Sustainable Sanitation

Practice

EcoSan Club

Issue 9, 10/2011

- Digesting Faeces at Household Level - Experience From a “Model Tourism Village” In South India
- Biogas Systems in Lesotho: an effective way to generate energy while sanitizing wastewater
- Evaluation of formulas to calculate biogas production under Moroccan conditions

Biogas Systems

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Sustainable Sanitation Practice (SSP) aims to make available high quality information on practical experiences with sustainable sanitation systems. For SSP a sanitation system is sustainable when it is not only economically viable, socially acceptable and technically and institutionally appropriate, but it should also protect the environment and the natural resources. SSP is therefore fully in line with SuSanA, the Sustainable Sanitation Alliance (www.susana.org). • SSP targets people that are interested in sustainable sanitation systems and the practical approach to it. • Articles are published after blind review only. • Sustainable Sanitation Practice is published quarterly. It is available for free on www.ecosan.at/ssp.

Sustainable Sanitation Practice (SSP) hat zum Ziel praxisrelevante Information in hoher Qualität im Zusammenhang mit „sustainable sanitation“ bereit zu stellen. „sustainable“ also nachhaltig ist ein Sanitärsystem für SSP wenn es wirtschaftlich machbar, soziokulturell akzeptiert, technisch als auch institutionell angemessen ist und die Umwelt und deren Ressourcen schützt. Diese Ansicht harmoniert mit SuSanA, the Sustainable Sanitation Alliance (www.susana.org). • SSP richtet sich an Personen, die sich für die praktische Umsetzung von „sustainable sanitation“ interessieren. • Artikel werden nur nach einer Begutachtung veröffentlicht. • Sustainable Sanitation Practice erschient vierteljährlich, kostenlos unter: www.ecosan.at/ssp.

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Publisher: EcoSan Club, Schopenhauerstr. 15/8, A-1180 Vienna, Austria • chairperson: Günter Langergraber • website: http://www.ecosan.at/ • scope: EcoSan Club was funded as a non profit association in 2002 by a group of people active in research and development as well as planning and consultancy in the field of sanitation. The underlying aim is the realisation of ecological concepts to close material cycles in settlements.

Medieninhaber: EcoSan Club, Schopenhauerstr. 15/8, A-1180 Vienna, Austria • Obmann: Günter Langergraber • Gegenstand des Vereins: Der EcoSan Club wurde 2002 als gemeinnütziger Verein von einer Gruppe von Personen gegründet, die in Forschung, Entwicklung, Planung und Beratung in der Siedlungshygiene - Sammlung, Behandlung oder Beseitigung flüssiger und fester Abfälle aus Siedlungen - tätig waren und sind. Das Ziel des EcoSan Clubs ist die Umsetzung kreislauforientierter Siedlungshygienekonzepte (EcoSan Konzepte) zu fördern, um einen Beitrag zum Schutz der Umwelt zu leisten.

Cover Photo / ***Titelbild***

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Editorial

During the last years a number of biogas systems have been installed as part of sanitation systems. Issue 9 of Sustainable Sanitation Practice (SSP) on „Biogas systems“ shows successful examples.

- The first paper presents results from a study in Kerala, India, for digesters on a household level.
- The second paper shows the results of a long-term implementation program for biogas systems in Lesotho.
- The third paper presents first results of a digester constructed in a small village in Morocco.

As EcoSan Club will celebrate its 10 year anniversary in 2012, the thematic topic of the next issue will be „10 Years EcoSan Club“ (SSP issue 10, January 2012).

Information on further issues planned is available from the journal homepage (www.ecosan.at/ssp). As always we would like to encourage readers and potential contributors for further issues to suggest possible contributions and topics of high interest to the SSP editorial office (ssp@ecosan.at). Also, we would like to invite you to contact the editorial office if you volunteer to act as a reviewer for the journal.

SSP is available online from the journal homepage at the EcoSan Club website (www.ecosan.at/SSP) for free. We also invite you to visit SSP on facebook (www.facebook.com/SustainableSanitationPractice).

With best regards,
Günter Langergraber, Markus Lechner, Elke Müllegger
EcoSan Club Austria (www.ecosan.at/ssp)

Content

eawag
aquatic research

Sandec
Water and Sanitation in Developing Countries

Digesting Faeces at Household Level - Experience From a "Model Tourism Village" In South India

Analysis of household scale faeces treatment by anaerobic digestion in Southern India shows some critical factors which must be overcome if sustainability and scaling up is expected.

Authors: Christian Zurbrügg, Yvonne Vögeli, Nicolas Estoppey

Abstract

The scope of the study was to assess the strengths and weaknesses of existing household level biogas systems treating toilet waste as well as organic kitchen waste. The biogas systems studied had been implemented on Kumbalangi Island in South India within the framework of a Tourism Development Project to improve sanitary conditions. The assessment comprised a technical monitoring of two selected facilities over a period of two months as well as a household level users survey. Results reveal that the systems are working quite satisfactorily and are generating enough biogas to cook the main dishes of a family along with replacing most of the traditional cooking fuel. The treatment efficiency of the organic pollution is as good as to be expected from biogas systems. However, the effluent does not match the legal requirements for use without any restrictions as organic fertilizer or for discharge into surface water bodies without any further treatment. The current investment costs are high as subsidies formerly provided are not available anymore. This severely limits the potential of wide spread replication.

Introduction

Kumbalangi is an island-village surrounded by backwaters and paddy fields on the outskirts of Cochin city of Kerala State in South India. The Kerala backwaters are a series of brackish lagoons and lakes lying parallel to the coast and include five large lakes linked by canals, both manmade and natural, fed by 38 rivers, and extending virtually half the length of Kerala state. In a unique initiative to transform the tiny island of Kumbalangi, to attract tourism and enhance local income opportunities, the „Kumbalangi Integrated Tourism Village Project" set on re-establishing a sustainable approach for the management of local ecological resources such as fish and mangroves. Low impact tourism, where tourists live and dine with the villagers, wander around the village, fish and go canoeing is promoted. The government of India declared it a "model fisheries and tourism village" of India and supported the development with respective funding.

Within the same initiative, one goal is to improve the hygienic situation on Kumbalangi Island. To date, "hanging toilets" and other unimproved toilet facilities are still frequently being used which discharge excreta and wastewater directly into surface waters thus polluting the backwaters (Figure 1 and Figure 2). The idyllic landscape is also threatened by a lack of solid waste management services. Waste is dumped all over, burnt in the garden or thrown into the backwaters.

Key messages:

- the reactor design is for one household, connected to the toilet effluent whereby kitchen waste can also be added
- the reactor is designed as floating dome type, constructed with cement and fibreglass reinforced plastic materials
- the input material consists of toilet waste and organic waste from the kitchen
- the average daily biogas production is 590 l and replaces a large part of the traditional cooking fuel
- the effluent exiting the reactor is not further treated and is used as fertilizer in the gardens or discharged into the backwaters, although based on the quality characteristics this would not be allowed.
- the current high investment costs to construct and install such a system make it unaffordable for most families

Figure 1: Hanging toilets

Figure 2: Toilet discharging into the backwaters

In order to reduce the environmental problems and health hazards of inhabitants, caused by the lack of appropriate sanitation infrastructure and municipal solid waste management, the local Kerala based NGO BIOTECH assisted the community with the endeavour to improve 150 toilets linking them to biogas digesters as well as setting up 650 digesters for food waste from kitchens. Main objective, besides reducing environmental degradation of the backwaters, was to hereby generate biogas for cooking, as well as produce organic fertilizer for the families and their gardens.

In collaboration with BIOTECH, Eawag/Sandec conducted an assessment of the currently implemented household scale biogas plants in 2010 to evaluate the strengths and weaknesses and establish recommendations for improvement. The assessment comprised a technical performance evaluation, economic feasibility and social acceptance (Estoppey, 2010). As there is a overall general lack of well documented information on the performance of household biogas systems using faeces and solid waste in low and middle income countries, the technical assessment evaluated two reactors; one fed only with organic solid waste (called: Food Waste Biogas Plant) and the other fed with food waste but also connected to the toilet (called: Toilet Linked Biogas Plant). Parameters which were monitored during the technical assessment comprised: gas production, treatment efficiency and effluent quality.

This present paper focuses on the results related to the toilet linked biogas plant and discusses the results with regard to the suitability as a sustainable sanitation option.

Methods

Understanding the functionality of the biogas plant and assessing key parameters was a challenging task in the local context. A first period of two weeks entailed discussions with the family operating the biogas plant to obtain an idea on how the owners and users operate the facility and to engage with them on clarifying the objectives of the study and designing specific procedures for data collection. The study tried to limit its influence on usual practice, nevertheless one has to assume that the influence of having a researcher on site regularly may in fact influence normal practice of the family. The biogas plant was monitored during an 8 week period regarding the following aspects:

- Analysis of feedstock in terms of mass and characteristics
- Analysis of effluent in terms of volume and composition
- Measurement of gas production and gas composition

The users were asked to collect their kitchen waste daily in buckets, separating the solid food waste from the organic waste water (waste water that originates in the kitchen). This waste was then sorted on five days per week to better characterise the waste amounts and type. On the two other remaining days, the families were asked to write down the estimated quantities of what they fed into the biogas plant. Those estimations were not used in the calculations but rather allowed a cross-check or unusual quantities of waste. After sampling, the feedstock samples were homogenised with a kitchen blender at the BIOTECH offices for about 30 minutes. Smaller portions of these homogenized samples were then analysed for Total Solids (TS) and Volatile Solids (VS) at "Cochin University of Science and Technology".

For estimating toilet waste, the users were asked to note on a sheet of papers if he/she urinated, defecated or did both, as well as if he/she used the 4L toilet flush or not. Once a week, over a period of 24 hours, the family collected the black water (urine, faeces and flushing

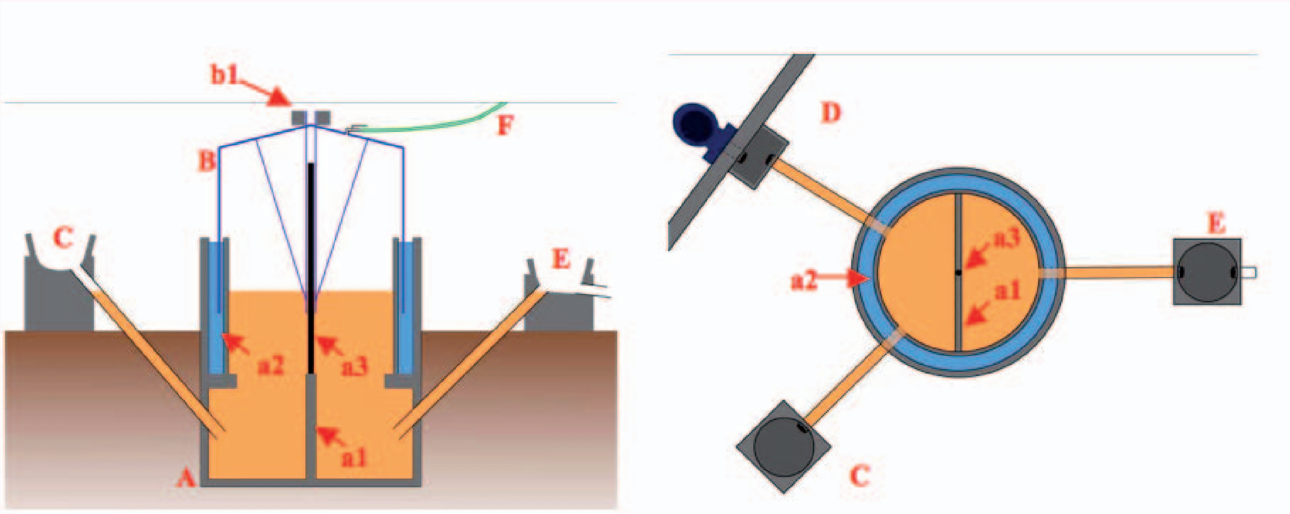

Figure 3: Cross section and top view of a toilet linked biogas plant

water) by connecting the toilet to a 10 litre bucket which was emptied regularly into an 80 litre storage tank. This tank then served as sampling point, where after strong stirring and mixing 500 ml of liquid was collected for analysis. In addition, two samples of black water were taken using sterile tubes of 15ml for pathogens measurements.

To gain information on the economic feasibility and the socio-cultural aspects of the new sanitation system, a household survey was conducted with 17 owners of a toilet linked biogas plant and 10 owners of a food waste biogas plant.

Specifications of biogas system and cost

The domestic toilet linked biogas plants installed by BIOTECH all have a floating dome design and consist of a digester tank (A), a gasholder drum (B), a food waste inlet (C), a toilet waste inlet (D), an effluent outlet (E) and a biogas outlet (F).

The digester tank with an external diameter of 142 cm is made of prefabricated reinforced cement concrete (RCC) elements fitted together in an excavated pit. An orthogonal barrier (a1) of 70 cm height separates the lower part of the tank into two compartments in order to increase the retention time of solid particles.

The gasholder is made of fibreglass reinforced plastic (FRP). A metallic central rod as axis (a3) serves as a guide frame for the gasholder and prevents the gasholder from tilting when the gasholder is elevated (i.e. full). The water jacket (a2) is a newer development by BIOTECH. It provides water filled guidance groove for the lifting and descending gasholder and avoids contact between digesting material and atmosphere thus also avoiding gas losses. In the stagnant water of the water jacket a few drops of kerosene are added to avoid breeding of mosquitoes. In order to increase the gas pressure, a stone of 20 kg is put onto the gasholder (b1).

Whereas the toilet waste is directly flushed into the digester (using either pour flush or full flush toilets), the food waste is first cut into small pieces, mixed with water and then fed into the digester through a separate inlet. The generated biogas is used directly for cooking without any gas cleaning step. Merely the condensed water in the gas pipe is removed regularly. The effluent from the reactor, the digestate, is either used as fertilizer in the garden, but more often is directly discharged into the backwaters without any further treatment.

The total costs of such a biogas system amounts up to around 600 US$. In the past subsidies were granted from the Central Government, the Kerala Local Government and the Kumbalangi basic unit of administration (Panchayat). The financing system for construction involved the families paying for the cement (100 kg), the bricks (25 normal and 8 cement ones), the excavation of the pit and the cow dung (100 kg) to inoculate the system. In total the contribution of a family was around 120 US$. However, for all biogas systems installed since 2010 a new design and new materials were established as standard. These are prefabricated portable plants entirely made of fibreglass reinforced plastic. Although this makes it significantly easier to construct a biogas systems it also makes the system more expensive (about 800 US$ per unit). At the same time the governmental subsidies decreased considerably and the costs for installing a biogas plant amounts to 600 US$ per family. This high cost makes the system unaffordable for most families.

Results and Discussion

Technical performance

The monitoring of the toilet linked biogas plant (TLBP) showed that the system is working satisfactorily regarding its technical performance. The system receives an average of 3.6 kg waste per day, consisting of faeces and kitchen waste, whereby these are mainly

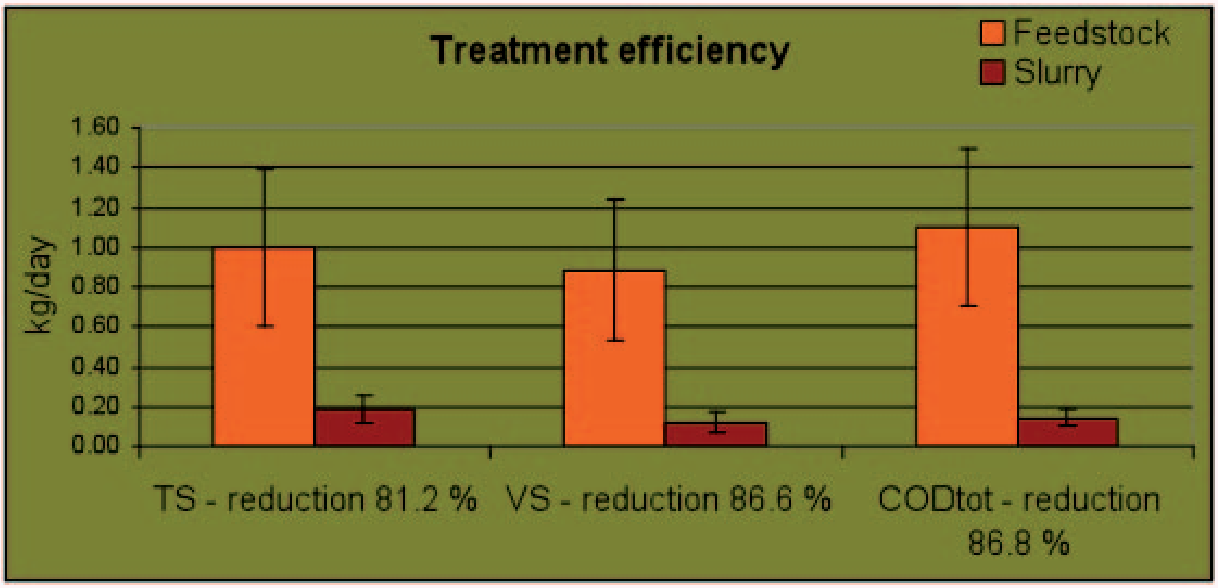

Figure 4: Treatment efficiency of TLBP plant

rice leftovers. Interestingly, the owner of the monitored facility also collects kitchen waste from three other families to increase the gas production. The liquid waste added to the reactor amounts to an average of 36.5 litres per day. Half of this liquid waste is flushing water without any or very little organic content and the rest is urine and greywater from the cooking of rice.

The high amount of flushing water in the TLBP leads to a very low concentration of volatile fatty acids of 82 mg/l and a low organic loading rate of 0.58 $kgVS/m^3$. Nevertheless the average hydraulic retention time is 37 days which corresponds to the range as recommended in literature. The treatment efficiency of the plant can be regarded as good showing a high reduction in total solids (TS), volatile solids (VS) and chemical oxygen demand (COD) (Figure 4). Of the generated biogas the methane content was always stable at around 60%. The average daily biogas production of 690 litres is sufficient to cook the main dishes of a family. The pH remains stable at 6.9 and thus is in the optimal range for anaerobic digestion which lies between 6.7 - 7.5. The temperature inside the digester was stable at around 29 C°, which is slightly below the optimum of 32-42°C for mesophilic conditions (Deublein and Steinhauser, 2008).

Quality of effluent

The effluent from the biogas plant (i.e. the digestate) is very high in water content as most solid parts are decomposed during digestion. The nutrient content in the effluent shows nitrogen values of N_{tot} = 871 mgN/l, potassium of K_{tot} = 766 mgK/l and phosphorus of P_{tot} = 61 mgP/l. However, it is difficult to evaluate its quality as a liquid fertilizer as this depends very much on the plants where the fertilizer is applied.

The reduction in pathogen content was found to be very high, but nevertheless comparing the concentration of E. Coli and total Coliforms with the WHO-guidelines for "safe use of wastewater, excreta and greywater" (WHO, 2006) would only allow for restricted irrigation. Thus the families should be careful and only use the effluent on crops that are cooked before consumption. In addition, contact with mouth or wounds have to be avoided and hands must be washed after contact. Furthermore the effluent should be applied directly on the soil as close to the roots as possible and not be sprayed over the crops. Appropriate use includes irrigation of banana and coconut trees.

A household survey revealed that several families discharge the effluent directly into the backwaters (Figure 5). Given the environmental standards for discharge of environmental pollutants by the Ministry of Environment & Forests (Government of India) and the measured values for COD_{tot} and N_{tot} of the effluent, it is obvious that the environmental standards are exceeded and an additional treatment step would be needed (e.g. filter bed) to further reduce the organic load of the effluent before safe discharge.

Figure 5: Biogas plant discharging directly into the backwaters

Economic feasibility

With the change in materials used for the biogas reactor and the decrease in governmental subsidies, the investment costs of a biogas reactor for a family amounts to approximately 600 US$. This is a significant increase compared to a cost per family of 120 US$ when the initiative could still benefit from subsidies and cheaper material design. The amount of 600 US$ corresponds to about five monthly salaries of an average labourer on Kumbalangi. Costs for operation and maintenance however are comparatively low, the system proves to be very robust and low in maintenance. About 3 US$ per year have to be invested to replace broken pieces (stove knob, valve lever on gas holder).

In terms of financial benefits, the generated biogas can substitute traditional cooking fuel, mostly firewood and liquefied petroleum gas (LPG). The savings from replacing firewood and LPG with biogas account for about 40 US$ per year. The 690 l/d of biogas are enough to cook for approximately 3h and 15min per day and thus allows preparation of the main dishes. The families however can not completely rely solely on biogas as they will still need a second stove for cooking.

The payback period of the new design with its current subsidy system compared to the old design and subsidies increased from 3 years to 15 years, taking into account savings in replacing other fuels. Costs of previous kitchen or toilet waste management are not considered, as most families used to dispose of their waste in the streets and used to defecate into the backwaters. The environmental benefits as a result of the new sanitation system and replacement of the old unacceptable situation were not quantified.

The economic feasibility of the system is thus rather weak. Hence widespread replication and implementation is only possible if the investment costs can be reduced considerably. Mass production, cheaper materials, higher subsidies or other incentive systems could be options to reduce investment costs. Else, using the current design, biogas plants will only be affordable to wealthy families.

Social aspects

A household survey showed that the acceptance of the biogas systems is in general very good and most families that have one would recommend it to others. The improved waste management and the production of biogas were mentioned as the main advantages. The smell of the effluent (when using toilet waste), not enough biogas, slower cooking with biogas and the difficult access and design of the toilet facilities (steep and unsafe stairs) were mentioned as main disadvantages.

Regarding the use of biogas which derives from faeces for cooking, only one family had objections. The odorous effluent however was of major concern; an issue which was not raised with families only feeding kitchen waste into their digester.

The majority of families are pleased with the amounts of biogas they can obtain on a daily basis. All use an additional cooking fuel when they want to cook faster or when they need a second stove.
User knowledge of operation and maintenance instructions were lacking. None of the families interviewed were aware of the recommended maximum daily load or on the recommended dilution of the feedstock. Only half of the users were aware that they shouldn't use chemicals to clean the toilets. Despite of these difficulties and challenges, all biogas plants were working well and the gas production was satisfactory.

Conclusions

In principle biogas sanitation systems for the household level could be an appropriate sanitation technology. Main benefit is the production of biogas which is easily available for cooking and replaces a considerable amount of traditional cooking fuel. The co-treatment with other organic household waste is highly recommended in order to increase the gas production. The survey showed a high satisfaction of the users and little objection to using the biogas from faeces as cooking fuel. Furthermore, the low operation and maintenance efforts required makes the system attractive as also waste handling is simple and does not require any direct human contact with the toilet waste.

However two major challenges still must be researched and improved if such a technology was to be implemented at wide scale in the region.

1. The study showed clearly that the quality of the effluent is not sufficient for use as fertilizer without restrictions or even for discharge into water bodies and that a post-treatment step is needed. Basically, the same technologies as for wastewater can be considered. In the context of decentralized biogas systems in low and middle-income countries, this can for example be an anaerobic baffled reactor with a subsequent planted horizontal or vertical filter (Borda, 2009, Tilley et al, 2008, Morel and Diener, 2006).
2. Current investment costs for a biogas reactor, of the type that is disseminated in the region, are far too high for an average family on Kumbalangi Island. With the current subsidy system and the current design and construction cost, the payback rate is 15 years. Additional technical measures for effluent treatment would even increase the

current investment cost making the system surely unaffordable for most families. Reducing cost contribution by the individual family is an urgent requirement, be this through subsidies or reductions of construction costs. Possible solutions could be to lower cost though mass production, to lower the unit cost, or else provide solutions constructed with other materials, such as the older brick built versions or simple plastic drum type reactors.

Acknowledgements

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Biogas Systems in Lesotho: an effective way to generate energy while sanitizing wastewater

TED
Technologies for Economic Development

In Maseru, Lesotho, the Non-Governmental Organization TED constructs biogas systems for decentralized wastewater treatment (BiogasDEWATS) since 2003 in households, schools, orphanages and military camps, improving food security through the re-use of plant nutrients in the treated water by irrigation.

Author: Mantopi MdP Lebofa, Elisabeth M. Huba

Abstract

This article describes Biogas as a decentralized wastewater treatment system implemented in Lesotho, where in 2002 a group of technicians, with strong interest in the link between environmental protection and human well-being, started to implement household biogas digesters for sanitation purposes in peri-urban settlements of the capital Maseru. The demand for the technology is created by problems with overflowing or leaking septic tanks and high-priced drinking water commonly used for irrigation. No subsidy is provided, thus owners pay the real cost for the systems. Although the investment cost for BiogasDEWATS is a little higher than for a conventional septic tank, the operation costs are significantly lower, plus it pays for itself in only three years. Biogas generated in these systems substitutes at least 15% of the daily required cooking fuel.

Introduction

The Kingdom of Lesotho (Figure 1):

- country with the highest lowest point above sea level in the world
- 30‘000 km^2 – all above 1‘400m above sea level; 80 % above 1‘800 m
- 28° - 31°S latitude and 27° - 30°E longitude
- completely surrounded by South Africa
- about 2 million people, the Basotho
- majority of households subsist on farming or migrant labor
- annual urbanization rate of 5.2 % (Maseru City Council, April 2011) due to droughts and floods – generally related to global climate change – that impact on agricultural yields and livestock herding
- level of urbanization: 23 % (2002 Survey, National Bureau of Statistics)
- exports diamonds, mohair, jeans, footwear
- water sold to South Africa through the multi-billion-dollar Lesotho Highlands Water Project (LHWP), which commenced in 1986
- is identified as one of the most vulnerable countries to climate change worldwide (Lesotho-Africa Adaptation Programme 2009).

Key Facts:

- Since 2003, TED designs systems according to the number of residents, mostly from 4 to 30 people (although sometimes even up to 300).
- Sizes of Biogas Digesters built so far range between 5 and 50m^3.
- Systems are constructed on site in brickwork (not pre-fabricated).
- Masons and craftsmen are trained by TED in skills and responsibilities for quality labor.
- System components include (1) fixed dome Biogas Digester (BD), (2) Anaerobic Baffled Reactor (ABR), (3) often combined with integrated Anaerobic Filter (AF), and (4) Planted Gravel Filter (PGF).
- Treated water is used for irrigation in the owners’ gardens, according to their preferences.
- Owners are trained by TED to understand and correctly maintain their systems.

Sanitation challenges and the MDGs:

- Improved sanitation coverage in 2008: 25 % in rural and 40 % in urban areas (WHO/UNICEF Joint Monitoring Report (JMP) 2010)
- If shared facilities were assumed to provide safe, convenient access to sanitation, then a further 35 % of the urban population would be covered, and Lesotho would be close to achieving the MDG sanitation target of 81 % in urban areas.
- Most of the sanitation facilities used are simple pit or unsealed VIP structures – even in middle-income households, as people do not know about other alternatives

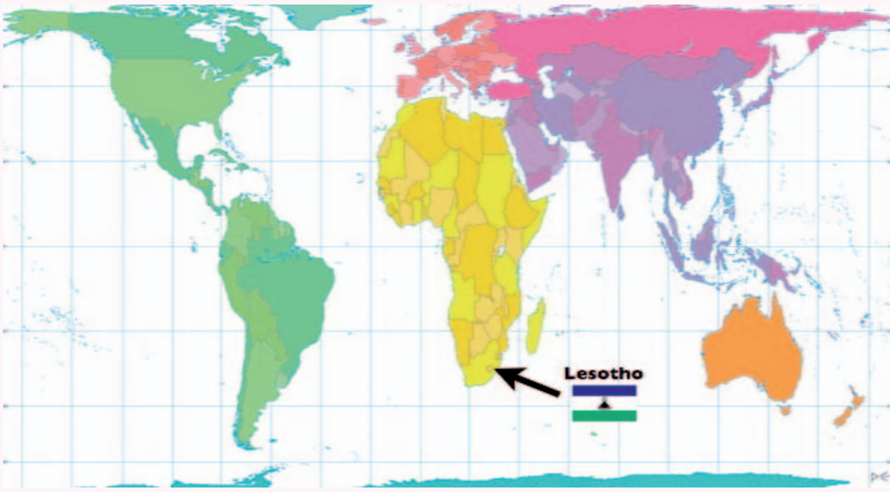

Figure 1: Location of Lesotho

Why Biogas Sanitation in Lesotho?

"Lesotho has water as its most important natural resource, second to her people. The ownership of all water within Lesotho is vested in the Basotho Nation. The Government of Lesotho has the duty to ensure that this resource is used in a sustainable manner and to the benefit of all users, and the responsibility to provide security of access to water sources and improved sanitation." (Lesotho Water and Sanitation Policy, Ministry of Natural Resources, 2007). Statistics may show an encouraging trend with regards to water coverage, but sanitation coverage is still far below the target. Based on the most recent data, from 2008, Lesotho has seven years to raise sanitation coverage from 40% to 81% in urban areas and from 25% to 66% in rural areas.

In 2007, diarrhoea and gastroenteritis were responsible for 14% of deaths of children under 13 years of age. They also accounted for 3% and 5% of deaths of men and women, respectively, in the same year (Ministry of Health and Social Welfare, Annual Joint Review Report, 2009).

Experience shows that it is hard to keep water and sanitation infrastructure functional, as it often fails before its planned lifetime, thus being a massive waste of investment. Water supply projects in rural and peri-urban areas are usually implemented in isolation, ignoring important links with sanitation, health and education. Children's education is directly influenced by the quality of water and sanitation facilities in schools, since low quality water supply and dark, dirty facilities do not promote a healthy learning environment.

In addition, people moving to one of the 11 urban centers in the country rarely find complete infrastructure provided by the city administration. While piped water supply is often available, centralized sewer systems do not, and will not, reach the new settlement areas within the next decades. The mountainous topography of the country, with steep slopes and rocky soils, impedes "business as usual" in wastewater collection and treatment. In Maseru, the connection rate to sewer lines is only about 4% (Water and Sewerage Company (WASCO), April 2011). A decentralized, privately financed and maintained wastewater handling system seems necessary.

TED's decentralized biogas sanitation system

Technologies for Economic Development - TED

TED is a Lesotho-based, non-profit, non-governmental organization, founded and registered in 2004 (Registration No. 2004/90). It began as the Biogas Technicians' Self-Help Group, which was established in 2003 by Basotho technicians who wanted to make sure that the environment, especially the trees and the ground water, are protected. They identified biogas digesters as a reliable technology for decentralized wastewater treatment and cooking gas production to tackle many of the most pressing problems faced by the people of Lesotho, like health, food, water, energy, environment and employment.

Since 2003, the primary focus has always been the engineering and fine-tuning of appropriate technologies (such as biogas systems, UDDTs, efficient wood stoves) to foster their long-term adoption by the Basotho. The NGO contributes to international knowledge sharing through consultancy work and lectures at national and international Universities since 2005, and in 2006 TED started cooperation with BORDA (Bremen Overseas Research and Development Organization), a German NGO specialized in community-based Decentralized Wastewater Treatment Systems (DEWATS).

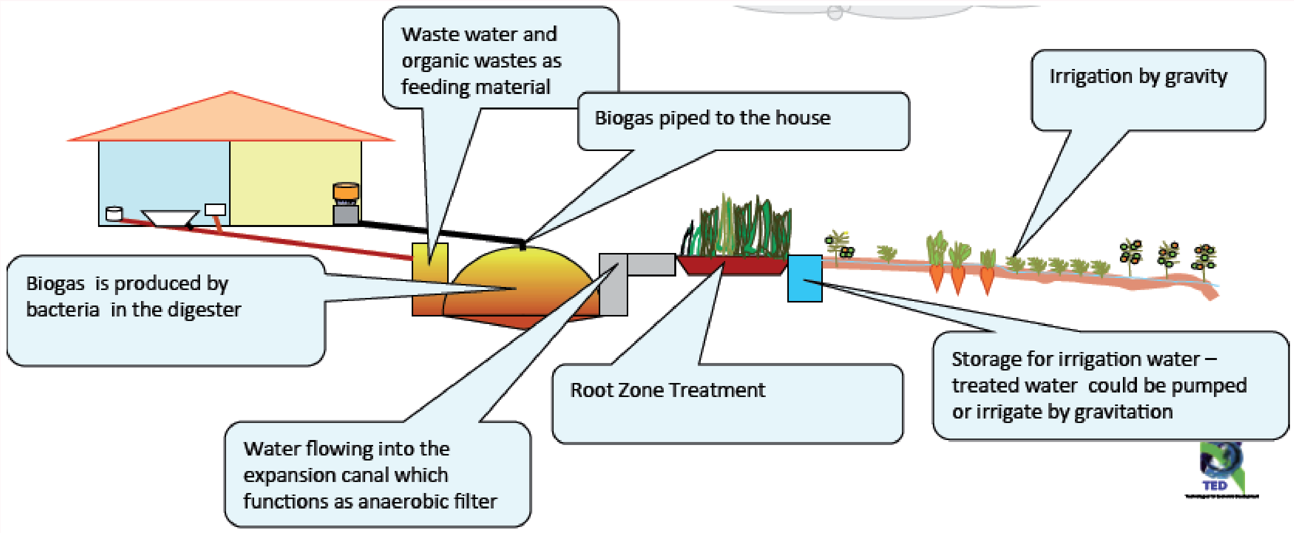

Figure 2: Original TED design for biogas sanitation

In 2007, TED started working under a seven-year agreement brokered by the Programme for Basic Energy and Conservation (ProBEC) and Climate Care Trust Ltd to roll out, in alliance with the World Food Programme, an efficient wood stove project, financed on the international carbon trading market. The initiative aims to minimize wood fuel gas emissions; Pioneer Carbon Ltd (PCL), a UK registered company, handles the carbon verification process and ensures the procedures for obtaining carbon credits.

Aiming at long-term sustainability of sanitation systems, TED applied for and was appointed, in 2010, the Country Coordinator of the WASH United Campaign that uses sports (mainly football, rugby and other ball sports) and celebrities to promote Hand Washing with Soap, and water and sanitation as a human right.

Technology details

The original TED Biogas Digester design is displayed in Figure 2, which is also used to explain the system to clients.

Solids settle at the bottom of the digester where bacteria feed on them, and convert any organic matter into gas and liquid. Thus, over time any organic solids are decomposed. Therefore education of system users not to throw plastic, sand, gravel into the digester is crucial. The same applies for water consumption: system owners are trained to control their water consumption in flush toilets and bathrooms, as highly diluted wastewater does not enhance biogas production.

TED has constructed over 150 systems since 2004. However, about 300 Biogas systems are known in Lesotho, due to the fact that several trainees and laborers left TED, after some weeks of experience, and set up their own similar business. In a large number of cases, their systems are not performing properly, due to problems in the quality of craftsmanship, lack of understanding of the biological processes taking place in the system, or simply having based the faulty construction on copied plans without knowing the engineering details. If the owners show up in TED's office asking for help TED offers support; however, to repair these systems – once constructed with wrong levels of inlet, outlet and overflow - is not possible in most of the cases. Nevertheless, TED intervenes to pamper the negative effects for the owners, and thus avoid a bad reputation for this technology.

The TED Biogas Digester is an underground, dome-shaped structure with an inlet and an outlet, which was adapted, and further developed, from Chinese, Tanzanian and Ethiopian models. At the inlet – without any additional stirring device, organic wastes from humans, animals or plants enter the digester, where solids settle and are converted into biogas. The air-tight, waxed dome made of bricks captures and pressurizes the biogas, and stable biogas production may be expected three to five months after wastewater starts flowing into the system, depending on its organic content.

Figure 3: Approaching the final stage of construction: biogas digester and anaerobic baffled reactor before being covered with soil and installation of planted gravel filter will start

From its first design, the TED biogas sanitation system was always connected to an Anaerobic Filter as a second treatment step and a constructed wetland for a third treatment, before using the effluent for irrigation in order to recycle the contained plant nutrients.

Since 2006, entering in cooperation with the DEWATS specialized German NGO BORDA (Bremen Overseas Research and Development Association), TED included an Anaerobic Baffled Reactor (ABR) as the second treatment step: an ABR is a biological treatment system where the almost solid-free effluent from the biogas digester passes through a series of chambers, leading to the formation of stabilized bio-sludge sediments at the bottom of mainly the first chambers. The size of the chambers depends on the sewage flow rate, such that the up-flow velocity of the water is less than the settling velocity of the solids. Figure 4 provides a sketch of an ABR displaying how the wastewater flows through this treatment step. In this sketch, the first chamber functions as settler and is equipped with a gas outlet. In the most common TED Design, the biogas digester replaces this first chamber.

In TED's design, the also mostly underground constructed ABR integrates an Anaerobic Filter (AF), shown in Figure 5. Like in the Baffled Reactor the water passes the filter vertically from the bottom to the top. The chambers are filled with filter material like stones, gravel or recycled and cut plastic bottles; these surfaces are proven to offer living space for bacteria dedicated to absorb organic particles.

The Planted Gravel Filter (PGF) is filled with gravel or with recycled pumice stones from Maseru-based jeans factories, and planted with aquatic plants. The PGF performs the final treatment to the effluent before its reuse in irrigation: biological conversion, physical filtration and chemical adsorption by gravel or pumice stones and absorption by plant roots take place in the PGF. The water is purified as is flows horizontally and slowly through the filter material. The plants provide a nice appearance to the whole system.

TED does the first planting in the PGF as soon as water accumulates in the third treatment step. Only locally available aquatic plants from riverbanks and wetlands are planted. As experience show that they will grow very fast in their new environment due to the offer of plant nutrients in the treated wastewater, planting starts with only few plants distributed in the PGF. Owners take over responsibility for maintaining the plant cover adding real flowers, even roses, to the wetland plants.

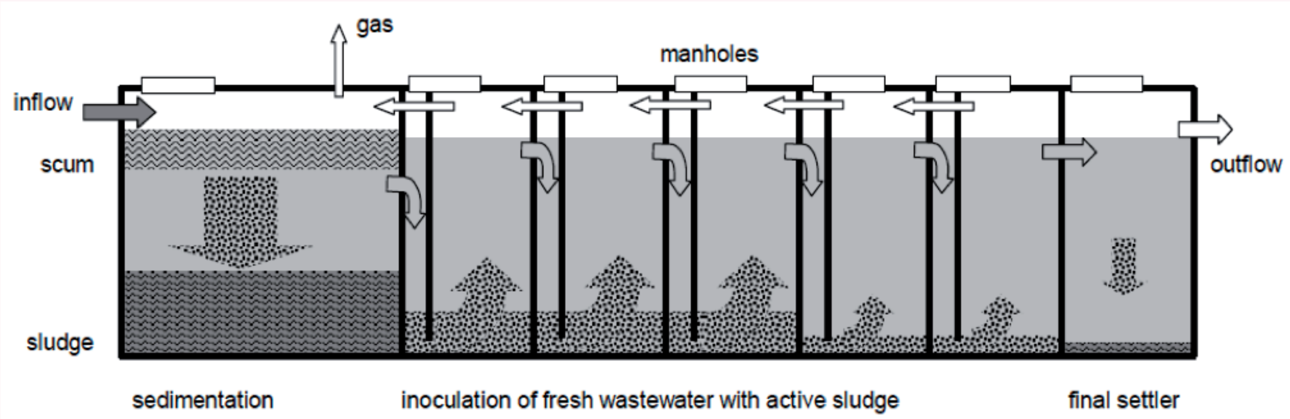

Figure 4: Wastewater flow through an ABR TED BORDA 2006

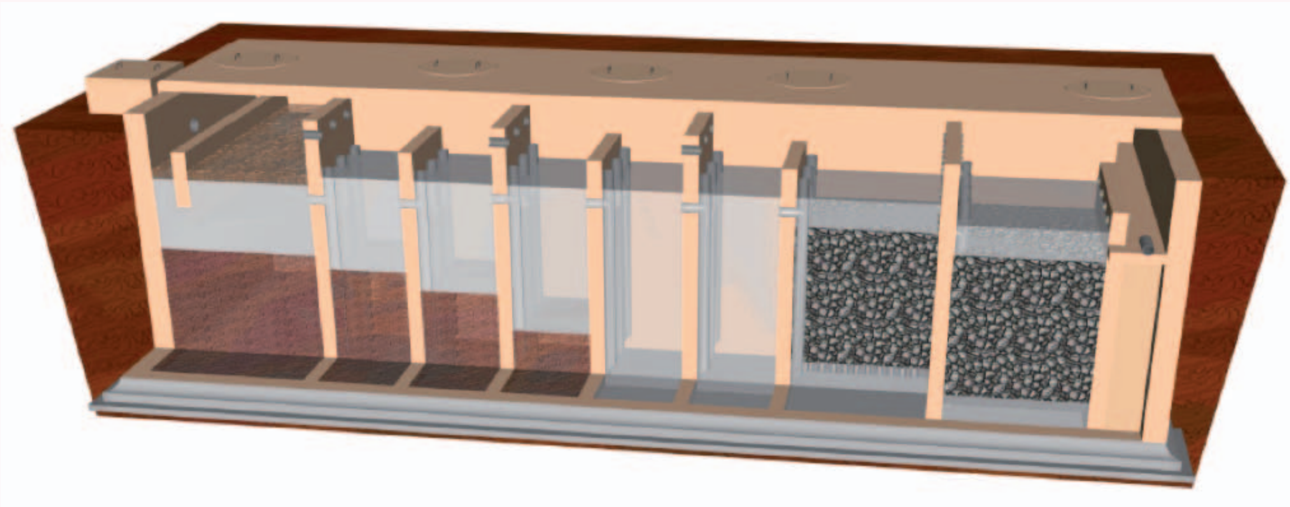

Figure 5: Example of an underground ABR with integrated Anaerobic Filter as last chambers before the treated wastewater overflows into a planted gravel filter TED BORDA 2006

The effluent water is tested ever since, often carried out as research work by international students; no harmful substances or pathogens have been detected so far. However, TED recommends to the system owners to stick strictly to soil and root irrigation.

Figure 6: Nice-looking on-site wastewater treatment: treated water at a PGF with recycled pumice stones shortly after system start (left) and PGF after 3 years of operation

Sustainability factors

Social and cultural sustainability

Hygiene awareness, health and nutrition aspects and community and family participation are key aspects for TED to achieve social and cultural sustainability of sanitation technology in general and the installed Biogas DEWATS systems in each specific case. This is enhanced by the strong involvement of the homeowners in the decision on where to place the treatment system for the household's wastewater and the choice of re-use options. Also, wherever possible, already existing septic tanks and sanitation facilities are integrated into the new design of the treatment system. Due to these close and personal relations with its clients, TED's promotion strategy relies on "word of mouth" and clients' testimonies to other interested households.

In cases where communities (such as villages, schools, orphanages) ask for upgraded sanitation systems, TED informs the communities about different options, including Urine-diverting Dry Toilets (UDDTs). Urine diversion technologies and BiogasDEWATS may also be successfully combined.

Working closely with local partners, TED spreads the message about the importance of sanitation, hygiene and water for human well-being to different groups via various educational materials. Local authorities, civil society organizations, and the media form part of this still informal sanitation network that TED is creating in Lesotho.

Economic and financial sustainability

"Social Marketing Principles" are adapted to sanitation requirements and TED's strategy is based on three pillars: (1) stimulating demand, (2) private sector involvement in supply chain, i.e. construction material is purchased only on the local market, and (3) social status.

BiogasDEWATS has several "unique selling points", as a real alternative to the conventional septic tank. Price comparison between conventional on-site waterborne sanitation systems and BiogasDEWATS results currently in lower investment costs for the conventional system, but in significantly lower operational costs for BiogasDEWATS. The example of a Bill of Quantity and quotation given in Table 1 relates to a 6 m^3 biogas digester with corresponding ABR, AF and PGF; the total cost for "construction and supervision" depends on the size of the system and the distance between the construction

Figure 7: Before and after the installation of BiogasDEWATS

Table 1: Bill of Quantity in 2011 for 6m³ BiogasDEWATS installation

Material	Unit	Quantity	Supplied by	Unit Price (Maluti)	Total Price (Maluti)
Ordinary portland cement 50kg	bags	50	Client		
Plastering sand	m^3	3	Client		
Rough sand	m^3	4	Client		
Course aggregates (19 mm)	m^3	3	Client		
Burned bricks grade 2, 220x110x70mm	Items	2000	Client		
Concrete blocks 4“	Items	400	Client		
Water proofer	bags	10	TED	40,00	400,00
Chicken mesh (15x1200x25) (60m^2)	m^2 /roll	1	Client		
Lintels (105/0,9m)	Items	2	Client		
Manhole covers 450x600mm	Items	2	Client		
Manhole covers 300x300mm	Items	1	Client		
4“ (110mm) PVC pipe	m	5	Client		
4“ (110mm) t-junctions	Items	16	TED	70,00	1.120,00
4“ (110mm) elbow joints	Items	6	TED	45,00	270,00
Pipe Cover (110mm) female	Items	20	TED	30,00	600,00
Filter material	m^3	2	TED	300,00	600,00
100l drum	No.	1	TED	180,00	180,00
Water for construction	m^3	31			
Wax and oil	Items	1	TED	150,00	150,00
Gas connection set	Items	1	TED	200,00	200,00
Galvanized pipe 4/3“	m		later/Client		
Water trap galvanized	Items	1	later/Client		
Electrical pump	Items	1	later/Client		
Biogas stove	Items		later/Client		
Subtotal Material					3.520,00
Labour					
Earthwork including landscaping (We request Client to do this, we will supervise)					1.500,00
Contruction and supervision					9.800,00
Subtotal Labour					10.400,00
Total					13.920,00

site and TED’s office. In September 2011, it equals to USD 1,850 and is paid by the clients in three quotas.

Given the specific geophysical context of Maseru and its growth rate into peri-urban mountainous areas, the connection to centralized sewer lines and wastewater treatment plants is for most of TED’s clients just not possible.

Wastewater naturally produces biogas and the treated effluent that still contains plant nutrients is reused in the garden.

- Owners save money because they do not have to call a truck to empty the septic tank. They can use daily biogas for cooking: at least 15% of the cooking fuel (electricity, LP gas or fire wood) could be substituted by biogas, some households replace up to 100% of their cooking fuel during summer time.

- They can use the water for irrigation, thus reducing the fresh water bill. The money saved within a reasonable time (some owners calculate a maximum of three years for amortization) can be used for further investments to develop the local economy.

The costs for a biogas digester and related wastewater treatment steps are divided into production costs, running costs and capital costs:

Production costs depend on the size of the BiogasDEWATS and the prices of materials and labor; they include all expenses necessary for building the system (e.g. land, excavation work, construction, piping and gas utilization system).

Running costs include: the feeding and operating of the system; supervision, maintenance and repairs; storage, re-use and/or disposal of the effluent; gas distribution; and administration. TED's BiogasDEWATS in general have very low running costs, as the feeding happens by gravity, and maintenance required is very low, due to strict quality control during construction. In some cases, where the treated water cannot flow by gravity to the gardens being irrigated, electrical pumps are used.

Capital costs consist of pay back and interest for the capital taken up to finance the installation. Many customers provide building materials to cut costs, therefore only a few have to borrow money. In calculating the depreciation, the economic life span of BiogasDEWATS can be taken as 15 years, provided maintenance and repairs are carried out regularly and as needed (Renwick et al., 2007). This life span is understood as an international average and depends on the quality of the construction, regular feeding, gas use and maintenance of gas pipes and system parts that are above ground.

TED's clients have various problems and therefore various reasons why they want to install a BiogasDEWATS in their premises. The money saved by using "waste" as energy source and ferti-irrigation needs to be calculated for each specific case.

Environmental sustainability

BiogasDEWATS installed by TED fit into a local, ecologically sustainable cycle:

- Natural processes take place in the BiogasDEWATS
- Anaerobic digestion improves the fertilizer quality of human and animal waste by converting the contained plant nutrients into liquid form and therefore more easily accessible for plants
- The system avoids pollution of sub surface and groundwater by treating wastewater to manure up to required standards
- Using biogas instead of firewood or fossil fuels reduces greenhouse gas emissions, especially since the methane of biogas would otherwise be a greenhouse gas itself.
- As the system is mostly constructed underground, the landscape is not negatively affected.

Technical sustainability

In order to assure technical sustainability and continuous updating of technical staff, TED applies the following approaches:

1. Integration into worldwide networks and cooperation with research partners, like BORDA and the University of Science & Technology Beijing – Centre for Sustainable Environmental Sanitation (USTB-CSES),

2. Collaboration with other partners to integrate the technology into a broader environmental sanitation concept and "Service Packages". This includes school sanitation, community-based sanitation, and sanitation systems for hospitals, hotels and tourism resorts, military camps, and agricultural enterprises.

3. Inclusion of applied research into implementation. Research & Development include topics like sanitation and renewable energies, sustainable environmental sanitation, and energy from agriculture and livestock. Monitoring of system performance and data evaluation by academic partners support R&D. TED offers future-oriented researchers to gain experience in reuse-oriented wastewater treatment, even though this topic is not yet included in the curriculum of the National University Lesotho or technical colleges.

Figure 8: Underground BiogasDEWATS: beautifying the compound with flowers in the PGF and treated water always available for ferti-irrigation of lawn and bushes

4. Training of home owners and operators, and the offering of after-sales services. During the first 12 months after construction, TED provides training to the owners and operators (in the case of schools or enterprises), in order to familiarize the responsible

person with all relevant details for successfully maintaining a wastewater treatment process for biogas production and irrigation water re-use. Understanding that BiogasDEWATS functions due to a well-maintained biology of micro-organisms minimizes requests for maintenance support as the owner will maintain survival of the micro-organisms.

Lessons learned for implementation

TED's experience and "success story" so far shows that there are acceptable, affordable and ecologically safe sanitation technologies already installed in peri-urban settlements in Lesotho. The fact that TED is implementing BiogasDEWATS without subsidies indicates clearly that a sanitation market is viable, as customers pay fully for the systems.
Sanitizing wastewater on-site, making it fit for irrigation, saving valuable drinking water and encouraging home gardening, especially in a country with high incidence of HIV/AIDS, where it helps to improve the living conditions of the population. Turning organic waste into biogas for cooking is an important measure for mitigating and adapting to Global Climate Disruption.

Challenges & Lessons Learned

Challenges encountered and relevant for the way forward refer to craftsmanship quality, expertise in BiogasDEWATS construction, ownership and the means of coping with the increasing demand. TED's way of dealing with these challenges is and was always developed in a very pragmatic manner, due to its characteristics as a small non-profit organization in a country with an endless number of constraints and limitations. The following overview should be read as an outline for "lessons learned" on how to up-scale implementation of "Biogas for Sanitation" purposes.

i. Craftsmanship Quality: continuous quality control of construction staff, in-house training and a quality management system.

ii. Expertise in construction: TED's national construction team carries out standardized constructions up to 50 m^3; only for very special situations international cooperation partners provide short-term engineering consultancy, paid for by TED.

iii. Ownership: BiogasDEWATS sponsored by a third party suffer increased system performance problems, due to the lack of responsibility and ownership; this is often observed at community-based systems. TED developed a user training principle that includes not only the technically responsible person but also the person who will benefit most from a well-functioning BiogasDEWATS, like the cook in a school or orphanage.

iv. Increasing demand: this may only be answered by an increasing number of skilled and responsible BiogasDEWATS constructors. Therefore TED applied for funds to train five masons, and received financial support in 2010 from Levi Strauss Foundation to this aim. Today, the trainees are integrated into the construction team.

v. International cooperation as partners is giving and receiving: partners are learning from TED's experiences, and TED is learning by being actively integrated into international networks.

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Evaluation of formulas to calculate biogas production under Moroccan conditions

This paper presents different formulas for calculating biogas production and evaluates them for use in the Moroccan context.

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Abstract

A biodigester was installed in Dayet Ifrah and connected to a farmer's toilet and to a barn in June 2010. This is the first pilot unit built in Morocco used to produce biogas from anaerobic treatment of human excreta and animal slurries. The biogas produced is used as energy in cooking food and heating water. The entire biogas system works normally and operates properly. But, after one year, the only problem we met is that the biogas production is low. The purpose of our study is to check if the weakness of the biogas volume is due to the dimensions of the biogas system. Our study confirms why biogas production is low. So, five other dimensioning formulas are evaluated and compared to the formula used by GIZ. All formulas are compared and ranked by the ELECTRE III method and then by the sensitivity analysis. Results indicate that under Moroccan conditions Vedrenne's formula (Vedrenne, 2007) is the most appropriate equation to calculate the biogas production in Moroccan context. In addition, the formula used in Dayet Ifrah over-estimated the volume and the Vedrenne's formula should be used.

Introduction

Anaerobic digestion is a biological process of degradation of organic input materials. In the anaerobic digestion process, micro-organisms convert complex organic matter to biogas, which consists of methane (CH^4) and carbon dioxide (CO^2) saturated with water. It seems to be an efficient way of wastewater treatment and renewable energy production. De La Farge (1995) provides an overview of biogas production and its environmental issues. A biogas plant can not only solve environmental problems, but also produce renewable energy or green energy.

In Morocco, biogas is not yet well developed for the following main reasons:

- Limited financial aids
- Technical problems (corrosion, sealing, …)
- No continuous training for managers and technicians
- No after-sales service
- Conventional energies (wood, butane, etc…) competitive and subsidized
- Little interest of people : wood is free and butane is prestige
- No integration of the private sector as manufacturer, repairer…

Key Messages:

- The biodigester is designed for 17 inhabitants, 5 cows, 3 calves, one mare, 2 donkeys, one mule and about 50 sheep and lambs.
- The biodigester's volume is about 40 m^3
- Organic load per person is 50 g COD per day in Moroccan rural areas.
- Total organic load of the farmer COD_{tot} = 30,61 kg COD per day.
- Dry matter in the manure is 20%.
- The blackwater and the manure are treated in the biodigester.
- Agriculture based economy.
- Water source – ground water

'Douar' (nomad village) Development Project, pilot project to reinforce local capacities in Dayet Ifrah (population 1500) with a participative approach. Activities include training, improvement of conditions for access to drinking water and sanitation, and creation of income generating activities (reuse of wastewater etc. on-going activities).

Dayet Ifrah village was selected as rural Moroccan area in order to test the experimentation of producing and recovering biogas for domestic or public uses. This place, with latitude of 33°34'N and a longitude of 4°55'W, is a wetland and a water resource for drinking water. It's recognized as a biological and ecological interest site to be preserved in Morocco. It's characterized by a sub-humid climate with cold winters and cool summers, with an annual rainfall of 1118 mm.

The project of Dayet Ifrah village is supported by GIZ within the AGIRE programme „Support to the Integrated Management of Water Resources program in Morocco“. It is the first pilot project in Morocco in term of experimentation and research in this field.

The purpose of our study is to compare different formulas used for counting biogas productions and then to choose the best one for the Moroccan context using a Principal Component Analysis. Our study shall allow better design of the future biodigesters planned in Dayet Ifrah by GIZ. It seems that the one built in June 2010 produces less biogas than expected.

Materials and Methods

Design and description of the biodigester

This digester is a continuous type with fixed dome, built entirely underground. As its name indicates, this type of digester has a fixed collection gas dome. It's built using bricks and mortar as it's shown in the Figure 1.

The users of biogas in the Dayet Ifrah village used a filtering individual pit to collect its domestic wastewater. But, this way of wastewater collection is inadequate and out standards of Moroccan laws. Since June 2010, the wastewater has been collected in a biodigester, which also receives the slurry of cattle.

Organic wastes from cattle slurry and domestic wastewater are mixed and treated continuously in our digester type psychrophilic fermentation because the temperature varies between 12°C and 17°C (Benhassane, 2011). The biogas produced is stored in the gasometer capping digester (Figure 2). It is used as fuel in the farmer home, and the heat generated is used for heating and cooking (Figure 3). As it is shown in Figure 4, the objective is of the digester is threefold: i) to reduce the pollution load, ii) to enhance fertilising elements and iii) produce biogas.

Figure 2: Gasometer capping Dayet Ifrah biodigester (Photo: GIZ, 2011)

Figure 3: Biogas cooker at the farmer's kitchen in Dayet Ifrah (Photo : ABARGHAZ, 2011)

Figure 1 : Biogas plant during construction in Dayet Ifrah village, Morocco (Photos : ABARGHAZ, 2010)

The study considered manures and slurries produced by the farm and human excreta produced by all members of the family which is composed of 17 people and has until eight cattle (five cows and three calves), about 50 sheep and lambs, one mare, two donkeys and a mule that are used for transportation.

The daily input into digester is 124 kg of slurries and 42 kg of human waste. According to Amahrouch and Jlaidi (1995) the manure should be mixed with water at a ratio 1:1, therefore 124 liters of water and/or urine are added to dilute slurries. The hydraulic retention time chosen is 150 days. The volume of the biodigester was chosen as follows: (124 x 2 x 150)/0.95 = 40 m^3. The volume of biogas produced per day varies from 0.7 to 5 m^3 (Abarghaz, 2009).

Calculation of biogas production

a: Formula used in Dayet Ifrah:

For the biodigester built in Dayet Ifrah village, GIZ used the following model „Formula used in Dayet Ifrah“ to dimension the production volume of biogas.

According to the study done by GIZ in 2009 in designing the existing biodigester in Dayet Ifrah village, the biogas production in summer can reach 35 liters per kg of fresh matters (Wauthelet et al., 1996). In winter, production can be reduced to 5 liters per kg (Wauthelet et al., 1996). This production is dependent on the hydraulic retention time of matters in the biodigester, on the temperature and on the quality of organic matters. The substrates should be collected as often as possible (once or twice a day) and be the freshest possible.

The daily quantity of biogas produced by the slurries alone and if the toilet is also connected to the biodigester is shown in Table 1. When adding faeces, biogas production will be increased by 190 liters per day.

We also need to estimate total chemical oxygen demand that could be converted to biogas :

- COD_total = COD_human + COD_manure
- The percentage of dry matter (DM) in the slurry represents 20 %, corresponding to 200 g DM/kg
- COD_manure = (DM + 20 % . DM) x 124 = 240 x 124 = 29‘760 g/d
- COD_human = 50 * 17 = 850 g/d
- COD_total = 29.76 + 0.85 = 30.61 kg/d

It is assumed that half of COD_total was converted to 4.53 m^3 of biogas at 20°C and to 0.81 m^3 at 10°C.

So, the equation used in the Dayet Ifrah project to calculate the produced biogas Q_biogas (m^3/d) was:

$$Q\_biogas = 0.3 \times COD\_total \qquad (1)$$

b: Other formulas:

In the following, 5 other formulas for calculating the volume of the produced biogas which seem to be applicable in the case of continuous fermentations of completely mixed animal and human substrates are explained below:

i: Formula according to Boursier (2003) :

$$Vg = Ps \times COD\_reduced \qquad (2)$$

where:

- Vg : the quantity of biogas produced (m^3)
- Ps : the specific gas production (Figure 5)
- COD_reduced/d: Chemical Oxygen Demand removed per day (kg COD/d)

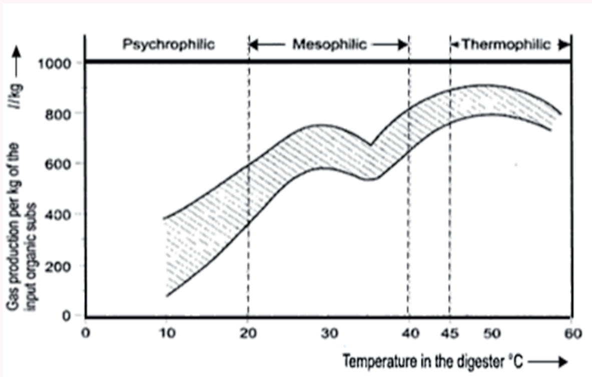

Figure 5 : Temperature effect on gas production (Nijaguna, 2002)

ii: Formula according to Bouille and Dubois (2004):

$$Q = Bo.Mo \qquad (3)$$

where:

- Q: The amount of biogas produced (m^3)
- Bo: the potential of biogas production (Figure 5)
- Mo: oxidisable matter.

Table 1 : Biogas production per day (Slurries and faeces)

Quality of Biogas production					
Slurry (kg/d)	Faeces (kg/d)	Summer (20°C)		Winter (10°C)	
		(l/kg)	(l/d)	(l/kg)	(l/d)
124	-	35	4340	5	620
124	42	-	4530	-	810

Mo could be expressed in relation of COD by using the empirical relationship of Mo according to BOD_5 and COD, i.e. Mo = (BOD_5 + 2 COD) / 3. Additionally, we know that COD/BOD_5 = 2.5 and therefore Mo = 0.6 COD.

iii: Model Hashimoto according to Nijaguna (2002) (equation n° 3).

$$Q\_m\ (m^3/d) = VVJ.V \qquad (4)$$

where:

- VVJ : Technological efficiency
- V : Biodigester volume (m 3)

$$VVJ = B.(Mo/HRT) \qquad (5)$$

where:

- B: Biological efficiency
- Mo: matter oxidizable
- HRT: hydraulic retention time.

$$B\ (m^3\ CH_4/\ kg\ Mo) = Bo.\ [1 - (K/(Mm.HRT) + K - 1)] \qquad (6)$$

where:

- K: Constant of inhibition
- Mm : kinetic coefficient
- Bo : Production potential of methane = 0,35 /kg Mo

$$Mm = 0.013 * T - 0.129 \qquad (7)$$

$$K = 0.6 + 0.021.10^{0.05}\ .Mo \qquad (8)$$

iv: Formula according to Vedrenne (2007) :

$$QCH_4 = Bo\ .\ Mo\ .\ MCF\ .\ Sg \qquad (9)$$

where:

- Bo : potential production of methane per kg of matter oxidizable ,
- Mo: matter oxidizable
- Sg : Part of faeces directed towards anaerobic system,
- MCF : Methane conversion factor (Table 2)

v: Formula according to Executive Board-CDM (2008):

$$QCH_4 = S_y\ .\ COD\ .\ FCM\ .\ COD_f\ .\ F\ .\ 16/12 \qquad (10)$$

where:

- S_y: Volume of wastes feeding the biodigester
- COD: Fraction of degradable organic matter
- FCM: Methane conversion factor,
- COD_f: Fraction of COD converted to biogas
- F: Fraction of methane in gas (0.5, IPCC, 2006).
- 16/12: Conversion factor carbon to methane.

Evaluation of the formulas

Before implementing the pilot project, GIZ recommended Eq. 1, the „Formula used in Dayet Ifrah“ for estimating the biogas production. However, this equation may is not adapted to the Moroccan context. Therefore n this paper we wanted to answer the following question: Which equation should be used to estimate the biogas quantity in Dayet Ifrah?

In this paper, for comparing the equations described above we chose principal component analysis (PCA, Le Moal, 2002). The results of the PCA are then compared and ranked using the ELECTRE III multi-criteria method, and then a sensitivity analysis will be applied in order to check the stability of the ranked formula.

PCA is one of the most known methods and flexible for data analysis; it's a descriptive method that aims at describing and graphing the similarities between individuals from all variables. The implementation of PCA can be used according to the Factor Analysis procedure of SPSS (Statistical Package for the Social Sciences) software. Factor Analysis is based on the calculation of averages, variances and correlation coefficients. It's a multivariate data analysis technique whose main purpose is to reduce the dimension of the observations and thus simplify the analysis and interpretation of data, as well as facilitate the construction of predictive models. PCA is a linear dimensionality reduction technique, which identifies orthogonal directions of maximum variance in the original data, and projects the data into a lower-dimensionality space formed of a sub-set of the highest-variance components.

ELECTRE (ELimination and Choice Expressing REality) is a family of multi-criteria decision analysis methods. ELECTRE III was developed by Roy (1968, 1991) in response to deficiencies of existing decision making solution methods. It is a mathematical method of decision aid, typically used in the field of waste management, its principle is based on the ranking of the different proposed actions to choose the most appropriate (Saaty, 1980). We chose ELECTRE III method

Table 2 : Methane conversion factor (MCF) for storage of cattle slurry for different temperatures and retention times.

Retention time (Days)	Temperature (°C)			
	10	15	20	30
30	0	0	0,02	0,34
100	0	0	0,31	0,63
180	0,15	0,27	0,41	0,77

because it was applied with success during the last two decades on a broad range of real-life applications in ranking problematic.

Results and Discussions

According to the measurements at the biogas system in Dayet Ifrah carried out from April 2011 to July 2011 by Benhassane (Benhassane, 2011), the results are summarized as follows:

- As it is shown in the Table 3, the ratio acidity on alkalinity found is around 0.5, which shows that there is no accumulation of volatile fatty-acids (propenoic acid, acetic acid, butyric acid) which certainly disturb the anaerobic digestion process and consequently the production of biogas.

Table 3: Measurements of $CaCO_3$ and fatty-acids concentrations

	Alkalinity (g $CaCO_3$)	Acidity (g)	Acidity/ Alkalinity
June 13, 2011	11	3	0,27
June 16, 2011	14	6,75	0,48
June 23, 2011	10,45	4,76	0,46
June 27, 2011	12,23	5,66	0, 46

- The measured pH value in the influent of the digester was 7.4 (N = 17, standard deviation = 0.2) and in the outlet 8.1 (N = 17, standard deviation = 0.2). The higher value of the pH in the effluent corresponds to the results of a search carried out by Kupper and Fuchs (2007).

- According to the BOD_5 analysis the performance of the digester was 82 % (Table 4). On May 18, 2011, we observed COD to BOD_5 ratio of 1.35 showing high biodegradability of the substrate.

Table 4: BOD_5 and COD analysis results

	BOD_5 inlet (mg/l)	BOD_5 outlet (mg/l)	COD inlet (mg/l)
May 18, 2011	8500	1550	-
May 27, 2011	9200	1200	-
June 13, 2011	-	1150	-
June 16, 2011	9550	1400	-
June 23, 2011	7600	1180	-
June 27, 2011	8500	1100	-

- The measurements regarding removal of bacteriological parameters are shown in Table 5

According to the results shown above, the Dayet Ifrah biogas system works normally and operates properly. So, the lower volume of biogas produced is only due to the equation used to dimension the production of biogas.

By using the evaluation methods described above, it was found that Vedrenne's formula (Eq. 9) is the most appropriate to estimate the production of biogas in the context of our biodigester. Vedrenne's formula was ranked first among all formulas when applying the ELECTRE III method.

When applying the different formulas to estimate biogas production, we calculated the quantity of biogas produced daily, corresponding to a rate of COD removed (varying from 10 to 100%) and under different temperature conditions (minimum =10.5°C and maximum =20°C). The formula used in Dayet Ifrah (Eq. 1) is over-estimating the biogas quantity compared to Vedrenne's formula (Eq. 9) especially in summer (Figure 6).

Conclusion

The decision to construct an UDDT also involved the The results of our study have shown that the quantity of biogas produced in the digester as estimated by the Formula used in Dayet Ifrah (Eq. 1) are overestimated especially in conditions of high production i.e. high temperature. Using principal component analysis, ELECTRE III method and sensitivity analysis, we obtain the most appropriate formula for calculating the amount of biogas produced in the digester existing in Dayet Ifrah under Moroccan rural conditions. Therefore, we can consider that the Vedrenne equation (Eq. 9) is the closest to the reality of the Moroccan context in estimating quantities of biogas produced.

The results can help with designing new biogas systems planned for Morocco. However, the biogas volume should in second step be measured in the area of this study to confirm that indeed the equation found is the closest to the reality of the produced biogas volume. The technology is new in Morocco and as such will need demonstration at other farms in the study area to further the information on these systems and confirm the study's conclusion.

The overall outcome of this study is the optimization costs investment, operating and maintenance. This attainment allowed us to correct the calculation methods for future sites with more efficiency and effectiveness. The biogas system works normally if operated properly and well designed.

Table 5 : Bacteriological analysis results

Date	Localisation	Total coliforms	Faecal coliforms	Faecal streptococci	Clostridium
June 14, 2011	Inlet	$3,2\ 10^5$	$4,2\ 10^4$	$3,9\ 10^3$	$4,2\ 10^4$
	Outlet	$4,2\ 10^2$	$2,1\ 10^2$	$3,1\ 10^2$	< 1
Elimination rate		99,87 %	99,5 %	92,05 %	> 99,998%
June 20, 2011	Inlet	$4,2\ 10^4$	$2,2\ 10^4$	$1,3\ 10^3$	$2,1\ 10^4$
	Outlet	$2,1\ 10^2$	$3,5\ 10^1$	$2\ 10^1$	< 1
Elimination rate		99,5 %	99,84 %	98,46 %	99,995 %
June 07, 2011	Inlet	$5,1\ 10^3$	$2,1\ 10^3$	$4,1\ 10^2$	$2,1\ 10^3$
	Outlet	$1,4\ 10^2$	2,1 101	$1,5\ 10^1$	< 1
Elimination rate		97,25 %	99%	96,34 %	> 99,95 %

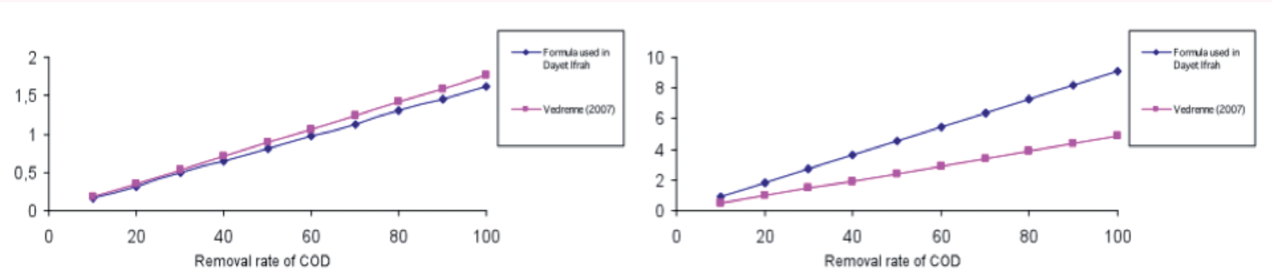

Figure 6 : Daily quantity of biogas produced (m³) depending on the COD removal rate in winter (left) and summer (right) calculated using the Formula used in Dayet Ifrah (Eq. 1) and Vedrenne's formula (Eq. 9).

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