts have to be adapted according to the institutions active in the anaerobic sector in the respective country or region and to the already existent know-how.

Key Points for Decision Makers – Training

- What is the level of know-how that is available on a secure basis?
- Is a sufficiently trained workforce already in place? If so, how many people does it comprise?
- What kind of training and educational programmes and institutions are in place?
- What are the necessary resources to be made available in respect of time, personnel and financing?

Summary

- *Municipal wastewater...* — *...needs temperatures above 18 °C and a Chemical Oxygen Demand above 250 mg/ℓ for an economic implementation of anaerobic processes at the current state of technology development. If these criteria are met, anaerobic processes as a rule require less treatment costs than intensive aerobic processes. In most cases, post-treatment is recommended in order to achieve the desired effluent values and to reduce the nutrient and pathogen content. Compared to extensive pond systems, economic advantages can be expected for land prices exceeding 12 US$/m^2.*

- *Industrial wastewater...* — *..., if heavily loaded with organic matter, allows substrate heating also from an economic point of view, so that even wastewater of low influent temperature can be treated in a space-saving manner. Wastewater composition and toxic compounds must not hinder the degradation process. In spite of sometimes higher investment costs in comparison with intensive aerobic processes, the low operational costs result in low overall treatment costs, at least for large-scale plants. The economic advantage increases with higher concentration of organic matter in the wastewater and with stricter legal regulations.*

- *Solid waste...* — *...and sludge with high organic matter content (in practice: disturbing substances mostly < 10%) can generally be treated anaerobically, independent of the ambient temperature. The material and energetic reuse of the waste is realised in a space saving manner. Regarding costs, anaerobic treatment of solid waste is similar to composting; compared to incineration, it shows economic advantages, compared to landfilling it is more cost intensive, at least in the short term. Combined systems can additionally make use of numerous synergies.*

- *Favourable...* — *...for the implementation of anaerobic technology are generally high costs of energy and land, of waste and sludge disposal or high compost prices, high costs of equipment and high foreign exchange rates. Strict environmental laws, the economic valuation of environmental and climatic effects as well as the possible utilisation of secondary products from the process are further favourable factors.*

- *Pre-condition...* — *... for a long-term successful technology implementation is qualified planning and management and reliable financing of plant operation.*

Project Partners and Sources of Information

Project Realisation

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Universidad Nacional de Ingeniería, Ing. Roncal Fausto, Lima, **Peru**

Financing Institutions

Inter-American Developmant Bank (IDB), Washington DC, **USA**

(GEF) Global Environmental Fund Washington DC, **USA**

Asian Development Bank (ADB), Manila, **Philippines**

The World Bank, Washington DC, **USA**

Accompanying Networks and Associations

IAWQ Specialist Group, University of Ottawa, Prof. Kennedy, Ottawa Ontario, **Canada**

Arbeitskreis zur Nutzbarmachtung von Siedlungsabfällen (ANS), Dr. Leonhardt, Mettmann, **Germany**

Red Colombia de Biotecnologia Ambiental (RECBAM), Universidad del Valle, Dr. Rojas Chacon,Cali, **Colombia**

Fachverband Biogas, (FB), Michael Köttner, Weckelweiler, **Germany**

Project Literature and Information Material from the Sectoral Project "Promotion of Anaerobic Technology for the Treatment of Municipal and Industrial Wastewater and Waste"

Final Report
Summary of project results

Status Reports
Volume 1 Basics, Economy, Energy, Environment (German)
Volume 2 Anaerobic Treatment of Wastewater (German)
Volume 3 Anaerobic Treatment of Solid Waste (German)

Country Reports on Wastewater and Waste Situation from
Latin America:
Bolivia, Brazil, Ecuador, Jamaica, Colombia, Mexico,
Asia:
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