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Sandec
Water and Sanitation in
Developing Countries

Anaerobic Digestion of Biodegradable Solid Waste in Low- and Middle-Income Countries

Overview over existing technologies and relevant case studies

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Dübendorf, May 2007

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Abbreviations

AD	Anaerobic digestion
AIT	Asian Institute of Technology (Thailand)
ARTI	Appropriate Rural Technology Institute (India)
ASTRA	Centre for Application of Science and Technology to Rural Areas (India)
BARC	Bhabha Atomic Research Centre (India)
BMW	Bioorganic municipal waste
CDM	Clean Development Mechanism
COD	Chemical Oxygen Demand
FSTP	Faecal Sludge Treatment Plant
GTZ	Gesellschaft für Technische Zusammenarbeit
IISc	Indian Institute of Science
LPG	Liquified petroleum gas
MBT	Mechanical biological treatment
MSW	Municipal Solid Waste
NARI	Nimbkar Agricultural Research Institute (India)
OMSW	Organic Municipal Solid Waste
PFR	Plug Flow Reactor
SPRERI	Sardar Patel Renewable Energy Research Institute (India)
SS	Sewage Sludge
SSB	Solid-state Stratified Bed
SWM	Solid Waste Management
TERI	The Energy and Resources Institute (India)
TEAM	TERI enhanced acidification and methanation
TIDE	Technology Informatics Design Endeavour (India)
UASB	Upflow Anaerobic Sludge Blanket (reactor)
USW	Urban Solid Waste
VFA	Volatile Fatty Acids

Summary

In many cities in developing countries, the most serious environmental and health problems are related with inadequate solid waste management (SWM). Urbanization or an increase in population, respectively, leads to increased waste generation in urban areas. Most problems are strongly related to inappropriate treatment of the organic fraction of municipal solid waste (OMSW).

Composting and anaerobic digestion (AD) are seen as the most favored options to deal with OMSW. Both treatment options reduce the environmental burden and enable the generation of a nutrient rich fertilizer. Furthermore, in the case of AD energy in form of biogas is produced. Nowadays, energy is scarce and its production out of biodegradable waste is willingly seen. Thus, AD is attaining more relevance in SWM.

Anaerobic digestion of OMSW is commonly and successfully used in industrial countries. In some developing countries, such as China, India and Nepal AD already has a long tradition, but is almost exclusively used in rural areas mainly for the treatment of animal feces.

Biomethanation of organic solid waste is considered as an issue that has only come up in the recent past. Various low-tech digesters have been developed in order to treat biodegradable solid waste. But information about the status-quo in that field is still missing.

Thus, Sandec, the Department of Water and Sanitation in Developing Countries at the Swiss Federal Institute for Aquatic Science and Technology (Eawag), was conducting a research on biomethanation of biodegradable solid waste in low- and middle-income countries. The study was focused on case studies of currently working biogas plants that produce biogas mainly out of solid waste, such as kitchen waste, market waste etc. and was mainly based on an internet research and e-mail correspondence.

The research revealed that mainly India and China have been making efforts to develop AD technologies applicable for organic solid waste treatment. Various institutes and NGO’s have been trying to establish such kind of anaerobic digesters for the SWM on household, institutional or municipal level.

Most of the anaerobic digesters implemented did or do not work properly. Many projects in that field failed, not only due to technical reasons, but also as operation and management has been done inadequately. Nevertheless there are successful projects mainly related to a few types of technologies.

Based on this research the technologies being the most promising in the field of low-tech AD of biodegradable waste are BARC (developed by the Bhabha Atomic Research Institute, Mumbai), ARTI (Appropriate Rural Technology Institute, Pune), BIOTECH and Mailhem Engineering PVT Ltd, all of them located in India.

Regardless of type of low-tech digester research needs to be continued in order to enable AD to be a successful and sustainable MSW treatment option in developing countries.

Introduction

SWM Concerns in Low- and Middle Income Countries

In many cities in developing countries, the most serious environmental and health problems are related with inadequate solid waste management (SWM). Urbanization or an increase in population, respectively, leads to increased waste generation in urban areas. The service provided by municipal institutions and private companies is not keeping pace with the amount of waste generated.
Several problems are due to the disposal of organic waste into still commonly used open dumps. The waste, mainly organic waste, dumped in open places causes heavy environmental pollution to soil, groundwater and surface waters (Veeken A., Hamminga P. et al., year unknown (after 2005)).

Approach Composting and Anaerobic Digestion

In order to tackle these problems the disposal of organic material needs to be avoided (as already done in some industrial countries). Aiming at sustainable development the organic waste as a source of nutrients and energy has to be reused. Nowadays, composting and anaerobic digestion (AD) are seen as the most favored options to deal with organic solid waste. Both treatment options reduce the environmental burden and enable the generation of a nutrient rich fertilizer. Furthermore, in the case of AD energy in form of biogas is produced. Nowadays, energy is scarce and their production out of biodegradable waste is willingly seen. Thus, AD is attaining more relevance in SWM sector.
In the past, this approach was rarely considered as a feasible and sustainable solution for the SWM in developing countries. Only in industrial countries (especially Europe), as well as in China and India biogas production out of SW has become more and more popular. In some European countries political and economic frameworks changed so that biogas production became economically advantageous for agricultural and industrial applications. New systems have been developed and successfully implemented, also in the field of MSW.
In many low- and middle-income countries, AD has been applied using manure or faecal sludge as main feedstock material. Especially in India, China and Nepal millions of biogas plants have been installed, but mainly in rural areas.
The extraction of biogas out of solid waste is considered as an issue that has only come up in the recent past. Various low-tech digesters have been developed in order to treat biodegradable solid waste. But Information about the state-of-the-art of these digesters is scarce.
Thus, Sandec, the Department of Water and Sanitation in Developing Countries at the Swiss Federal Institute for Aquatic Science and Technology (Eawag), was conducting a research on biomethanation of biodegradable solid waste in low- and middle-income countries. The research was focused on case studies of currently working biogas plants that produce biogas mainly out of solid waste, such as kitchen waste (food waste), market waste, coffee pulp (agricultural waste) etc.
This report summarizes the case studies found. It gives an overview about existing biogas projects in the field of SWM in low- and middle-income countries. Besides that some other projects in context with AD are listed.

Objectives

The main objective of this research is to assess case studies of biogas plants in low- and middle-income countries that use organic solid waste as feedstock material.
The case studies should be summarized in a short report giving a basis for further investigations.

Table 1: Research questions

	Main research questions in terms of AD in low- and middle income countries
1	Are there biogas plants whose feedstock material is mainly biodegradable waste?
2	Where are they and how do they perform?
3	What are the main problems in terms of operation and management of such biogas plants?
4	Can AD of biodegradable waste be considered as an appropriate technology for MSW management?
5	What are the current R&D topics in the field of AD of biodegradable waste?

Methodology

The research for relevant case studies in the field of biomethanation of biodegradable waste was mainly based on three steps:

1) Internet research mainly based on the Google search engine

2) Contacting with experts, institutions and companies involved in the AD sector.

- Joining the internet forum: http://listserv.repp.org/mailman/listinfo/digestion_listserv.repp.org
- E-mail correspondence

3) Literature review

Relevant case studies found are summarized in this report.

Anaerobic Digestion of Biodegradable Solid Waste

Historical background

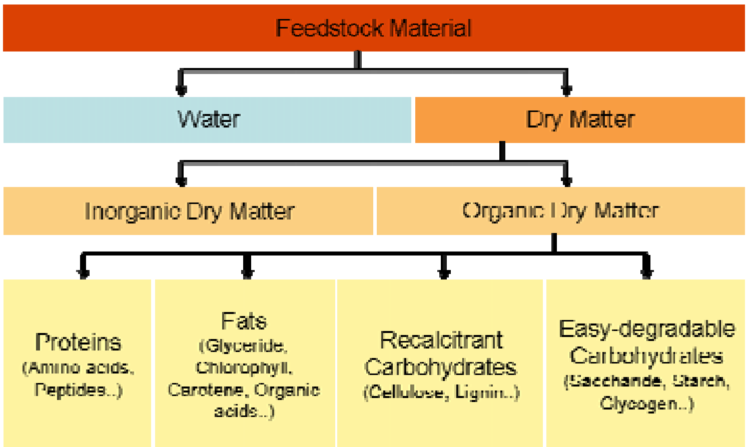
Historical evidence indicates that the AD process is one of the oldest technologies. Biogas was already used by the Assyrians during the 10th century BC and later in Persia during the 16th century.
The industrialization of AD began in 1859 with the first plant in Bombay, India. Prior to 1920, most of the AD took place in anaerobic ponds. As understanding of AD process control and its benefits improved, more sophisticated equipment and operational techniques emerged. The result was the use of closed tanks and heating and mixing equipment to optimize AD. The design then spread throughout the world. But due to low coal and petroleum prizes the AD technology was not numerously implemented. A comeback was made during World War II with a shortage of fuel hitting Europe. But after the war AD technologies got again replaced by fossil fuel applications.
The energy crisis in 1973 and again in 1979 triggered renewed interest in development of AD systems for methane production. India, China and Southeast Asia responded to the crisis with market expansion of AD. Most of the AD systems were small digesters using combined human, animal and kitchen wastes. Also, Europe, North America and the Soviet Union became involved with research in AD for methane production from animal manure.
The rush for development of AD systems to meet energy needs also led to many foreign-aid projects. Unfortunately, there knowledge regarding AD was still growing state and therefore numerous projects failed.
With time AD systems became more complex and were not limited to agriculture or animal waste treatment. Mainly in industrial countries the technology is now being applied for treatment of municipal and industrial waste. (Shefali 2002)
There are various AD technologies each of them specially designed for a certain feedstock material. Europe (mainly Germany) is seen as the leader in the field of AD. Especially for applications in the solid waste sector several sophisticated technologies are available.
Also in low- and middle-income countries, such as in China and India, efforts are being made to use the potential of biodegradable waste. Energy production and reduction of methane emissions, both results of AD, are willingly achieved by municipal authorities. The political intention of producing renewable energy resulted in the development of various AD technologies more or less appropriate for the practical applications.
In order to meet the demand for solid waste treatment options also high-tech technologies were implemented, but mostly failed as being oversized or not being adopted to local conditions.
The long-term experience in AD for human and animal waste helped developing AD technologies suitable for digestion of biodegradable waste. Nevertheless AD technology for biodegradable waste seems to cause more problems in terms of technical aspects. Until now, also economic and social aspects have been avoiding the widespread distribution of such digesters (also known from composting process). In the following some of these hurdles shall be discussed.

Technical aspects

In terms of process engineering various aspects have to be taken into account. In the following a few of them shall be listed:

The biological stability: The production of volatile fatty acids (VFA) by hydrolysis-acidification should be in balance with the consumption of VFA by methanogenesis. Methanogenic bacteria are very sensitive and their activity is drastically reduced by the presence of VFA. If the VFA production is higher that the methanogenic rate, VFA will accumulate and the reactor system will fail. If the methanogenic rate is higher, the system is stable but performs under its optimal level. (Veeken A. 2005)

In respect to the applicability of a feedstock material it is important to know that only the organic dry matter content of the feedstock material contributes to biogas production (see picture 1).



Picture 1: Classification of feedstock material (adopted from (Eder B. and Schulz H. 2006))

The organic dry matter can be divided into proteins, fats and carbohydrates (recalcitrant and easy degradable) that all have different degradation characteristics.

- Fats are degraded to Glyceride and organic acids. Too much fat in the feedstock material leads to accumulation of organic acids. This again leads to the decrease of pH. Thus, acetic acid, as well as methane production is inhibited.
- Carbohydrates are degraded to various compounds, such as mono-saccharides or acidic acids. Amount and fraction of the corresponding compound depends on the composition of the initial feedstock material. Feedstock material being rich in starch and saccharide is quickly converted into acids by acidic bacteria. The pH level turns to be below 7, towards to acidic range. This again leads to conditions that favor the growth acidic bacteria. The result is that the feedstock is even quicker converted into acids. The digester is likely to be turned into the irreversible state of acidification. (Eder B. and Schulz H. 2006)
- Proteins (such as fats and carbohydrates) also contain carbon, hydrogen and oxygen. In addition they consist of nitrogen, sulfur (and phosphorus) that are responsible for the production of ammonium (NH_3) and hydrogen sulfide (H_2S), respectively (Eder B. and Schulz H. 2006).

Dung is already partly digested material. The organic load of dung is therefore lower compared to easy-degradable solid waste. Thus, the feeding with biodegradable waste tends to result in a lower biological stability compared to the usage of human or animal feces.

Biogas yield: In contrast to the biological stability the use of biodegradable organic waste is advantageous in terms of the biogas yield. A comparison of biogas yields per ton of feedstock material between cow manure and kitchen waste reveals that kitchen waste potentially generates several times more biogas than cow manure (http://www.ines-energy.ch/pdf_dokus/biogasertrag.pdf).

Biogas quality: Biogas can be used for various applications, such as for cooking, lighting, electricity production etc. The required gas quality depends on the corresponding application. Dewatering of biogas is recommended for all applications, whereas desulfurization is mainly done before usage in an engine. Hydrogen sulfide is a very aggressive gas responsible for fast corrosion. Biogas used for electricity production in a block heat and power plant has therefore to be treated by desulfurization. Independently from biogas application the gas storage is preferable protected against corrosion.

The mixing and transport of the reactor content: Intensive mixing reduces mass transport limitations and improves the processing rate of reactor system. For a well operating system, mixing has to be provided by mechanical stirring, gas circulation or displacement under gravity (Veeken A. 2005).
Biomass particles generally have a lower density than the digester liquid or aquire it as soon as biogas bubbles adhere to them. As a result they float throughout their stay in a reactor. When not continuously stirred, powdered or pulverized, biomass feedstock always segregated into distinct liquid and solid phases (floating) in typical fermenters, leading to incomplete or cessation of fermentation.

Temperature variation: Each bacteria culture has its degradation optimum in a certain temperature range. Beyond or below this range their degradation efficiency decreases. In order to get bacteria adopted temperature fluctuation should be avoided. Bacteria working under thermophilic condition are even more sensitive to temperature fluctuations than mesophlic bacteria.

Variability of feedstock: Basically bacteria prefer stable living conditions (see temperature or process stability) in order to be efficient in the conversion of biomass into biogas. Variability in feedstock does not allow bacteria to get adopted. This means no specialization of a few bacteria cultures is taking place leading to a process performance under the optimal level.

Economic aspects

The assessment of economics of AD of biodegradable waste has not been part of this study. Nevertheless a few points in this context shall be mentioned.
Basically AD of biodegradable waste can be seen as one option to treat the organic fraction of MSW. Waste treatment is a service mainly provided by municipal or private institutions. Independent of whose service provision it is the responsible institution is seeking for the cheapest option to treat or dispose the MSW. Regardless of socio-economic aspects and external costs the use of open dumps is still the cheapest way of disposing waste.
In contrast if socio-economics and externalities are considered composting, as well as AD become economically more interesting. Some of the benefits shall be mentioned. The benefits 2), 3), 4), 5), 6) do also apply to composting.

1) Replacement of fossil fuel: The production of biogas out of biodegradable solid waste can be used for cooking and light applications (low-tech) or for the production of electricity and heat (high-tech block power and heat plant). Biogas also replaces LPG or other energy sources. Thus, the use of locally available energy resources is, at least on the long-run, more economically compared to imported fuel.

2) CDM funding: AD of biodegradable solid waste reduces greenhouse gas emissions. Therefore such kind of projects can be classified as CDM projects. CDM projects get financially supported as part of the carbon trading system. More information can be found on: http://cdm.unfccc.int/index.html.

3) Production of nutrient rich fertilizer: Organic waste can be seen as a valuable resource of nutrients. Degraded organic material can be applied as a fertilizer for agricultural purposes. AD even improves the fertilizer quality by killing germs and making the nutrients more plant accessible. If there is a market for such kind of fertilizer revenues can be generated.

4) Employment generation: Operation and management of anaerobic digesters require man power. Especially low-tech plants that are not completely automated have to be fed, emptied and supervised. Depending on the activities required skilled and unskilled, but trained labor is needed.

5) Extension of landfill lifespan: The reuse of organic material leads to a MSW reduction. Based on this reduction less waste needs to be disposed of. Space can be saved and the landfill lifespan can be extended. The construction of a new site could therefore be postponed.

6) Reduction of external costs: Organic waste potentially causes environmental burdens. Anaerobic degradation leads to the production of methane that is a greenhouse gas 21 times more effective than CO_2. Produced within an unsanitary landfill body organic acids get washed out and pollute ground water aquifers. Impact of air and water pollution is hardly quantified in monetary terms. Anyway, AD of organic solid waste reduces the external costs significantly.

Social aspects

In terms of social acceptance anaerobic digestion generally has a good reputation. This is due to the successful application in many sectors all over the world. In developing countries AD is predominantly applied in rural areas (slurry based dung digesters), where biogas has several benefits:

- Biogas is a renewable energy source that can also be produced on household level.
- Biogas reduces deforestation in many rural areas by replacing fire wood (at least partly).
- Biogas improves living conditions for rural poor, mainly for women responsible for cooking and fire wood collection. Biogas generates less air pollution by the combustion instead of wood or animal dung. By the usage of biogas less fire wood needs to be collected, hence time is saved.
- Digested material is a nutrient rich fertilizer and willingly applied by farmers.

In the context of MSW management the implementation and operation of a digester plant on institutional or municipal level becomes more complex compared to a household level dung digester. In order to make a proper feedstock quality available segregation or separation of MSW is a prerequisite. The system of interest is not only the digester plant itself, but also the whole MSW management including collection, transport and disposal or reuse of residues.

It is important to raise awareness in this context, to make people considering biodegradable waste as a resource of nutrients (composting & digestion) and energy (digestion).
According to the situation in India where a renewable energy program has been initiated in the recent past, the introduction of anaerobic digestion into urban areas seems to be welcome. The failures of various projects are more due to technical problems, inadequate planning or inappropriate management.

Recent failures of projects in the field of AD are comparable with them in the field of composting. Thus more information can be found in literature that refers to composting in developing countries.

Assessment of Anaerobic Digesters for Biodegradable Solid Waste in Developing Countries

Situation in India

In the recent decade, as a result of Ministry of Non-Conventional Energy Sources (MNES) programs, there has been much interest in generating power through biomethanation of municipal solid waste. Various institutions and NGO's have been involved in the development of technologies. The development was more focused on low-tech digesters applicable for local conditions in India.
In the context of MSW mainly cities are increasingly accepting the role of non-government and community-based organizations in urban waste management. Some cities are experimenting with community contracting to complement service provision by urban local bodies (Kirti 2001).
Besides low-tech digesters also large biogas plants have been implemented in many places. There are several cases where the operation of such kind of biogas plants failed. Also projects conducted on low-tech level have not been successful on a wide range.

The situation in India reveals that most of the biogas reactors are not working, although internationally in technical literature Indian climatic condition are considered to be favorable. But there are several other issues besides climate. In the last few years many projects failed only due to their tremendous size. There was a plant based on the advanced BIMA technology (Lucknow) having a capacity of 300 MT per day that stopped within 6 month of commissioning. Likewise a plant in Chennai has been closed as well. In Europe typically 30 to 50 Mt/day is an average capacity in context with MSW.
Another problem when implementing biogas plants is the mindset of the people expecting energy generation from so-called "low cost systems". They underestimate the robustness of biogas plants required for sustaining operation over 5 to 10 years (Asit Nema, General Secretary Foundation for Greentech Environmental Systems, e-mail correspondence).

Based on this research the following types of low-tech anaerobic digesters (AD) are implemented in India, at least on a pilot scale level. The list does not claim completeness:

- TEAM digester (developed by Energy and Resource Institute (TERI))
- ASTRA digester (Centre for Sustainable Technologies): this type of biogas plants are built by TIDE (Technology Informatics Design Endeavour)
- ARTI digester (Appropriate Rural Technology Institute)
- SPRERI digester (Sardar Patel Renewable Energy Research Institute)
- BARC digester (Bhabha Atomic Research Institute)
- Mailhem Engineering PVT Ldt.: They are planning and building AD plants, also for treatment of organic solid waste
- BIOTECH

In the following these types of AD technologies will be presented more in detail.

The Energy and Resources Institute (TERI), New Delhi

TERI was formally established in 1974. The Institute is working in various fields such as research, training and demonstration projects leading to development of specific problem-based advanced technologies.

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Web: www.teriin.org

TEAM digester

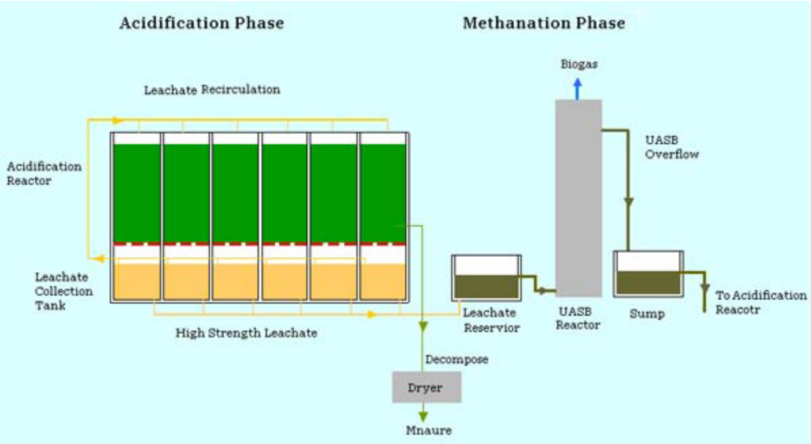
TERI began to work on the development of a high-rate digester for biomethanation of fibrous and semi-solid organic wastes in 1996. TEAM (TERI Enhanced Acidification and Methanation) process, for which a patent has been filed, is the result of these efforts. A waste treatment plant with a capacity of about 50kg green leafy vegetables per day was installed at TERI's Gual Pahari campus, Gurgaon. The plant has been generating good quality biogas and manure from the organic wastes for a few years (declaration on the webpage). TEAM plant has also been installed in two more places in corporate units like NTPC India (for household waste management) and Sona steering Ldt, Haryana (for canteen waste management).



Pictures 2, 3 and 4: On the left: Team plant operational at Teri's Gual Pahari campus. In the middle: Waste is fed into the acidification module. On the right: UASB unit (Source:Webpage).

The TEAM process is a two-phase process. The first phase, regarded as the acidification phase, consists of extracting a high organic strength (chemical demand of 15'000-20'000 mg/l) liquid called leachate from the solid waste in the acidification reactor. In the second phase, known as the methanation phase, biogas is generated by treating the leachate in an upflow anaerobic sludge blanket (UASB) reactor (see also page 33).
Before the process gets started the organic solid waste is cut into small pieces and fed into the acidification reactor. The waste bed is kept submerged in water. Organic acids formed as a result of bed degradation lead to the formation of leachate. This leachate is periodically recirculated through

the bed at a predetermined fixed rate to have uniform concentration of microorganisms and nutrients through the bed and to wash off organic acids formed as a result of further bed degradation.



Picture 5: Schema of TEAM digester with six acidification reactors (acidification phase) and a UASB unit (methanation phase).

Once a high COD (chemical oxygen demand) concentration is reached, the leachate is extracted in the leachate collection tank. The acidification phase has a retention time of six days; therefore, six such reactors are provided to ensure continuous operation. Anaerobic conditions prevail inside the reactor during the whole process. The phase separation provides suitable environment to the microorganisms in acidification and methanation stages, thus enhancing the activity. The residue inside the acidification reactor is dried in the sun and then used as manure.

Comments

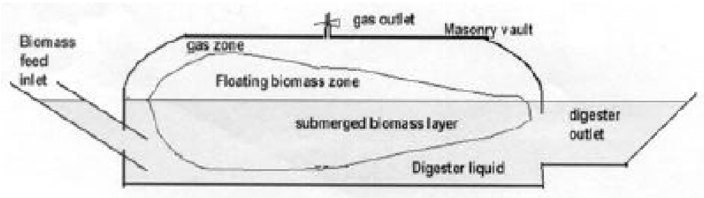
- There is a TEAM biogas plant at TERI's campus and two others have been installed in corporate units like NTPC India (for household waste management) and Sona Koyo Steering Ltd., Haryana (for canteen waste management) Further it is said that many international queries are in process (e-mail correspondence with Dinesh Chandar Pant, TERI)

- TEAM of TERI is a variant of UASB for sludge and solid waste treatment. It seems that they have not been able to go beyond the pilot/bench scale plants.

Centre for Sustainable Technologies (formerly ASTRA Centre), Bangalore

The Centre for Sustainable Technologies (formerly ASTRA Centre) has been developing two types of digestion reactors:

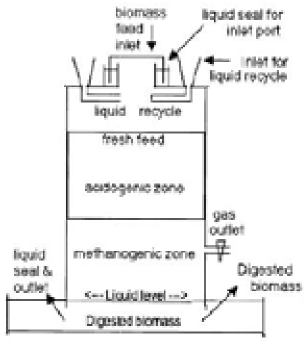
Plug flow reactor (PFR) process



Picture 6: PFR process (Chankaya H. N., Pajabapaiah P. et al. 2004)

The PFR process combines a pretreatment step along with a horizontal plug flow like digester. The primary feed stock, urban solid waste (USW) or rural solid waste is allowed to undergo a rapid initial digestion under the digester liquid where the simple to digest fractions in the USW and rural residue biomass are released quickly into the digester liquid. This kind of a pre-treatment built into the design of the reactor obviates any form of pre-processing of the feed stock, especially fibrous plant material.

Solid-state stratified bed (SSB) process



Picture 7: SSB process (Chankaya H. N., Pajabapaiah P. et al. 2004)

The SSB process is another attempt at a process to obviate the need for pre-processing rural and USW biomass components for anaerobic digestion in the small scale. This is derived from the two-step process based in the key principle that digested biomass itself can be used as an immobilized biofilm reactor. Instead of operating from two separate containers, the two stages are maintained as zones in transition from predominantly acidogenesis and methanogenesis. A small quantity of liquid is recycled daily (manually) to keep the freshly fed upper layers in acidogenetic stages and transferring VFA produced to methanogen colonized old biomass in the lower layers (Hoynell N., Chanakya H. N. et al. 2005).

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Karnataka, India
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This type of biogas plants are built by Technology Informatics Design Endeavour (TIDE) that is a registered non -profit society set up in 1993 and registered under the Societies Registration Act.

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ASTRA plug flow reactor (PFR) projects implemented by TIDE

TIDE has constructed bio-reactors for producing energy and resources from various types of organic wastes including municipal solid wastes, leaf litter, kitchen wastes and coffee pulping effluents. For the treatment of the organic fraction of the municipal solid waste it is important that well segregated waste comes in adequate quantity to the treatment site.

Eight modules in three locations have been constructed for the treatment of municipal solid waste. Kitchen waste based bioreactors have been demonstrated in a couple of places in Bangalore and forty modules of coffee bioreactors have been constructed in 15 coffee estates (see webpage TIDE).

Bioreactors for Organic Fraction of Municipal Solid Waste at Siruguppa, Bellary district, Karnataka (*Supported by Infrastructure Development Corporation Karnataka Ltd. (IDeCK)*)

The project consists of a plug flow digester that converts the organic fraction into methane and compost. The amount of biogas produced depends of the amount of waste fed into the plant, but data collected shows that 1 kg of waste gives between 50 - 60 liters of biogas. The project encounters problems in sourcing segregated waste and its delivery to the project site.

Integrated Solid Waste Management - Chikmagalur and Raichur, Karnataka

Supported by Centre for Sustainable Technologies, Indian Institute of Science, Bangalore, India

This project was initiated at the instance of Directorate of Municipal Administration, Government of Karnataka and the Indo Norwegian Environment Program to demonstrate an Integrated Solid Waste Management system in compliance with the Municipal Solid Waste (Management and Handling) rules 2000 as notified by the Ministry of Environment and Forests.

TIDE was associated with the component involving conversion of the organic fraction of the municipal solid waste into energy and resources in the towns of Chikamagalur and Raichur in Karnataka.

TIDE has constructed the bioreactors and the compost yards that would each treat 1 ton of waste per day.

Picture 8: A biomass based biogas plant adapted for USW built for a small town in North Karnataka. This is a 1.5 tpd plant and the gas outlet and feed inlets are seen in the picture. This was built by TIDE with design from ASTRA and funding from IDeCK. The plant has been producing gas since March 2003.

Bio Reactor for Canteen waste at Transport House, KSRTC, Bangalore

Immobilized cell bioreactor is a high rate biomethanation plant using spent biomass as the bacterial support. Methane producing bacteria (methanogens) are trapped on partially digested leafy biomass. Biomass wastes can be fed to these biogas plants in a totally dry state (such as rice straw, bagasse, paper shreds, etc.) or in green state (garden cuttings, lawn mowings, vegetables peels and wastes having on an average 85% moisture and 15% dry matter) or in a slushy state (food wastes such as uneaten rice, plate and dish washings, fruit and vegetable rejects, etc. having 90% moisture and 10% dry matter). These feedstocks need not be powdered or mashed before feeding. On the basis of dry matter fed to the bioreactors, every kilo fed produces between 50 and 80 liters of biogas.

The typical volume of the plant set up at Transport House, KSRTC is designed to handle 25 kg of canteen rejects along with the leaf litter. About 1.5 cubic meters of biogas is produced every day. The plant is a masonry structure, which was built and commissioned in the month of February 2005. A floating dome gasholder has been provided at the top for the collection of the biogas. Pipelines have been provided to the canteen and stove connected. At present, the gas is being used to keep the cooked food warm. The gas utilization time per day is around

Picture 9: Canteen biogas reactor at KSRTC; Bangalore.

Comments

- There are large plants constructed in Siriguppa and Chikamagular that were running and operational for about 2 years and one year, respectively, when TIDE was operating the plant. After the transfer to the civil authorities a dilution of the stringent practice of segregation of waste and feeding only the biodegradable fraction to the digester was observed. Later for various reasons, not related to the performance of the plant, the practice of delivery of waste to the project was discontinued.
  The plug flow digesters that have been constructed to treat the kitchen waste in industrial establishments are in operation and working satisfactorily (e-mail correspondence with Mrs. Svati Bhogle, TIDE, 20.4.2007).

Literature

Summary of the performance characteristics of various types of biomass based biogas plants that have been developed, pilot or field tested (Chanakya H. N. and M. R., year unknown (after 2004)).

Paper on ASTRA technology (Chankaya H. N., Pajabapaiah P. et al. 2004)

Summary of the performance and limitations of various types of biogas plants in India (Hoynell N., Chanakya H. N. et al. 2005)

Appropriate Rural Technology Institute (ARTI), Pune

Appropriate Rural Technology Institute (ARTI) is an NGO based in Maharashtra, founded by a group of scientists and social workers in 1996. The mission of the organisation is to serve as an instrument of sustainable rural development through the application of scientific and technological knowledge.

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ARTI has developed a compact biogas plant which uses waste food rather than dung/manure as feedstock, to supply biogas for cooking. The plant is sufficiently compact to be used by urban households, and about 2500 are currently in use – both in urban and rural households in Maharashtra. A few have been installed in other parts of India and even elsewhere in the world. The design and development of this simple, yet powerful technology for the people, has won the *Ashden Award for Sustainable Energy 2006* in the Food Security category (http://www.ashdenawards.org/winners/arti06). This makes ARTI the only organization in the world to win the prestigious Ashden Award twice. ARTI won its first Ashden Award in 2002 for its chain of technologies for converting agricultural waste into charcoal, and using this as a clean domestic fuel.

ARTI Compact Biogas Plant

The compact plants are made from cut-down high-density polythene (HDPE) water tanks, which are adapted using a heat gun and standard HDPE piping. The standard plant uses two tanks, with volumes of typically 0.75 m^3 and 1 m^3. The smaller tank is the gas holder and is inverted over the larger one which holds the mixture of decomposing feedstock and water (slurry).

An inlet is provided for adding feedstock, and an overflow for removing the digested residue. This contains a much smaller amount of solid matter than the residue from a manure-based plant, and ARTI recommend that the liquid is mixed with the feedstock and recycled into the plant.

A pipe takes the biogas to the kitchen, where it is used with a biogas stove. Such stoves are widely available in India which has a long tradition of using manure-based biogas plants.

The gas holder gradually rises as gas is produced, and sinks down again as the gas is used for cooking. Weights can be placed on the top of the gas holder to increase the gas pressure. (Karve A.D., year unknown (after 2004))

Picture 10: Construction of an ARTI compact biogas plant.

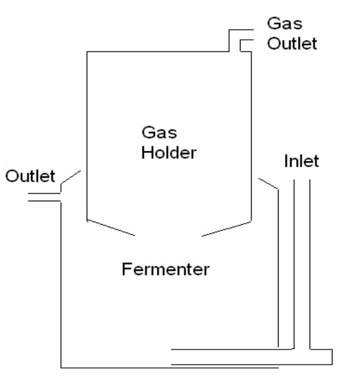
Picture 11: ARTI biogas plant for treatment of kitchen waste at household level.

Installation

The plant is provided as a kit that takes only 2 to 3 hours to install. It needs a space about 2 m^2 and 2.5 m high, although adaptations can be made if it is placed under a roof.

Starting the plant

The plant is filled with a starter mix, either cattle dung mixed with water and waste flour or else effluent from an existing biogas plant mixed with starch. The feeding of the plant is built up over a few weeks until it provides a steady supply of gas, typically 250 g of gas per day from 1 kg (dry matter) of feed.



Picture 12: Schematic description of the small ARTI compact biogas plant. (Source: ARTI webpage)

Feedstock material

The feed can be waste flour, vegetable residues, waste food, fruit peelings and rotten fruit. Feedstock with large lumps (more than 20 mm) can be broken up with a food blender. Hand and pedal powered food blenders are being developed, for when electricity is not available. Oil cake, left over from oil-pressing, is another useful feedstock. Even rhizomes of banana, canna, nutgrass, non-edible seeds (e.g. Leucaena, Sesbania, tamarind, mango kernels) and spoilt grain serve as excellent feedstock material.

Precaution

A biogas plant can become acidic and fail if it is over-fed, and this is a particular challenge with a plant using highly digestible organic materials. If this happens, the plant can be recovered by ceasing feeding and then building up the feed rate slowly. This problem was more common with the early smaller systems (0.5 or 0.75 m^3) than with the later, larger systems.

Cost & Payment

Samuchit Enviro-Tech (SET) Pvt. Ltd., a company set up by members of ARTI, is in charge of commercialising the ARTI compact biogas system. ARTI's trained technicians install the biogas plants using locally available plastic tanks (commonly used for water storage) and a plumbing kit supplied by SET. SET also supplies a single burned biogas stove made of cast iron, and a gas cock. This set, consisting of the plumbing kit and a single burner biogas stove, costs Rs. 2350 (M.R.P. inclusive of taxes and transport anywhere in India). The total estimated cost of the compact biogas system for a typical household (around 1000-1500 lit capacity) is about Rs.10'000, but the actual cost may vary based on local prices of plastic tanks and local labour costs.

Table 2: Comparison with conventional biogas plant

	Conventional Biogas System	**ARTI Biogas System**
Amount of feedstock	40 kg + 40 lit water	1-1.5 kg + 15 lit water
feedstock material	Dung	Any starchy material
Amount and nature of slurry to be disposed of	80 lit, sludge	15 lit, watery
Reaction time for full utilization of feedstock	40 days	48 - 72 hours
Standard size for household	4000 lit	1000 - 1500 lit
Capital Investment per unit including stove	Rs 20'000	Rs 10000
Running expenses per meal	Rs 25	Rs 0 - 5

Source: Webpage ARTI

Comments

- There has been quite a lot of discussion about the ARTI Compact biogas system on the Biomass Cooking Stoves Discussion list. You can see the stories at: http://www.bioenergylists.org/en/taxonomy/term/278 (Google "Search Discussion Archive" for "ARTI biogas" to see all the discussion, e-mail correspondence with Tom Miles, www.bioenergylists.org)

Literature

Description of ARTI's small scale compact biogas technology that used for household application (Karve A. D. unknown (after 2004)).

Presentation of ARTI technology that won the Ashden Award in 2006:
http://www.ashdenawards.org/winners/arti06

Sardar Patel Renewable Energy Research Institute (SPRERI)

SPRERI was established in 1979 as a result of the initiation taken by a group of foresighted persons led by Late Dr. H.M. Patel and Late Shri Nanubhai Amin. The objectives of SPRERI are to develop technologies and provide services to promote the use and application of renewable energy.

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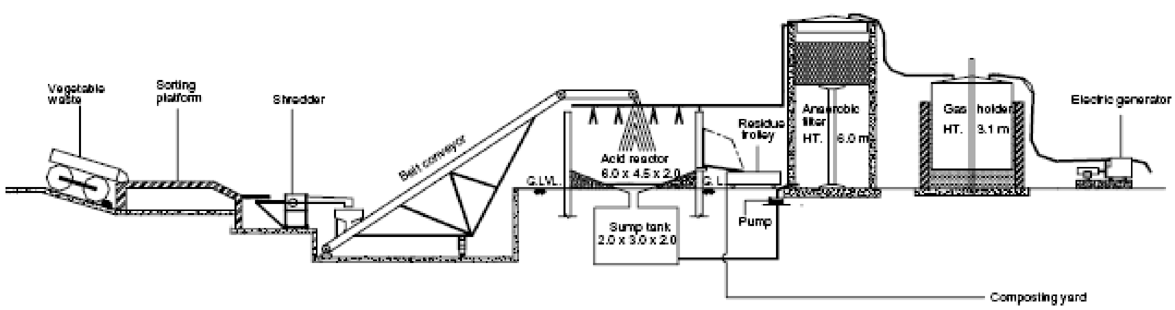
Functionality

The functionality of the SPRERI plant is described based on the case study in Anand (see picture 13), where vegetable market waste is converted into biogas and compost. The treatment process is divided into several treatment steps. First the delivered waste gets manually sorted on a platform. After being sorted the waste is shreddered and with the means of a belt conveyer fed into a so-called acid reactor. Within the acid reactor the waste gets percolated in order to dissolve organics that are flushed away into a sump tank. After a while (retention time is not known) the residual waste is disposed of into a residue trolley that serves as transport vehicle to the composting yard.

Further the liquid, organic rich percolate in the sump tank is pumped into a gastight anaerobic filter where the degradation of organics is taking place. Biogas is produced, stored at the top and then pressed into the close-by gas holder. From there the biogas can be used as energy resource for various purposes, such as for cooking or electricity production.



Picture 13: Schematic description of the SPRERi biogas plant in Anand (Source: SPRERI).

Case studies

Picture 14: SPRERI biogas plant in Anand, India converting vegetable market waste into biogas and compost. Plant commissioning was in 2004, but until now the plant is operating under its design capacity (Source: SPRERI).

Comments

- SPRERI has installed a 3 t/d biphasic plant to convert the vegetable market waste of Anand town into biogas and compost. The plant became functional in the year 2004. SPRERI operated the plant for the Anand Municipality for one year at below its design capacity because the vegetable market waste received daily at the plant site was only 1-2 t/d. Also, the waste was not segregated at the source and SPRERI had to employ additional manpower to remove non-degradable and other unwanted materials. In place of about 75 m^3 of biogas expected from this plant operating at its full capacity, only 30 m^3 of biogas/day were generated. The biogas was used to operate a 5 kW generating set to provide power for plant operation and lights at the site. Two years back, the plant has been taken over by the Municipality. Since then the plant has not been operating on regular basis, mainly because of management problems including assured supply of vegetable market waste. SPRERI is still negotiating with the Municipality officials to improve the plant management and to operate the plant as its designed capacity.

  While operating the plant, SPRERI had no difficulty to convert the semi decomposed solid residue of the acid reactors into good quality compost in 4-5 weeks.

  Although the plant for Anand vegetable market waste is not working regularly, one private industry engaged in processing of fruits and vegetables and a larger Municipal Corporation have decided to install larger capacity plants (10 t/d vegetable and market waste each). SPRERI is providing technical support to these two organizations and hope that in one year these plants will become functional (e-mail correspondence with B S Pathak, Director SPRERI, 23.4.2007).

Bhabha Atomic Research Centre (BARC), Mumbai

Bhabha Atomic Research Centre (BARC) provides a broad spectrum of scientific and technological activities extending from basic laboratory bench scale research to scaled up plant level operations. Its functional domain covers all walks of science and technology – stretching from classical school of thoughts to the emerging novel fields of interest. The core mandate of this institution is to provide Research and Development support required to sustain one of the major peaceful applications of nuclear energy viz. power generation (see webpage).

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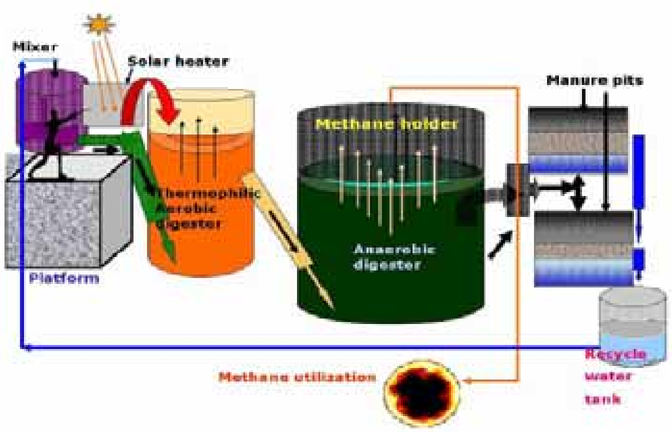
Functionality

The system is based on a floating dome design, a proven technology for manure digestion in India and China. It is a two stage continuous wet system. The waste gets hydrolyzed in a first stage and in a second stage methane is produced. The reactor is constructed underground, reducing the building costs, and the reactor contents flow under gravity by volume displacement. Every time the digester is fed the equal amount for reactor content will leave the digester.

The biogas plant runs on kitchen waste that is pretreated (mixed with hot water that is heated up by solar heating and pulped) and discontinuously fed (Batch-System) to the thermophilic aerobic pre-digester. The effluent from the pre-digester is fed to the methane reactor where biogas is produced. The effluent from the methane reactor is collected in open pits that are provided with sand filters. When the pit is filled up, the manure is taken out and spread under shade for drying. The excess water filters out in an underground tank and is reused in the system. (Veeken A. 2005)



Picture 15: Schematic description of the Nisargruna biogas plant. The plant operates in two-phases with a thermophilic and a mesophilic digester (Source[1]).

[1] http://www.no-burn.org/wna07/wna2007.presentations/WNA07.Wastepickers.SMS.pdf

Table 3: Parameters of BARC technology based on the Govandi digester plant

Parameter	Govandi digester plant
Amount of feedstock	5000 kg/day
feedstock material	Kitchen waste
Total solids content of waste	20 - 25%
Reactor volume	60 m3 (pre-digester) + 175 m3 (methane reactor)
Residence time	4 days (pre-digester) + 12 days (methane reactor)
Amount of biogas (or methane)	500 - 650 m3 / day
Area required	600 - 700 m2
Application type of biogas	Electricity
Revenues(cost savings) biogas	25 kW
Application type of compost	in garden
Revenues(cost savings) compost	-
Employed staff	5
Capital Investment	65'000 $
Running expenses per meal	400 $/month

Source: (Veeken A. 2005)

Case studies

BARC's NISARG-RUNA plant for solid waste management enables the treatment of organic solid waste. Several such plants have been installed in India (see table X) for disposal of the waste generated in kitchens of various canteens in the premises. NISARG-RUNA plant can process almost any biodegradable waste including kitchen waste, paper, grass, gobar (indian expression for cow dung), dry leaves etc.

Picture 16: Biogas Plant at Trombay. The plant produces biogas from kitchen waste by using thermophilic microorganisms that flourish in extreme environment. The biogas plant has following components: A mixer/pulper (5 HP motor) for crushing the solid waste, Premix tanks, Predigester tank, Solar heater for water heating, Main digestion tank (35 m^3), Manure pits, Gas lamps for utilisation of the biogas generated in the plant (Source[2]).

[2] http://www.dae.gov.in/ni/ninov02/biogas.htm

Table 4: Existing BARC biogas plants in India

Existing Biogas plants			
Location	Capacity	Date of commissioning	Utility of Gas
BARC, Mumbai	1 tpd	June 2001	Kitchen
Anushaktinagar, Mumbai	5 tpd	June 2002	Kitchen
BARC Hosptial site	5 tpd	June 2003	Kitchen
Govandi, Mumbai	5 tpd	June 2003	Electricity
Deonar, Mumbai	5 tpd	February 2005	Boiler
INS Kunjali	1 tpd	June 2004	Kitchen
Ohter Biogas plants			
Matheran, Maharashtra	5 tpd	December 2005	Kitchen
Malvan, Maharashtra	5 tpd	December 2005	Electricity
Hiranandani, Thane	5 tpd	October 2005	?
INS Chilka	2 tpd	December 2005	Kitchen

Source: (Kale S. P. 2005)

Comments

- Asit Nema visited a BARC plant and has done a complete analysis of the technical system and the institutional model BARC has adopted. As per his understanding this technology represents state-of-the-art under the developing country context. It is affordable, odour free and compact. The technology can be tailored for higher degree of sophistication and reliability (e-mail correspondence with Asit Nema, General Secretary Foundation for Greentech Environmental Systems)

- According to a study on the BARC technology done by the University of Wageningen (Veeken A. 2005) two BARC digesters were assessed. The study revealed that both of these digesters were operating successfully. Key factors are besides the proven technology, proper operational management of the digester. Biodegradable waste is inspected and impurities are removed. Also operation and maintenance of the biogas plant are sound, adequate and trained personnel are present and the premises are clean.
  BARC system is a reliable technology but already advanced in terms of the used equipment and the complexity of the system; pulping, solar heating device, pre-digester, methane reactor, sand filters, recycling of effluent water. The biogas production rate and stability of two-stage system are good but it can be questioned if this semi-advanced technology is necessary in a developing country. It is questionable if higher investment and operational cost can be compensated by higher biogas production. Dry and fibrous market wastes are difficult to handle in this type of digestion systems as the solids will settle in the reactors and clogging of the system will occur sooner or later.

Literature / studies

A study in Kotte MC, Sri Lanka (Veeken A. 2005) assessed the overall performances of a BARC digester fed with domestic and market biodegradable waste.

Dr. S. P. Kale has developed the Nisargruna Biogas plant for solid waste management. In a the IANCAS Bulletin he is extensively presenting the innovative technology (Kale S. P. 2005), (Kale S. P. 2005).

Paper briefly summarizing the idea and functionality of BARC's Nisargruna Plant (Mehetre S. T. and Kale S. P., year unknown (after 2002))

BIOTECH, Trivandrum

BIOTECH is a nodal agency of the Ministry of Non-Conventional Energy Sources[3]. BIOTECH is engaged in the production of biogas from MSW, household waste etc. BIOTECH has been installing biogas plants that generate biogas from domestic biodegradable waste like cooked food waste, vegetable waste and waste water from kitchen. In a 3 to 5 member family 1 cubic meter plant is sufficient to treat domestic waste. It generates biogas to meet 50% cooking needs.
Generation of power from MSW / market / slaughter house waste is another area of specialization of BIOTECH. Under this category 9 (or more) plants are already completed in Kerala. The electricity generated from these plants is utilized for street lightning and to meet in house requirements (comments by Saji Das in the earthscan forum, 23.2.2006).

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Earthscan Forum: http://www.earthscan.co.uk/forum/forum.asp?sp=&v=7

Case studies

In order to have a real impact on the waste problem in Kerala and produce significant amounts of clean energy, BIOTECH has developed biogas digesters that are not only suitable for domestic use but also for schools, hostels and larger municipal sites. To date BIOTECH has built and installed 12'000 domestic, 220 institutional and 17 municipal plants ([4])

Picture 17: A BIOTECH Waste to Energy project in Trivandrum, India.


Picture 18: A BIOTECH plant gets fed with organic waste.

[3] http://drawat123.tigblog.org/post/50505?setlangcookie=true
[4] http://www.ashdenawards.org/media_summary07_biotech

Picture 19: A BIOTECH plant treating organic solid waste on an institutional level.

Picture 20: BIOTECH plant treating organic solid waste on a domestic level.

Comments

- A. Saji Das provided some preliminary information and pictures about BIOTECH. He states that BIOTECH is selected as a finalist for the international Ashden Award for Sustainable Energy (http://www.ashdenawards.org/). (E-mail correspondence with A. Saji Das, 31.5.2007)

Literature

Website presenting the finalist of the Ashden Award 2007: BIOTECH:
http://www.ashdenawards.org/media_summary07_biotech (technical report)

Newspaper article about BIOTECH: http://www.hindu.com/2007/05/30/stories/2007053008250400.htm

Mailhem Engineering Pvt. Ltd. / GIT Associates, Pune

GIT Associates is a proprietary consulting engineering company dealing in the field of consultation of turnkey design and installation of process plants. The present thrust area is design and installation of anaerobic treatment systems of various industrial and agricultural organic wastes.

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Mailhem Engineers Pvt. Ltd. has been floated in June 1995 to undertake assignments on turnkey basis and also to manufacture and supply proprietors items for various consultancy assignments (see webpage GIT). Mailhem Engineering Pvt. Ltd. is a company providing services in the field of solid and liquid waste treatment.

Mailhem Engineering Ltd. seems to be one of the leading companies in India in the field of anaerobic digestion of solid and liquid waste. Facilities recommended by Mailhem regarding anaerobic digestion of solid waste are mainly based on UASB reactors (see picture 21).
According to an actual report from the New Delhi Waste Processing Company Private Limited (Limited 2006) Mailhem got approached to propose a design option for a large UASB digester (plant capacity around 100 MT vegetable market waste /day) for a integrated MSW treatment project in Delhi.
Mailhem Engineering's sister consultancy concern GIT Associates (see above) are empanelled as consultants by Ministry of Non-Conventional Energy sources for GEF/UNDP projects.

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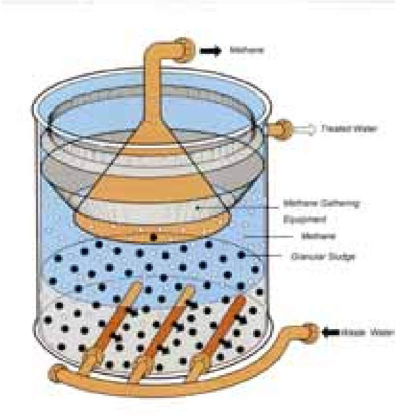
Technology description

Mailhem Engineering Pvt. Ltd. developed various types of digesters based on the UASB design and being fitted to the individual feedstock material (see webpage Mailhem):

- Modular design for upflow anaerobic sludge blanket (UASB) digester based on high rate biomethanation technique.
- Three stage UASB design for concentrated liquid waste like distillery, sugar, dairy waste water
- Two stage modified UASB design to tackle the problem of high percentage of suspended solids like slaughter house waste water, steep liquor, sorbitol and starch washings.
- Factory assembled two stage package plants to treat solid waste such as kitchen, canteen, poultry, food processing and agricultural wastes.
- Unique combined wet garbage and sewage treatment plants for hostels, housing complexes, and hospitals in lieu of Septic tanks



Picture 21: Schematic description of a upflow anaerobic sludge blanket (UASB) digester ([5]).

Case studies

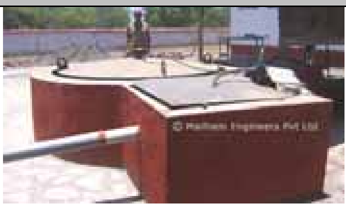
Table 5: Case studies of biogas plants installed by Mailhem Engineering PVT Ltd.

Picture	Location	Reactor type	Type of feeding	Remarks
	**Kandivali Plant at Mahindra & Mahindra in Mumbai**	UASB	canteen and kitchen waste	Set up: October 1998 Energy is used for heating milk and water in the canteen
	**Biogas Plant at Mahindra & Mahindra Nashik**	UASB	canteen and kitchen waste 800 kg per day	Set up: February 2000 heating milk and rice in the canteen
	**Maharashtra Scooters-Satara Plant Satara**	UASB	canteen and kitchen waste 300 kg per day	

[5] www.apec-vc.or.jp

Picture	Location	Reactor type	Type of feeding	Remarks
	**Hindustan Aeronautics Ldt. Bangalore**	UASB	Kitchen waste from township 3 tons per day	Set up: December 2004

Picture	Location	Reactor type	Type of feeding	Remarks
	**Baja Auto Ldt. Pune**	UASB	Canteen waste 500 kg per day	Set up: March 1999

Picture	Location	Reactor type	Type of feeding	Remarks
	**Sainik School Satara Satara**	?	Kitchen waste 100 kg per day	Set up: November 2002 Biogas is used for cooking

Picture	Location	Reactor type	Type of feeding	Remarks
	**Vijaywada Municipal Corporation Vijaywada**	?	Vegetables and slaughter house waste	Set up: January 2004 This project (demonstration plant) was funded by MNES under UNDP / GEF assisted program

Comments

- GIT Associates (Mailhem Engineering's sister consultancy) has the experience in installing one plant for 20 MT MSW with biogas recovery and power generation. There are also smaller installations varying from 100 kg/day to 2 MT per day. In most of the cases the biogas is used for cooking applications (e-mail correspondence with Vishaw Gokhale).

Literature / Studies

Report summarizing projects proposals regarding a large integrated MSW processing facility also containing a UASB plant that is recommended and designed by Mailhem Engineering Ltd. (Limited 2006).

Renewable Energy Centre Mithradham / BME BiomasseEnergie GmbH

Renewable Energy Centre Mithradham is a solar educational institution in India. It is a pilot NGO initiative in India for propagation of renewable energy (see Webpage: www.mithradham.org). In co-operation with the United National Industrial Development Organization (UNIDO (www.unido.org)) and the German BME BiomasseEnergie GmbH a biogas plant was installed in Kavaratti. The plant converts mainly residues from fish processing and small amounts of kitchen waste into biogas.

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Functionality

The biogas plant in Kavaratti is a two-stage biogas system. It consists of an acidification reactor and a methane reactor. After the acidification the dissolved organic matter is separated from the solids and fed into the methane reactor. Within the methane reactor the dissolved organic matter (fatty acids) is converted into biogas. Stirring devices are not necessary for a proper degradation of organics. The plant works under mesophilic condition in the range of around 37°C. The temperature level is kept constant by means of a solar panel.

As feedstock material residues from fish processing and small amounts of kitchen waste is used.

The degraded liquid phase is not post-processed. It is directly used for gardening or coconut plant applications.

The produced biogas is treated before fed into the engine. Desulfurization and dewatering is done in order to reach an appropriate gas quality.

Table 6: Parameter of Kavaratti biogas plant

Parameter	Kavaratti digester plant
Amount of feedstock	150 kg/day
feedstock material	Residues from fish processing and kitchen waste
Total solids content of waste	30%
Reactor volume	8 m3 (hydrolysis) + 25 m3 (methane reactor)
Residence time	10 days
Application type of biogas	Electricity
Revenues(cost savings) biogas	7.5 kW (current generator)
Application type of compost	in garden / coco nut plantation

Source: Ch.M/Sandec

Pictures 22 and 23: Biogas plant in Kavaratti, India treating residues from fish processing and small amounts of kitchen waste

Situation in Sri Lanka

Work on biogas in Sri Lanka dates back more to the 1970's, when the Department of Agriculture started to introduce 3000 small scale biogas plants of the Chinese type (Giudotti G. 2002). Many governmental and non-governmental organizations have been active in this area at various periods of time. Many of these initiatives lacked sustainability as they were implemented in isolation. ITDG South Asia (www.itdg.org) started its project on developing and popularizing biogas technology in 1996 by carrying out a sample survey to find out the status of biogas technology in Sri Lanka and to learn lessons from the past experiences. This phase was followed by a series of new activities aimed at widespread popularization of the AD technology.
Nowadays the most biogas types are built based on the Chinese type, only few are Indian types. A survey id provided by a study conducted in Kotte (Veeken A. 2005). Another technology was the NERD Dry Batch Digester that has been increasingly introduced (Premachandra H.S. 2006).

National Engineering Research Development Centre (NERD)

National Engineering Research Development Centre (NERD) is a pioneer research organisation in Sri Lanka that is responsible for the development of the Sri Lankan Dry Batch Biogas unit (more information under: http://www.kulasinghe.com/main.htm).

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The NERD Batch Dry Digester enables the treatment of straw, market garbage and water borne plants such as Salvinia, Water Hyacinth as their main digestive material. In respects to this digester NERD won the Silver Award in 1996 at the International Inventors Competition in Switzerland.
Nevertheless a study conducted in Kotte by the Wageningen University in 2005 (Veeken A. 2005) revealed that the batch dry system (NERD Dry Batch System) is not properly designed and anaerobic digestion of biodegradable waste in this reactor fails.
In the framework of this study several types of digester systems for different types of biodegradable waste have been visited. In total 7 biogas plants were visited (3 batch dry floating drum reactors, 2 continuous wet fixed dome reactors, 1 continuous dry fixed dome, 1 batch dry fixed dome). Basically it was concluded that the biogas technology is not yet successful in Kotte area due to various reasons.

- The batch dry system that is not properly designed
- Operational management of the digester systems is not adequate enough to be able to organize the supply of source separated biodegradable waste and to operate the digester system.

- And further there is a lack of an organization (Expert knowledge Centre) that has collected the necessary skills and capacity to assist in the operational management, dissemination and consolidation of digester technology in Sri Lanka.

Case Studies in Sri Lanka

Table 7: Various types of biogas plants that have been installed in Sri Lanka.

Picture	Location	Reactor type	Type of feeding	Remarks
	**Vajira Childrens Orphanage, Kotte**	Batch dry fixed dome	Market waste	The plant is **not** working. System was inoculated with cow dung but biogas production stopped after 2 months; a leak in the biogas collection system was detected.

Picture	Location	Reactor type	Type of feeding	Remarks
	**Convent, Negombo**	Batch dry floating drum	Market waste	The plant is **not** working. Not enough waste available to fill reactor; it took 1 month to fill a reactor

Picture	Location	Reactor type	Type of feeding	Remarks
no picture available	**Prison, Negombo**	Batch dry floating drum	Market waste	The plant is **not** working. No proper operation and supervision

Picture	Location	Reactor type	Type of feeding	Remarks
	**Wattala**	Batch dry floating drum	Mixed market waste	The plant is working. Problems with supply of (source separated) waste (city council cannot transport waste over city borders); also mixed waste is used

Picture	Location	Reactor type	Type of feeding	Remarks
	**Kolonnawa**	Continuous dry fixed dome	Market waste	The plant is **not** working. Operator was not able to collect and chop market waste into smaller particles in one day; biogas production stopped after 2 months of operation. Design does not work as the solid waste will not flow through the system.

Picture	Location	Reactor type	Type of feeding	Remarks
No picture available	**Convent, Negombo**	Continuous wet fixed dome	Manure and water from piggery	The plant is working. Biogas was produced but not used for cooking an a regular basis

Picture	Location	Reactor type	Type of feeding	Remarks
	**Sevanatha, Negombo**	Continuous wet fixed dome	Fish waste	The plant is working. Fish waste is mixed with water; hust started of and no effluent produced yet

Source: regrouped from (Veeken A. 2005)

Picture	Location	Reactor type	Type of feeding	Remarks
	**Manning Market, Colombo**	Semi-dry batch type anaerobic digester	Vegetable waste	

Source: Website NERD (http://www.kulasinghe.com/main.htm)

Situation in China

China may be famous for the ability to use organic wastes for biogas production. By the end of the 19th century and later China supported mass adoption of biogas mainly on household level. Thus the application of biogas technology is still primarily limited to decentralised small-scale digesters in rural areas in the South and South-West of China. The experience with large-scale projects is restricted. In the meanwhile some middle and large-scale plants were built, mainly under environmental protection aspects and biogas was a by-product. The current renewable energy legislation is more focused towards energy production out of biomass.
So far full-scale MSW/BMW biogas plants do not exist in China, but some 20 MSW-, food waste- and manure co-fermentation-AD projects are under preparation or implementation, respectively (Raninger B., Youcai Z. et al. 2007).

So-called Puxin digesters have their origin in China. The technology is based on the floating dome principle and the application of slurry based feedstock. Nowadays the Shenzhen Puxin Science & Technology Co. Ltd. seems to be successful in marketing this kind of technology also for treatment of organic solid waste.

Shenzhen Puxin Science & Technology Co. Ltd.

Shenzhen Puxin Science & Technology Co. Ltd. was founded in 2001 in Shenzhen City, China mainly by a doctor in physics who obtained his PhD in Canada and went back to China for venture. The company's business is focused on the research, development and marketing of biogas application systems. The company manufactures the related products mainly by OEM. After many years' concentration research, the company has developed a series new generation hydraulic biogas plants- Puxin Biogas Plants, and obtained a number of patents and Awards.

The products for Puxin family size biogas plant (steel mould; gasholder etc.) have been exported in batch to United States, Spain, India, Indonesia, Kenya, Nepal, East Timor, Panama, Mauritius and Ghana (see website).

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Shenzhen, P. R. China
Postal Code: 518172
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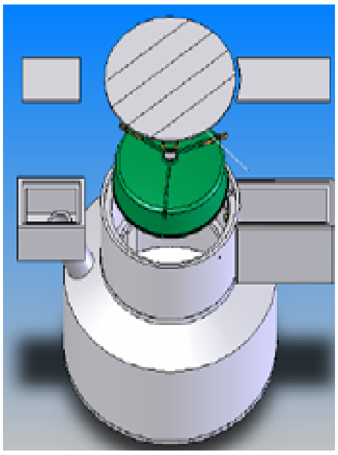
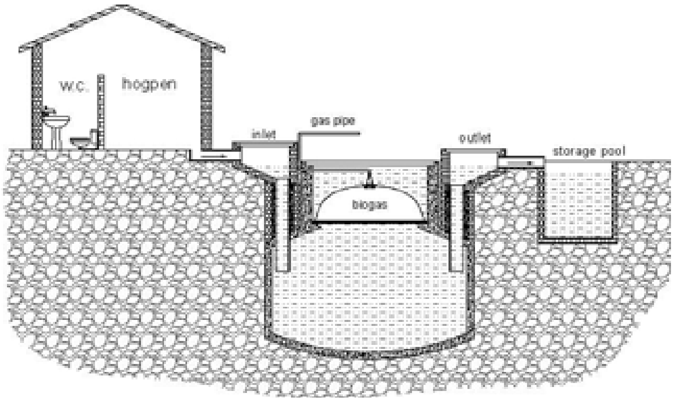
Fax: 86-755-28938252
Website: http://www.topsaving.com or other website http://biogas.diytrade.com
E-mail: topsaving@yahoo.com

Technology



Picture 24: Set-up of Puxin biogas plant. Puxin Biogas Plant is of the hydraulic pressure biogas plant type, ad it is composed of a digester built with concrete, a gasholder made with glass fiber reinforced plastic, and a digester outlet cover made with glass fiber reinforced plastic or concrete.
- Capacity: 6 to 10 m3
- Gasholder: 1.6 m diameter, 0.6 m height

The gasholder is installed within the digester neck, fixed by a component; the gasholder and the digester are sealed up with water. (Source: J. Wang)



Picture 25: Schematic description of a slurry based Puxin digester. Traditional biogas plant is mainly dung based, but Puxin biogas plant (it is said) can use any solid biodegradable material. When this plant is used as batch plant, there is a regular discharge of gas for long time (6-8 months). But these materials have to be replaced after 6-8 months.
The plant does not require daily water adding up because it is completely submerged below the water. (Source: J. Wang)

Case studies

Picture 26: Puxin Biogas Plant in Shenzhen City, China treating organic garbage and food waste (Source: website).

Case studies of various biogas suppliers in the field of MSW

Table 8: List of AD projects in the field of MSW (not based on low-technology biogas plants)

Location	Start	Feedstock	Technology Developer	Capacity million t/ a	Investment costs	Commends
Beijing Dong Cun Taihu Coun.	2007	Restaurant- & MSW, manure	Linde, Valorga, Biomax	0.2	18 Mio EURO Fee 13.5 EURO/t	Feasibility 2005, CDM
Beijing Dong Cun Taihu Coun.	till 2010	Restaurant- & MSW, ..				9 plants anticipated
Shanghai Jinshan	2008	MSW, BMW		0.22	32 Mio EURO	Public tender
Shanghai Putuo, Shanghai	2007	Municipal wet waste	Valorga, Biomax	0.18 to 0.29	30 Mio EURO Fee 17 EURO/t	Feasibility 2005, CDM PDD1/06
Guangzhou Likeng (Guandong)	2007	Municipal wet waste	Valorga, Biomax	0.36	32 Mio EURO	Preparation
Changsha Huiming (Hunan)	2005	MSW		0.73	11 Mio EURO	Biogas power plant
Mianyang (Sichuan)	2002	MSW	Tunnel Type	0.25 (AD: 3600t/a)		AD as pilot project
Yingkou (Liaoning)	2007	MSW; SS	Tsinghua Tongfang	0.27	20 Mio EURO	
Shenyang (Liaoning)	2010	BMW (source separation)	Wet AD recommended	0.12 to 0.20	12 Mio EURO Fee >6 EURO/t	Prefeasibility study

Source:(Raninger B., Youcai Z. et al. 2007)

Literature / studies

Summary of the current situation regarding biogas projects application in China, especially focused on the potential of MSW (Raninger B., Youcai Z. et al. 2007)

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Web: www.iceee.cn

Paper on the sustainability of Municipal Solid Waste Management in China: (Veeken A., Hamminga P. et al., year unknown (after 2005))

Comments

- There are different kinds of current CDM projects introduced in China. The projects are mainly related to biogas recovery from landfills or coal mines. One project is in the field of composting, but none in context with AD of OFMSW (e-mail correspondence with Liz Wang, 26.4.2007) E-mail: liz.wang@eco-energy-cities.com

- Jianan Wang stated that they have case studies of plants in the context of solid waste management in urban areas. Picture 26 shows a 60 m^3 Integrated Puxin Biogas Plant built in a living area of Shenzhen city for the treatment of organic garbage (food waste). The biogas is provided as fuel for a restaurant (e-mail correspondence with Jianan Wang, 3.5.2007)

Situation in Thailand

To strengthen energy security and sustainability, the Thai government has set 2011 as the target date for 8% of the nation's total energy, representing an estimated 1,900 MW, to be generated from renewable energy sources.

The development of alternative sources is critical to energy sustainability as Thailand relies substantially on crude oil imports. Renewable sources accounted for only 1% of electricity generated in 2004.

According to the Energy for Environment Foundation, biomass represents significant energy generating potential since it uses agricultural waste products, such as byproducts from rice, oil palm, sugar and wood processing mills which are plentiful in Thailand.

Waste water from agricultural processing industries as well as municipal waste is used by agricultural mills and municipalities, respectively, to produce biogas.

Asian Institute of Technology (AIT)

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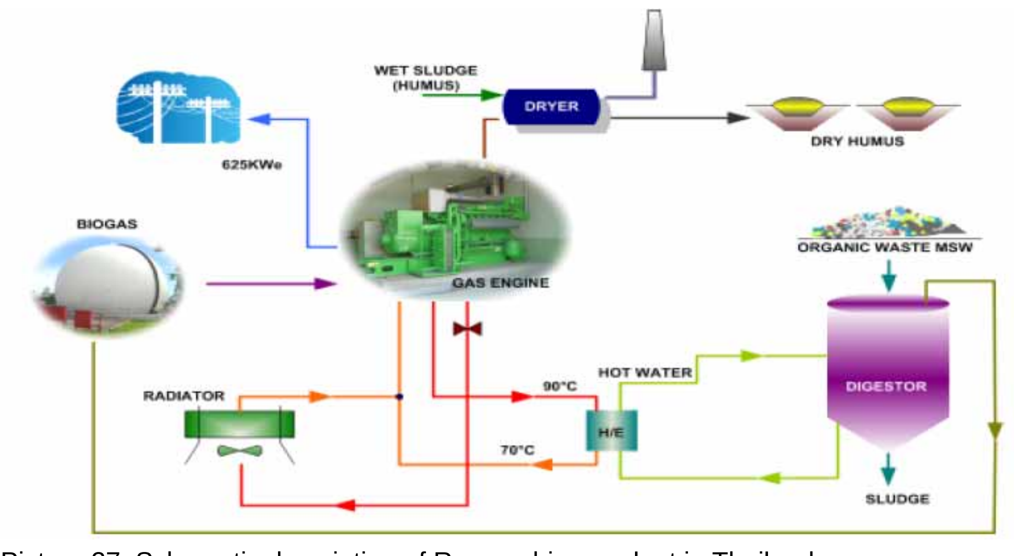
Case studies

The plant operation consists of front-end treatment, anaerobic digestion, and back-end treatment. The anaerobic digester is designed as wet-continuous and completely mixed single stage process under mesophilic condition (see schematic description below).



Picture 27: Schematic description of Rayong biogas plant in Thailand.

The project comprises of two systems; a process that converts waste to biogas and fertilizer and a biogas-fired cogeneration process (power and heat generation). The Rayong plant uses MSW, food-vegetables and fruit waste (FVFW), and night soil waste (NSW) as waste materials.
The plant has a capacity to handle 60 tons of waste per day turning out into an output of 5800 tons organic fertilizer and electricity of about 5 million kWh.

Picture 28 and 29: Rayong Municipality Co-Generation Plant: On the left-side the digester, and on the right side the gas storage.

Literature / Studies

Paper on anaerobic digestion technology with a case study in Thailand (Juanga J.P., Adhikari R. et al. 2006).

Assessment of Rayong Biogas Plant (Hadsoi S. 2006) treating MSW.

Comments

- There is only one full biogas (AD) plant treating organic fraction of municipal solid waste in Thailand in operation. The plant is at Rayong province owned by Rayong Municipality (Juanga J.P., Adhikari R. et al. 2006). Another is in construction at Chonburi province (owned by Chanburi provincal administrative organization). It is possible that there are some smaller installations of biogas plants in other rural areas of Thailand, but there are no publications about (e-mail correspondence with Dr. Chart Chiemchaisri, 15.4.2007). E-Mail: fengccc@ku.ac.th

- There are three biogas plants that are mainly treating municipal waste: A small-scale plant in Chiang Mai, and two other large scale plants in Bangkok and Rayong, respectively. The plant in Rayong was recently visited by GTZ (e-mail correspondence, Werner Kossmann, Principal Advisor GTZ, Phitsanulok Municipal Office, Thailand) E-mail: Werner.Kossmann@gtz.de

- According to John Diecker there are currently no MSW gasification projects operating in Thailand. There have been a number of technologies proposed over the years to utilize MSW for electricity production. But none of them has ever been fully developed (John Diecker, Managing Director, APT Thailand) E-Mail: jdiecker@aptthailand.com

International Office of Technical Assistance (Thailand) Ltd.

IOTA is a Swiss registered engineering consulting firm with its head office located in Mies, Switzerland. Established in 1982, it now has offices in different parts of the world offering expertise in various fields of engineering and environmental management. With IOTA staff of over 150 highly qualified engineers, technicians and senior executives, IOTA offers highly specialized services at both local and international levels.

IOTA Thailand was incorporated in Thailand in 1996 as a subsidiary of the Swiss Group, IOTA SA, to work as a process contractor in Wastewater Treatment, Water Purification and Solid Waste Management, building on its core business of technical assistance. It offers in-house design, engineering, contracting and consulting to answer regional needs and provide feasible and appropriate solutions to companies for their compliance to increasingly stringent environmental regulations.

They are interested in collaboration or establishing feasibility projects in Thailand or other developing countries.

Contact: Pegaso Gaol
E-mail: pegaso@iotaasia.com
Web: http://www.iotaasia.com/

Situation in South-Africa

University of KwaZulu-Natal

There is a Biogas-to-Energy project in Durban that is the first CDM project of its kind (methane extraction and conversion to electricity) in Africa. The project was conceptualized in 2002 by Cristina Trois , Durban Solid Waste and a representative of the World Bank. Phase 1 of the CDM project has been commissioned recently, after 4 years of preliminary work (e-mail correspondence with Cristina Trois, 10.4.2007).
Cristina Trois already published in Waste Management and in several international conferences.

The project in Durban seems to be a methane recovery project on a landfill and can therefore not be classified as AD project in a narrower sense. For more information, please contact Cristina Trois.

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Web: www.ukzn.ac.za/dep/civengund or www.ukzn.ac.za/dep/enveng

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AR Process Projects (Pty) Ldt.

AR Process Projects (Pty) Ltd. designs and builds chemical plants. One of the areas that the company has been drawn into is dealing with MSW. In the City of Cape Town Indaba there is a huge problem with solid waste. Currently local authorities encourage citizens to segregate their waste (e-mail correspondence with Rex Zietsman).

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Sales Director
AR Process Projects (Pty) Ldt.
Tel: 011 445 24 19
E-mail: Rex@Process.co.za
Web: www.process.co.za

According to Frank Schweizer (see contact) KNOTEN WEIMAR is also working in South Africa in the field of biomethanation. They are recommending AD plants to rural communities (e-mail correspondence with Frank Schweizer).

Contact: Frank Schweizer
Consultant at Knoten Weimar
E-mail: frank.schweizer@bionet.net

Situation in Kenya

JuaNguvu Ldt.

Currently there is no working biogas plant treating organic solid waste in Kenya. But since five years the company JuaNguvu Ltd. is trying to implement such kind of digesters. At the moment there are three projects of that kind in process:

Two projects are focusing on the methane extraction from the landfill of Mombasa City (current status is the acquisition of finances).

One project is financed by Rolf Lattmann. The project consists of a 14 m^3 digester that will soon treat organic solid waste from Mtwapa, and other leafy material from his farm. The biogas is used to generate electricity that is again used to run a water pump.

In February 2007 JuaNguvu Ldt. successfully implemented a Puxin Biogas Plant. (e-mail correspondence with Rolf Lattmann, 12.4.2007).

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Web: http://juanguvu.com/tn/

Currently there is no working biogas plant treating organic solid waste in Kenya. But since five years the company JuaNguvu Ltd. is trying to implement such kind of digesters.

Situation in Nepal

Sustainable Agriculture Development Program (SADP)

SADP - Nepal is a non-governmental organization (NGO) and non profit organization registered with Nepal government and affiliated with Social Welfare Council of Nepal working in the field of Agriculture emphasizing on development of Organic Agriculture in Nepal. They are also very much aware of the environment, especially in the field of pure water and waste management and therefore interested in biogas.

According to Ramesh N Sharma there is a Puxin biogas plant (see technology Puxin, China) under construction in Nepal that uses organic solid waste as feedstock material.

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Web: www.sadpnepal.org

Lesotho

Technologies for Economic Development (TED)

TED is a Lesotho based NGO dealing with the dissemination of appropriate technologies which are environmentally friendly and integrate well into the socio-economic conditions at hand. A primary focus of TED is the engineering and fine-tuning of suitable technologies to foster their long-term adoption by the Basotho. TED was founded in January 2004 as a successor of the Lesotho Biogas Technicians Self Help Group. Their main product is the TED - Biogas Digester which enjoys an enormous demand. TED is the local partner of the GTZ (German Technical Cooperation) to implement ProBEC (Programme for Biomass Energy Conservation in Southern Africa) (see website).

TED has from 2004 constructed 76 bio-digesters commercially. Roughly 90% of TED's digesters are for households (ranging from 6 m^3 - 11 m^3). These digesters treat mainly sewage and domestic waste. The rest are institutional (from 16 m^3 - 50 m^3 so far). They are also connected to sewage line but are fed mainly from animal dung.

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Technologies for Economic Development
c/o German Technical Cooperation (GTZ)
Lower Prison Gardens 12
PO BOX 1172, Maseru 100, Lesotho
E-mail: mantopi@yahoo.com
Web: www.ted-biogas.org

Rwanda

There are some biogas plants in Rwanda, but the very few still existing ones are mainly made of wastes from domestic uses like secondary schools, prisons (e-mail correspondence with Nadia Niwemugeni, regional manager, EFS consultants Rwanda)
E-mail: nadia.niwemugeni@esfconsultants.org

Republic of Benin

Shonghai Centre

Papa Abdoulaye Fall (vieuxfall@yahoo.com, GTZ) refers to the Centre of Songhai as they are the know-how centre in the field of biogas in the republic of Benin. SHONHGAI is a centre for training, production, research and development in sustainable agriculture. The aim of SHONGHAI is an integrated agriculture system where the three sectors of production - primary, secondary, and tertiary are highly integrated.
SHONGHAI is also engaged in the production of biogas, as well as in training of people in that domain. The training could be done either at the Songhai Centre Porto-Novo Republic of Benin or through distant training (e-mail correspondence with Guy Loueke, Training Manager, 2.5.2007)
E-mail: centre_songhai@yahoo.fr

Ghana

There are a few biogas plants as pilot projects installed, but all failed according to Jürgen Meinel, who was working within the Waste Management Department. He was involved in the FSTP project in Accra that was introduced in collaboration with Eawag. Currently he is working as a consultant for a recycling plant, where a lot of food waste is accruing. 10% of the food waste gets fed to pigs, the rest is disposed of (e-mail correspondence with Jürgen Meinel, 26.4.2007). E-mail: cwmcl@gmx.net

India

The State Rural Electric Power Co-ordination Services in Tamil Nadu are involved in the field of energy generation through AD using cow dung etc. (e-mail coresmondence with Varuthi B. U. Shankar, Founder & General Secretary, www.srepcos.in) E-mail: founder@srepcos.in

Report that summarizes the state of ecosan projects in 2005 in India in respects also of anaerobic digesters for faecal matter (Ecosan 2005)

Nepal

The Biogas Sector Partnership-Nepal (BSP-Nepal), a Non-Government Organization, is executing the biogas program with the financial and technical support from the Netherlands Development Organisation (SNV). BSP-Nepal is targeting the Nepali farmers who have at least one cattle and small piece of land. The Biogas Support Program (SNV/BSP) started in July 1992. By the end of December 2005, BSP has successfully achieved the following results:

- Installed 156,575 biogas plants
- 60 private Biogas Companies have been strengthened
- 15 Biogas appliances manufacturing workshops are developed
- Comprehensive quality standards and quality control system is developed
- 96% of constructed plants are in operation

- 93,251 toilets are constructed (motivated for construction) and connected with biogas plants.
- 80% of bio-slurry is utilized as an organic compost fertilizer
- Biogas programme is being developed as a first CDM project in Nepal
- BSP is an ISO 9001-2000 certification holder for its strong quality management system and subsidy administration.
- 118 micro finance institutes are mobilized on biogas lending
- 980,000 persons are directly benefited
- 11,000 persons got employment

For further information see webpage http://www.bspnepal.org.np.

Thailand

The Korat Waste to Energy Project developed by KWTE is an anaerobic digestion project, treating wastewater from the starch industry, at the Sanguan Wongse Industries facility in Korat, Thailand. (E-mail correspondence with John Dieker (jdieker@aptthailand.com), Managing Director of APT (www.aptthailand.com)).

Columbia

There are several municipal UASB reactors operating in Columbia. Also some biogas plants treating waste water from breweries. The Hochschule Wädenswil (HSW) is involved in a project using a small pilot plant. Other biogas projects in the field of solid waste are in preparation (e-mail correspondence with Urs Baier, HSW, 27.4.2007) E-mail: u.baier@hsw.ch

Costa Rica

There are so-called “Salsicias”-Plants (lying, cold cannels) used for agricultural purposes or liquid lagoons for the treatment of waste water from the coffee production (U. Baier, HSW).

Honduras

There is an EECOPALSA project (CDM project, CER’s bought by Schweizer Klimarappen) treating waste water from palm-oil production by using covered waste waster lagoons (U. Baier, HSW)

Assessment of Biogas Projects treating Organic Solid Waste in Industrial Countries

In industrial countries there are various companies that provide high-tech biomethanation facilities for the treatment of solid waste (municipal biowaste or agricultural solid waste). Basically these facilities are sophisticated, expensive and thus not favorable for implementation in developing countries. Nevertheless high-tech facilities are already implemented in countries, such as China, India and Thailand. Thus these biogas technologies might also be worth to be considered as a possible option for big cities in other low- and middle income countries. In the following a broad overview of existing companies providing high-tech solutions will therefore be given. The author does not claim for completeness. For more information about the companies or technologies the corresponding webpage need to be visited.

Table 9: Various suppliers of high-tech AD technology mainly for MSW / biowaste.

Company Name	Headquarter	Process Name	Feedstock material	Website
Valorga	France	Valorga	MSW, Biowaste	www.valorgainternational.fr/fr/
Linde-KCA-Dresden	Germany	Linde	Biowaste	www.linde-kca.de/
Kompogas	Switzerland	Kompogas	Biowaste	www.kompogas.ch/
U-Plus Umwelttechnik	Germany	ISKA	Biowaste	www.u-plus.de/de/
Organic Waste Systems	Belgium	Dranco	Biowaste	www.ows.be/
BTA	Germany	BTA	Biowaste	www.bta-technologie.de/
Onsite Power Systems	US, California	APS	Biowaste	www.onsitepowersystems.com/
Bioconverter	US (Hawaii)	BioConverter	Biowaste, SS	www.bioconverter.com/
Entec	Austria	BIMA	MSW, Biowaste	www.entec-biogas.at/
Bioferm	Germany	Bioferm	AP	www.bioferm.de/
Bekon	Germany	Bekon	MSW, Biowaste	www.bekon-energy.de/

SS = Sewage sludge

AP = Agricultural products (for example maize)

Source: Adapted from (Bioenergy 2001), (Williams R. B., Jenkins B. M. et al. 2003)

An overview of sophisticated biogas systems in the field of MSW is also presented in the following reports:

- (Bioenergy 2001)
- (Williams R. B., Jenkins B. M. et al. 2003)
- (RIS International Ldt. and MacViro Consultants Inc. 2005)
- (Veeken A. 2005)

Batch Dry Fermentation Systems: Bioferm GmbH and Bekon GmbH

Within the last decade two German companies (Bekon GmbH and Bioferm GmbH) have been developing biomethanation facilities that have a simpler set-up compared to already established facilities in the MSW sector. The two batch-systems basically have the same origin and a similar built-up and functionality. Currently one Bekon plant is working in the field of MSW management in Fröttmanning (Munich), Germany. Bioferm GmbH has no biogas plant for the treatment of MSW, yet. But more than 15 plants converting agricultural residues and crops into biogas are already installed.

As already mentioned the two companies provide a similar technology, nevertheless there are some differences regarding the standard dimensions of the digester, the precautions in terms of explosion or other technical devices. In the following the similarities or the common principle shall be presented.

For detail information the corresponding company / contact needs to be approached.

Bioferm GmbH

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(info@volkmar-matzel.de)
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Phone: +49 (0) 30 7676 8576
Mobile: +49 (0) 151 12442986
Web: www.bioferm.de

Picture 30: Bioferm GmbH biogas plant in Iffezheim, Germany. The plant consists of four parallel operating batch digestion reactors. Feedstock material is renewable raw material, such as maize. (Source: Sandec).

Bekon GmbH

Contact: Jakovos Theodoridis
(jakovos.theodoridis@bekon-energy.de)
Bekon GmbH
Feringastraße 9
85774 Unterföhring
Phone: (+49) 089/ 90 77 959-0
Fax:(+49) 089/ 90 77 959-29
Web: www.bekon-energy.de

Picture 31: Bekon GmbH biogas plant in Fröttmanning (Munich), Germany. The plant consists of four parallel operating batch digestion reactors. Feedstock material is mainly biodegradable municipal waste. (Source: Bekon GmbH)

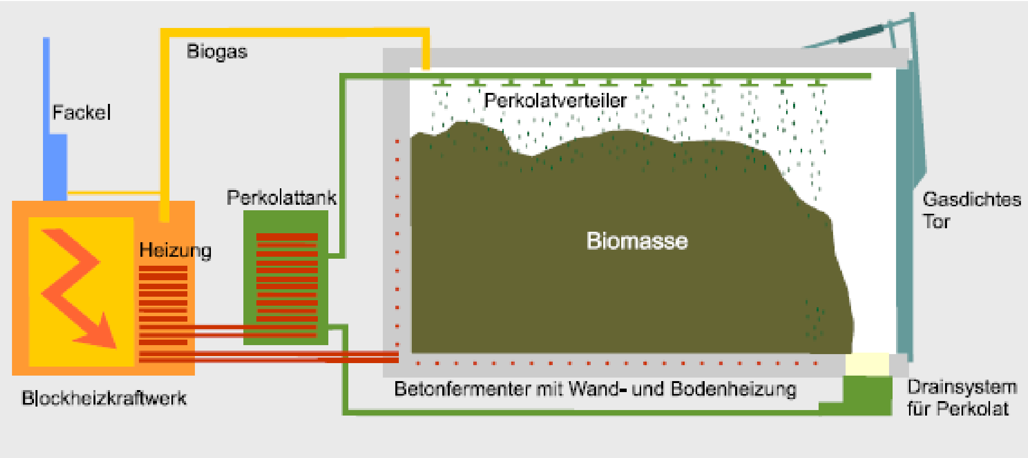
Functionality

The fermenter is built up and also looks like a common garage (see picture 30 and 31). The fermenter can be filled through a gas-tight door. Once the fermenter is full (with a new batch of stackable organic material) the door gets closed and the process starts. In a first stage where oxygen is still available the material gets aerobically degraded. Aerobic degradation results in warming up the biomass pile, but does not produce methane.

As soon as all oxygen is exhausted the anaerobic fermentation process and the biogas production (mainly methane) starts.

In order to increase the degradation rate or to provide optimal conditions for anaerobic micro-organisms, respectively, the fermenter needs to be heated up to 38 degree. In additional water has to be added. Heating is attained by a heater map and water is provided in form of percolation liquid that gets trickled from the top cover of the fermenter (see picture 32). The percolate, after flowing trough the feedstock heap, is collected into a drainage at the bottom of the fermenter. Then it is pumped back into the percolation tank.

During this percolation process the feedstock material gets degraded and converted into biogas. The biogas is collected at the top cover and cleaned before being used in block heat power plant. After 25 to 35 days the feedstock material gets replaced by a new batch load. The degraded material is composted until it reaches the required maturity.



Picture 32: Schematic description of a batch dry fermentation process (Bekon GmbH).

Gas production in a batch system is never continuously. But the block heat power plant needs to be fed continuously in order to operate efficient and economically. Thus, current batch systems consist of several batch fermenters that work parallel, but chronically shifted.

This kind of batch fermenter tends to have slightly lower investment costs than conventional high-tech biomethanation facilities. Due to lack of stirring devices within the fermenter chamber operational and maintenance costs are lower. Nevertheless the actual costs for electricity still tend to be higher due to lower gas production. There are still some hurdles to be taken in terms of biological process stability. In addition filling and emptying is labor intensive.

Some of the key factors regarding biological process stability are (Gronauer A. 2004), (Gronauer A. and Aschmann V. 2004):

Texture of material: the feedstock material needs to be stackable. The existence of flow paths for the percolat needs to be ensured everywhere and anytime during the process. Otherwise degradation of organic material does not take place without water availability. One way to ensure flow paths is the addition of straw or woody-like material that is not degraded.

Inoculation material: Prerequisite for degradation is the presence of bacteria. In order to increase the initial number of bacteria already degraded material (inoculation material) is mixed with fresh material before filling. This results in a better degradation process, but also in a loss of work space for fresh material. The biogas yield decreases proportionally to the amount of inoculation material added.

Aerobic pretreatment: In order to increase the temperature of the input material an aerobic pretreatment can be applied. After such a pretreatment the energy consumption within the fermenter chamber is lower. But also the biogas yield is lower due to the loss of aerobically degraded material.

Homogeneity of feedstock: The mixing of feedstock material within the fermenter chamber is not possible. Thus, the mixing outside has to be done sufficiently in order to attain a maximal homogeneity of the feedstock. Otherwise it is predominantly told that degradation rate is lower.

Percolation: Percolation needs to be done equally distributed all over the feedstock heap. Punctual irrigation leads to zones without water availability. Without water, no degradation takes place and the biogas yield turns out to be low.

Adaptation of bacteria culture: Different bacteria cultures contribute to the degradation of material. Various cultures try do adapt themselves and thus optimize the degradation of a certain the feedstock material. But adaptation of bacteria resulting in a more efficient degradation is only possible when keeping the feedstock quality constant.

Conclusions

Response to the research questions

Table 10: Responses to the research questions

	Response to the research question in the context of low- and middle income countries
1	Are there biogas plants whose feedstock material is mainly biodegradable waste?
	Yes, there are several types of technologies that have been implemented, a least on a pilot scale level.
2	Where are they and how do they perform?
	Mainly India and China seem to be the leading countries not only regarding the number of biogas plants, but also in R&D activities resulting in new technologies. Other countries, such as Thailand, Nepal, Sri Lanka are also involved in the field of AD of biodegradable waste. Most of the AD projects assessed do not seem to work properly. But there are also some promising technologies that have at least a good reputation.
3	What are the main problems in terms of operation and management of such biogas plants?
	> poor feedstock quality (no segregation), sometimes also quantity (inappropriate planning) > lack of skilled labor or poor training activities (lack of knowledge centre) > Overestimation of biogas output
4	Can AD of biodegradable waste be considered as an appropriate technology for MSW in urban context?
	In industrial countries it is! In developing countries many projects have failed. But there are also successful one‘s. It seems to be a question of time until AD is becoming a widely spread treatment option in the SWM, also in developing countries.
5	What are current R&D topics in the field of AD of biodegradable waste?
	Based on the status-quo of AD of organic solid waste current research topics are related to: > high dry solid digestion systems in developing countries > process control (acidification) > mixing arrangements in reactor > insulation (temperature fluctuations) > floating dome vs. rubber membrane for gas storage > hydrogen sulphide removal

State-of-the-art of anaerobic digestion

In industrial countries such as in Europe renewable energy production including biogas production is becoming more and more popular. In the agricultural and in the industrial sector high-tech digesters of various kinds are implemented. Based on a good planning, installation and operation know-how most of these plants are running economically on a regular basis. In order to improve the performance of anaerobic digestion research is continuously going on in various fields.

Until today there is a variety of companies that recommend their technology to be the best for the corresponding application. Consultants or interested parties hardly manage to get an overview of the state-of-the-art of each technology on the international market. Thus it is recommended to join the

internet forum http://listserv.repp.org/mailman/listinfo/digestion_listserv.repp.org that provides a platform for knowledge exchange in the field of anaerobic digestion.
In this forum near-to-market technologies in respect to treatment of source-segregated food and kitchen waste and all other aspects of AD can be discussed.
Research topics based on high-tech digesters are not comparable with problems faced in low- and middle income countries. Nevertheless the trend of sophisticated technologies is also showing in which direction it could go for low-tech digester plants, at least from a technical point of view.

Anaerobic digestion in low- and middle income countries

The critical factors for successful operation of digestion (and composting) for biodegradable waste management are the following (Veeken A. 2005):

- Biodegradable waste should be clean (not mixed with other municipal solid waste components like plastics, glass, metals, paper) before it enters the treatment system. Source separation before collection gives the best guarantee to have a waste stream that does not hamper the treatment technology and gives good quality compost. Manual sorting after integral waste collection is very labor intensive and provides insufficiently clean waste. Thus source separation of biodegradable waste is a prerequisite.
- Design of technologies that are simple, low-tech, reliable (robust) and can be managed on small scale by local operators.
- The necessary skills and capacity to implement, disseminate and consolidate digestion (and composting).
- A market for the products (biogas, compost, liquid effluent) should be available.

The following activities in the field of digestion (and composting) are often missing:

- Regular and adequate supply of biodegradable market waste
- Proper management of the digester: operation, supervision, maintenance.
- Commitment of experts to the activities: no activities are undertaken to solve the problem with the biogas plants that do not operate.

It is necessary to establish an independent organization that should be committed to the implementation and consolidation of biological treatment of biodegradable waste. It is advised to establish a national Expert Knowledge Centre. The Expert Knowledge Centre should be part of or under the supervision of a governmental organization (e.g. Ministry of Environment & Natural Resources) and should amongst others address the following activities:

- Organize and collect information on the technical and managerial aspects of biodegradable waste management including collection of source separated biodegradable waste, digester technology, composting technology and marketing of biogas and compost
- Capacity building
- Raising awareness of composting and digestion
- Develop and carry out demonstration projects
- Disseminate knowledge and information: e.g. publish newsletters, organize workshops
- Consultancy on design and implementation

- Helpdesk function, assist local operators with operational problems (troubleshooting)

There is not a single solution for the management of biodegradable waste. For each city a tailor-made biodegradable waste management system has to be developed. The first important phase of preparing a strategic biodegradable waste management plan is getting detailed information of the amount and composition of the waste. The availability of source separated waste and the composition should both be assessed. For the composition the distribution between wet, pulpy waste (easily degradable) and dry, fibrous waste should be monitored. Based upon the availability and composition of the biodegradable waste of the best biological treatment options should be chosen. The following options are recommended according to the study of the University of Wageningen (Veeken A. 2005):

- One-stage, wet biogas digesters for wet and pulpy biodegradable waste, decentralized on small-scale
- Passively aerated windrow composting for dry and fibrous biodegradable waste, decentralized on small-scale

For a mix of wet-pulpy and dry-fibrous waste the chosen treatment option will depend on the final composition of the biodegradable waste. For a mix rich in wet-pulpy waste, dry batch digestion in an accumulation system is preferred. For a mix rich in dry-fibrous waste, passively aerated windrow composting is the best option. When there are plans to operate large-scale digestion and composting facilities in future, attention should be paid to the marketing aspects of compost and biogas, and compost and biogas quality standards should be established. On national level, composting and digestion of domestic and market biodegradable waste should be promoted by institutional and legislation development. Moreover, technology and knowledge transfer should be initiated by the establishment of Expert Knowledge Centre that works amongst others on capacity building and demonstration projects (Veeken A. 2005).

Promising low-tech AD technologies for organic solid waste treatment

In the recent past the planning, construction, operation or management of low-tech biogas plants has not always been done appropriately, thus many projects failed. Some of the general lessons learned have been summarized above (see AD in middle- and low-income countries).
In this chapter a few technologies shall be mentioned that seem to be promising for future applications in the MSW sector. The selection of the following technologies is based on this research, means on literature review and e-mail correspondence and has to be seen as scientific founded findings. At least, this research revealed that some of the case studies are more successful than others. Some AD technologies seem to have several successful plants operating on a large scale level, whereas others do not have a good reputation. Based on these findings the following technologies are primarily recommended for further evaluation:

- **BARC, Mumbai:** This kind of technology is said to be the state-of-the-art in the low-tech context. Several plants work successfully in India and Sri Lanka.

- **ARTI, Pune:** It seems to be a promising technology. The small compact biogas plant is applicable for households. A good reputation and more than 2000 installed plants are a remarkable reference. In addition ARTI has won the Ashden Award in 2006.

- **BIOTECH, Trivandrum:** The technology has more than 12’000 references. Furthermore BIOTECH is selected as a finalist for the international Ashden Award for Sustainable Energy in 2007.

- **Mailhem Engineering Ltd., Pune:** Mailhem Engineering’s sister consultancy concern GIT Associates are empanelled as consultants by Ministry of Non-Conventional Energy sources for GEF/UNDP projects. They seem to be one of the leading companies in India in the field of AD, especially regarding UASB reactors treating organic solid waste.

Further promising technologies might also exists in China or South-America as this research was mainly done in English and German not covering all available documents and information. Anyway in the field of AD, especially in context with organic solid waste, consolidated findings can occur whenever. Thus knowledge-transfer with other experts in that field helps being up-to-date and covering the most relevant AD technologies.

Outlook

Energy shortage is an issue present in many, mainly rural parts of the world. In future as fossil fuel becomes scarce it will even become more relevant, also increasingly affecting urban areas. The focus of municipal authorities will therefore increasingly be on energy saving, as well as renewable energy programs, such as known from India and China.
The solid waste problem in developing countries is still seeking for efficient and sustainable solution. Today's AD technologies could be part of the solution to tackle these problems. Why not treating organic waste at household level by gaining energy for cooking applications? No matter on what level implemented AD could become more relevance regarding SWM and production of renewable energy.

Some of the actual technologies seem promising, but in order to have a real impact on the waste problem and to produce a significant amount of clean energy the systems need to be improved and numerously implemented.

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Department of Biological and Agricultural Engineering.

Annex: Institutions and Researchers

For this study, more than 60 people and institutions in about 25 countries all over the world have been contacted. The extensive list is available to the authors. Please contact *Eawag/Sandec* for further information:

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