Sandec
Water and Sanitation in
Developing Countries

Decentralised Co-Digestion of Faecal Sludge with Organic Solid Waste




Case Study in Maseru, Lesotho

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Bremen Overseas Research and Development Association (Borda), Germany
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Abbreviations

Borda	Bremen Overseas Research and Development Association, Germany
CIM	Centre for International Migration and Development, Germany
Eawag	Swiss Federal Institute of Aquatic Science and Technology
Sandec	Department for Water and Sanitation in Developing Countries, Switzerland
TED	Technologies for Economic Development, Lesotho

AD	Anaerobic Digestion
COD	Chemical Oxygen Demand
DEWATS	Decentralized Wastewater Treatment System
NGO	Non Governmental Organisation
SWM	Solid Waste Management

1. Summary

It is well known that inadequately treated sewage and industrial wastes are some of the main sources of water pollution and are responsible for the introduction of disease causing pathogens and toxic substances into the aquatic environment. In Lesotho, as in all other countries, urban areas generate large amounts of solid waste whose environmentally safe disposal is one of the biggest challenges to government. Therefore, there is need for investment in sanitation and solid waste management in order to reverse the situation and/or limit risks for disease vectors to proliferate (Statement of the Minister of Tourism, Environment and Culture, 2005).

In 2002, the small Maseru based NGO “Technologies for Economic Development” (TED) was established with the main focus to disseminate fixed-dome biogas digesters. By now, TED has built more than 70 digesters. In the first instance, the digester serves as on-site sanitation solution and replaces usually malfunctioning storage tanks, which discharge untreated wastewater into the environment and are associated with comparatively high costs of operation. The biogas is used for cooking, thereby mostly replacing expensive bottled gas. The digestate is used for irrigation and fertilization of the vegetable garden and increases the yield of domestic food production.

Some of these digesters are also fed with organic solid waste (OSW) or animal dung. The extraction of biogas out of organic solid waste in an urban and suburban context in low and middle-income countries is considered as an issue that has only come up in the recent past. Information related to this kind of digesters treating organic solid waste is scarce.

Thus, Sandec, the Department of Water and Sanitation in Developing Countries at the Swiss Federal Institute for Aquatic Science and Technology (Eawag), is interested in getting more information about these low-tech AD systems in Lesotho that are feasible to treat organic solid waste, either as a main feedstock or in combination with animal dung or faecal sludge. This report summarizes a case study conducted in Maseru, Lesotho.

In order to get more information about these biogas systems several plants installed by TED-Borda were analyzed. Gas production as well as the CO_2-content of the biogas were measured. Waste water samples were taken and analyzed according to chemical oxygen demand (COD), pH, Temperature, redox-potential and heavy metal content. Feedstock of material that was manually fed into the digester (kitchen waste, animal dung) was monitored by the owners. Furthermore, interviews with the owners or operators of the plants were conducted.

The results of the study reveal that the biogas plants are feasible to treat organic solid waste. The amount of biogas produced by the biogas plants is very differing. Agricultural plants with a lot or animal dung as feedstock generate a lot of biogas that covers most of the cooking energy demand (100% in summer, 20-40% in winter). Biogas plants that are mainly fed with faecal sludge generate less biogas, whereas adding kitchen waste increases the biogas yield to a certain extent.

2. Background

2.1. Anaerobic Digestion 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 municipal solid waste into still commonly used open dumps. The waste, mainly consisting of organic material, dumped in open places causes heavy environmental pollution to soil, groundwater and surface waters.

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 its production out of biodegradable waste is willingly seen. Thus, AD is attaining more relevance in the 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 feasible 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 feacal 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 organic solid waste in an urban and suburban context in low and middle-income countries is considered as an issue that has only come up in the recent past. Information related to this kind of digesters treating organic solid waste is scarce.
Thus, Sandec, the Department of Water and Sanitation in Developing Countries at the Swiss Federal Institute for Aquatic Science and Technology (Eawag), is interested in getting more information about low-tech AD systems that are feasible to treat organic solid waste, either as a main feedstock or in combination with animal dung or faecal sludge.

2.2. Situation in Lesotho

About 84% of Lesotho's total population lives in the rural areas, 62% of which has access to portable water, while in the urban areas, the water supply coverage is around 52%.
It is estimated that 52% of households in the rural areas have no toilet facilities, as opposed to 2.9% in the urban areas. In addition, 9.2% of the urban population have water or flush system, whereas 45% use Ventilation Improved Pit latrine (VIP). On the other hand, only 1% of rural households have access to flush system and 13.9% to VIP.

It is well known that inadequately treated sewage and industrial wastes are some of the main sources of water pollution and are responsible for the introduction of disease causing pathogens and toxic substances into the aquatic environment. In Lesotho, as in all other countries, urban areas generate large amounts of solid waste whose environmentally safe disposal is one of the biggest challenges to the government. Therefore, there is need for investment in sanitation and solid waste management in order to reverse the situation and/or limit risks for disease vectors to proliferate (Statement of the Minister of Tourism, Environment and Culture, 2005).

This report summarizes a case study conducted in Maseru, Lesotho, where AD technology is mainly implemented for faecal sludge treatment. But some of the fixed-dome digesters operated in Maseru are also fed with organic solid waste (kitchen waste, animal manure) and therefore of interest for further investigation.

3. Objectives

The objective of this study is to get precise information about the performance of the DEWATS-Systems of TED-Borda. The monitoring of operating DEWATS-systems shall give reliable data regarding the gas production as well as the suitability of the plant when getting fed with kitchen waste or animal dung in addition.

Monitoring data may also help in devising strategies for enhancing the performance of the DEWATS-systems.

Furthermore, the study shall analyse the convenience for the owner of the plant to operate the system and shall give detailed information about the use of gas and the effluent. This information is necessary regarding the improvement of plant operation and training / education of plant operators.

Some of the research questions are:

1) What is the treatment performance of the biogas plant regarding COD removal?

2) How much biogas is produced? What is it used for?

3) Are the plants feasible to treat organic solid waste, such as kitchen waste?

4) What are the advantages and disadvantages concerning the operation of a biogas plant?

4. Introduction

4.1. Technologies for Economic Development (TED)

In 2002, the small Maseru based NGO "Technologies for Economic Development" (TED) was established with the main focus to disseminate fixed-dome biogas digesters. By now, TED has built more than 70 digesters, which all are in operation. They are mainly domestic-size installations in the peri-urban vicinity of Maseru, but also larger-size constructions have been built. The scalable digester design has been developed for over 20 years. It is adapted not only to the typically encountered technical and cultural conditions of operation, but to also to the locally available materials and skills.

In the first instance, the digester serves as on-site sanitation solution and replaces usually malfunctioning storage tanks, which discharge untreated wastewater into the environment and are associated with comparatively high costs of operation. The biogas is used for cooking and eliminates the health hazard and environmental impact associated with the use of firewood which it substitutes. The digestate is used for irrigation and fertilization of the vegetable garden and increases the yield of domestic food production.

TED's construction activities are demand driven and not subsidized. This ensures that only technology which can stand its ground in the market place is actually implemented (Mantopi Lebofa and Harald von Waldow).

Basically, TED is structured as shown in Figure 1. TED consists of a director and several branches that deal with various issues related to the renewable energy or waste disposal sector. TED fulfills an umbrella function for partner organisations working in theses sectors that depend on local support (such as the Programme for Basic Energy and Conservation, ProBEC, www.probec.org, that is implemented by the German Agency for Technical Co-operation, GTZ, www.gtz.de).

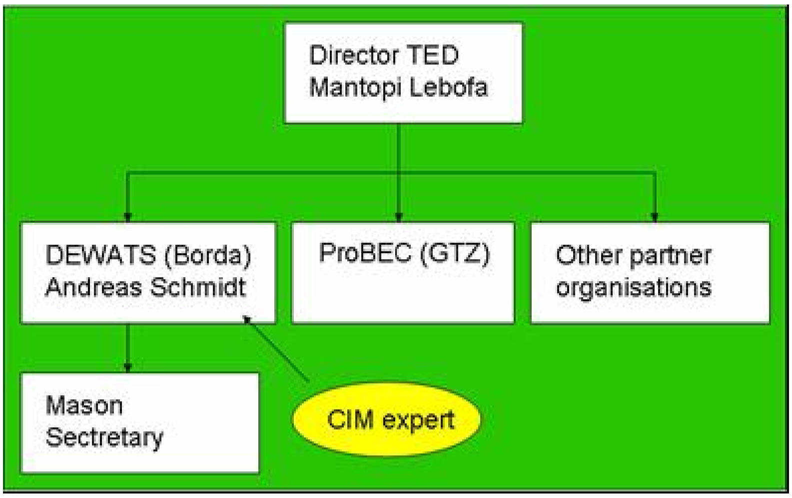

Figure 1: Current structure of NGO "Technologies for Economic Development (TED).

The fixed-dome biogas digesters are derived from so called Decentralised Waste Water Treatment Systems (DEWATS, see chapter 4.2). By disseminating these digesters, TED is supported by an expert that has been sent by the Centre for International Migration and Development, Germany (CIM). CIM sends experts to partners of the Bremen Overseas Research and Development Association (Borda, Germany). As TED is a partner of Borda, this CIM expert provides technical and financial support on site. The digesters are nowadays implemented in cooperation between TED and Borda (represented by CIM-expert).

TED-Borda wants logistical and administrative activities to be as low as possible, thus material has to be provided by the owners. The construction of the plants only gets started when the affordable material is available. Know-how and labour is provided by TED-Borda.

4.2. DEWATS–System of TED-Borda

DEWATS stands for "Decentralized Waste Water Treatment Systems". DEWATS is rather a technical approach than merely a technology package.

DEWATS applications are based on the principle of low-maintenance since most important parts of the system work without technical energy inputs and cannot be switched off intentionally. These systems provide a technology at affordable prices because all of the materials used for construction are locally available. DEWATS applications provide treatment for both, domestic and industrial sources. These systems provide treatment for organic wastewater flows from 1 up to 1000 m^3 per day. They are supposed to be reliable, long lasting and tolerant towards inflow fluctuation. Furthermore, they do not need sophisticated maintenance (Sasse, L. et al.1998).

Without considering facilities for necessary chemical pre-treatment of wastewater from industries, DEWATS applications are based on four basic technical treatment modules which are combined according to demand:

- Primary treatment: sedimentation and floatation
- Secondary anaerobic treatment in fixed-bed reactors: baffled upstream reactors or anaerobic filters
- Tertiary aerobic treatment in sub-surface flow filters
- Tertiary aerobic treatment in polishing ponds

DEWATS applications are designed and dimensioned in such a way that treated water meets requirements stipulated in environmental laws and regulations (DEWATS-Decentralised Waste Water Treatment Systems; Demand-based technical solutions to reduce water-pollution by small and medium enterprises and settlements in densely populated areas, Borda).

The systems that are implemented by TED-Borda are derived from the DEWATS-approach. Since the beginning of TED up to date, the systems were continuously adapted in order to meet the costumers demand. Compared to older systems, currently installed plants are more complex. For example, an Anaerobic Baffled Reactor (description see below) or water pumps are nowadays installed. This technology or approach will never be completely finalized. Any system can still be improved.

The currently installed TED-Borda system consists of three parts (see Figure 2):

1. **Digester:** Feedstock material (black water, kitchen waste etc.) enters the digester dome through the inlet. Some of the material gets settled and remains for a long time in the digester. Other material is directly transported to the dome outlet (shorter retention time). Inside the digester, the organic part of the material is slowly decomposed by bacteria. As a product of the decomposition process biogas is generated. The biogas is stored within the upper part of the dome till released through the gas outlet. At a certain gas pressure (around 25 cm water column) the biogas gets released automatically through the dome outlet.

2. **Anaerobic Baffled Reactor (ABR):** The waste water coming out of the dome outlet enters the ABR. The reactor consists of a series of chambers, in which the waste water flows up-stream. Activated sludge (containing bacteria) is located at the bottom of each chamber. Influent waste water is mixed up with the sludge, inoculating it with anaerobic bacteria which decompose the organic material (pollutants).

3. **Planted Gravel Filter (PGF):** The PGF fulfills a post-treatment step. After the ABR the effluent flows into the PGF. The main removal mechanisms within the PGF are biological conversion, physical filtration and chemical adsorption. The mechanisms of organic removal are theoretically mainly aerobic and anoxic. The PGF is made of reed planted filter bodies consisting of graded gravel. At the end of the PGF there is an outlet tank installed in order to collect the treated waste water.

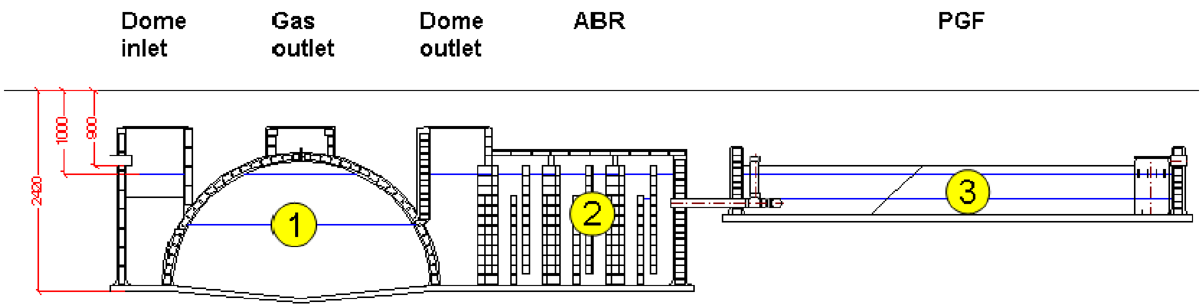

Figure 2: Scheme of DEWATS-Biogas-System of TED-Borda. The basic buildup consists of a digester (1), an anaerobic baffled reactor (ABR,2) and an planted gravel filter (PGF,3).

A manual that describes the construction aspects of such biogas digesters will soon be published by Christopher Kellner (see Contacts).

Some of the former plants were built without PGF or ABR but with an expansion chamber. The expansion chamber was filled with material (for example with crushed plastic pieces) in order to increase the surface area for bacteria to grow. With the expansion chamber the retention time and thus the treatment performance was enhanced.

5. Methodology

5.1. Approach

In order to meet the objective mentioned in chapter 3 the following approach is chosen. The approach consists of the following parts:

Part 1: Waste Water Analysis

Waste water analysis (feedstock, effluent) is done on a regular basis by taking water samples at various sampling points at the plant, such as dome inlet, dome outlet, ABR and PGF outlet (=effluent tank).

Temperature, redox-potential and pH are measured just after taking the water samples (on-site). COD analysis is done in the TED-Borda office in Maseru (see Appendix Picture Series Equipment Effluent Analysis).

The methods applied are mentioned in Table 1. Sampling and chemical analysis is done by Sandec / TED-Borda in Lesotho.

Table 1: Methods of parameter analysis

Parameter	Method	Responsibility	Conducted in
pH	pH-Meter	Sandec / TED-Borda	Lesotho
Redox-Potential	pH-Meter	Sandec / TED-Borda	Lesotho
Temperature	pH-Meter	Sandec / TED-Borda	Lesotho
COD dissolved	Hach-Lange rapid test, photospectro-meter	Sandec / TED-Borda	Lesotho
Heavy metals	Mass spectrometry[1]	Sandec	Switzerland

[1] Inductively Coupled Plasma – Mass Spectrometry (ICP MS) 7500cx, Agilent

Part 2: Measuring Biogas Production & Biogas composition

In order to get information about the biogas production, the volume of gas produced during a certain time span is measured with a gas meter. Two gas meters are available. One of them is fix installed at a site where biogas is not yet used (see Appendix Picture Series Garden Site). Another gas meter is used as a mobile gas meter to measure the gas production at three other sites (see Appendix Picture Series Me Palesa, Childrens Home and Mr Monethi).

CO_2 content is measured with a Testoryt device. In order to control the results, some gas samples are also analysed at ETH Zurich, Switzerland.

Table 2: Methods of parameter analysis

Parameter	Method	Responsibility	Conducted in
Biogas production	Gas meter	Sandec / TED-Borda	Lesotho
Biogas CO_2-content	Testoryt	Sandec / TED-Borda	Lesotho
Biogas composition	Gas chromatograph*	ETH Zurich	Switzerland

* The analysis was done with a Trace GC Ultra gas chromatograph from Thermo Scientific. The methane, carbon dioxide and oxygen values were measured with a packed Hayesep D 100/120 column equipped with a thermal conductivity detector. The oven and inlet temperature was set to 85°C, 150°C and 100°C respectively. The nitrogen carrier gas flow was 19.1 ml min-1.

Part 3: Monitoring of Biogas Consumption & Feedstock

Plant owners or operators monitor the biogas consumption as well as the feedstock material. The time biogas is used for cooking is recorded on a data record sheet. Similarly, the material manually fed into the digester is weighted and recorded.

Part 4: Interview

Operators of biogas plants are interviewed. Information about feeding habits, gas consumption, convenience of handling the plant and other information are collected and analyzed.

5.2. Selection of Plants

Out of about 80 DEWATS-systems already installed by TED-Borda in Lesotho (around 70 plants are located in Maseru), several systems were visited in Maseru in order to select some for closer investigations. In Table 3 the selected plants are presented. Basically, eleven systems have been approached, either for taking effluent samples, measuring the gas production, monitoring or conducting an interview. But only the results from eight plants are discussed in this report. The results of effluent analysis from Swampi Site and Yellow Shop (which is a storage tank) can be found in the Appendix.

Table 3: Overview of biogas plant analysis

	Name of plant	**Effluent analysis**	**Biogas analysis**	**Monitoring***	**Interview**	**Total****
1	Garden site	8	15	0	0	**23**
2	Me Palesa	5	5	1	1	**12**
3	Childrens Home	3	4	0	0	**7**
4	Mr Monethi	2	2	0	0	**4**
5	Mr Ntsihele	1	0	1	1	**3**
6	Me Lerato	2	0	1	1	**4**
7	Mr Mazenod	2	0	1	1	**4**
8	Mrs Nthama	0	0	1	1	**2**
	Mrs Dube	0	0	0	1	**1**
	Swampi site	1	0	0	0	**1**
	Yellow shop (storage t.)	1	0	0	0	**1**
	Total**	**25**	**26**	**5**	**6**	**62**

* Monitoring of feedstock and biogas consumption

** Number of measurements conducted

6. Location of Biogas Plants

The biogas plants that were installed by TED-Borda are rarely located in the dense city center. Most of them are outside the city center in more suburban areas of Maseru. The location of the biogas plants summarized in this report can be seen on Figure 3. In addition, the two offices from TED and TED-Borda that are close to the city center are marked on the map.

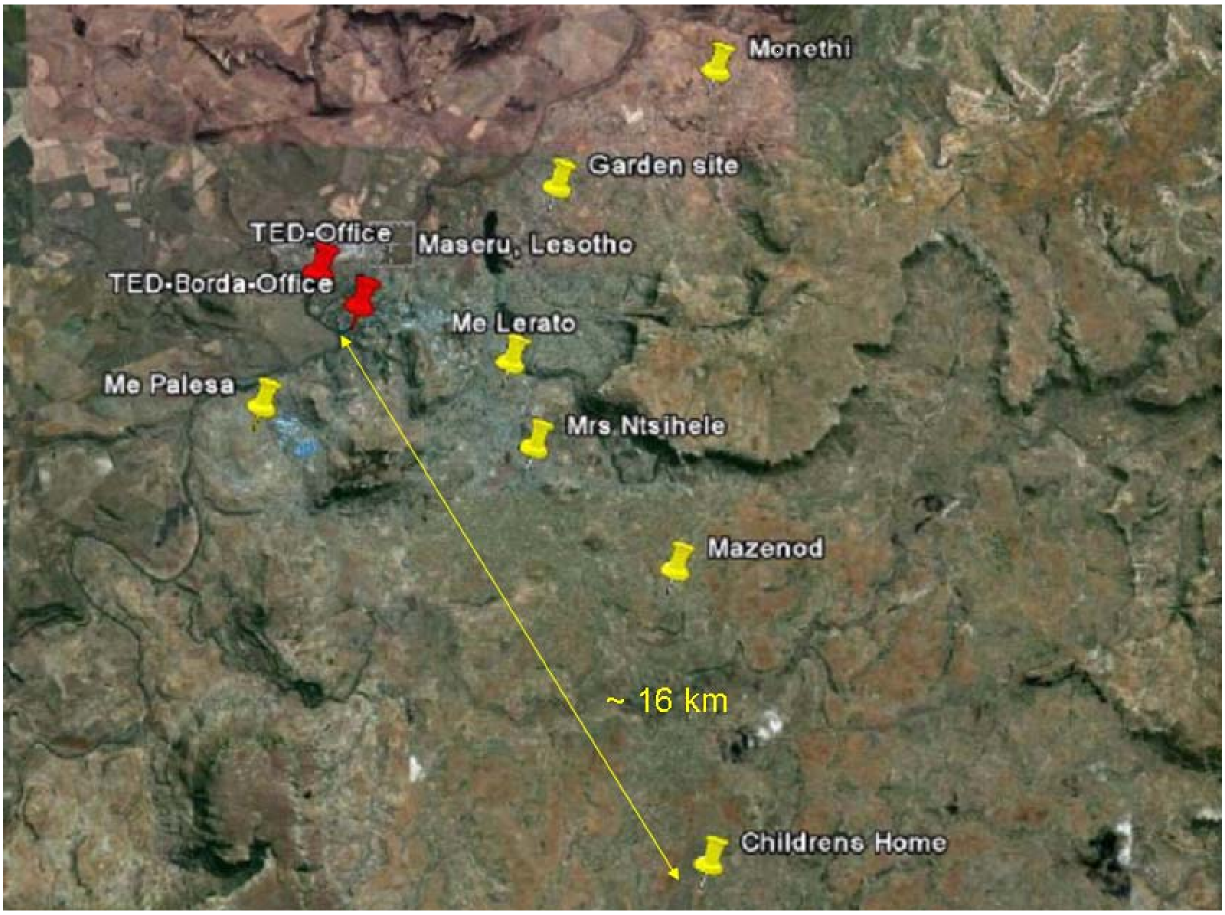

Figure 3: Map of Maseru and suburbs. Location of evaluated biogas plants (yellow) and location of TED- and TED-Borda-Office (red) are marked.

7. Characteristics of Biogas Plants

7.1. Garden Site

 **Picture 1:** In the background; dome inlet, gas outlet and dome outlet. On the right hand side; cover holes of ABR.	 **Picture 2:** The PGF including the effluent collection tank in the lower corner (partly visible).
Type of construction / construction plan	Brick built / construction plan DR08.1(Appendix)
Commissioning	≈ August 2007
Household size	4 people (2 adults, 2 children)
Volume biogas dome / ABR / Area PGF	≈ 6 m^3 / ≈ 5 m^3 / ≈ 5 m^2
Waste water source	toilet, bathroom, kitchen, laundry
Feedstock manually fed	no (only fed by Sandec between 5.12 -18.2.2008)
Effluent reuse	surface irrigation of garden
Effluent COD content: inlet / outlet dome / PGF	456 mg/l / 303 mg/l / 134 mg/l (average values)
COD removal efficiency: inlet- / outlet dome - PGF	70 % / 55 %
Biogas utilization	not yet connected to kitchen
Biogas production (measured)	≈ 60 - 70 liters per day
Biogas methane content	65 - 75 %
Fresh water consumption	528 liters per day / 132 liters per day and person
Total cost of plant (therefrom labor, material cost TED)	≈ 16’000 Maluti (7’450 Maluti) / ≈ 1’600 U.S. Dollar

7.2. Me Palesa

 **Picture 3:** Dome inlet, gas outlet, and dome outlet chamber in front of the ABR (all in a line).	 **Picture 4:** ABR (partly visible in front) and PGF (only covered with a few plants)
Type of construction / construction plan	Brick built
Commissioning	February 2008
Household size	4 people (2 adults, 2 children)
Volume biogas dome / ABR / Area PGF	≈ 8 m^3 / ≈ 5 m^3 / ≈ 3 m^2
Waste water source	toilet, bathroom, kitchen
Feedstock manually fed	kitchen waste / grass, around 2.1 kg/day
Effluent reuse	surface irrigation of garden
Effluent COD content: (inlet) / outlet dome / PGF	2’847 mg/l / 2’293 mg/l / 373 mg/l (average values)
COD removal efficiency: (inlet)- / outlet dome - PGF	86 % / 83 %
Biogas utilization	not yet connected to kitchen
Biogas production (measured)	≈ 100 - 140 liters per day
Biogas methane content	60 - 65 %
Fresh water consumption	304 liters per day / 76 liters per day and person
Labor cost (including material provided by TED)	9’395 Maluti
Total cost of plant	≈ 16’000 Maluti / ≈ 1’600 U.S. Dollar

7.3. Childrens home

 **Picture 5:** Dome inlet, gas outlet and dome outlet chamber and ABR on the terrace.	 **Picture 6:** View from opposite side. Two PGF-beds in front of the terrace (including ABR and digester).
Type of construction / construction plan	Brick built / construction plan DR01 (Appendix)
Commissioning	December 2007
Household size	very fluctuating (up to 10 adults, 20 children)
Volume biogas dome / ABR / Area PGF	≈ 9 m^3 / ≈ 10 m^3 / ≈ 30 m^2
Waste water source	toilet, bathroom (into dome), kitchen, laundy (into ABR)
Feedstock manually fed	no
Effluent reuse	surface irrigation of garden
Effluent COD content: outlet dome / PGF	1’048 mg/l / 350 mg/l (average values)
COD removal efficiency: outlet dome - PGF	66 %
Biogas utilization	not yet connected to kitchen
Biogas production (measured)	≈ 60 -80 liters per day
Biogas methane content	unknown
Fresh water consumption	unknown / no connection to public pipe
Total cost of plant	≈ 70’000 Maluti / ≈ 7’000 U.S. Dollar

7.4. Mr Monethi

Picture 7: Gas outlet, dome outlet and ABR.

Picture 8: Part of ABR (on the right) and PGF. At the upper end of PGF the collection tank (blue) is stored in the corner.

Type of construction / construction plan	Brick built / construction plan DR01 (Appendix)
Commissioning	June 2008
Household size	parents (2 adults) and 2 children (19y, 11y)
Volume biogas dome / ABR / Area PGF	≈ 6 m^3 / ≈ 5 m^3 / ≈ 5 m^2
Waste water source	toilet, bathroom, kitchen, laundry
Feedstock manually fed	no
Effluent reuse	surface irrigation of garden
Effluent COD content: outlet dome / PGF	472 mg/l / 267 mg/l (average values)
COD removal efficiency: outlet dome - PGF	43 %
Biogas utilization	not yet connected to kitchen
Biogas production (measured)	≈ 190 - 230 liters per day
Biogas methane content	70 - 76 %
Fresh water consumption	unknown
Labor cost (including material provided by TED)	9’395 Maluti
Total cost of plant	≈ 16’000 Maluti / ≈ 1’600 U.S. Dollar

7.5. Mrs Ntsihele

 **Picture 9:** Gas outlet, dome inlet and outlet in the front. In the background the open stable for the pigs. Pig waste water is directly flowing into dome inlet chamber.	 **Picture 10:** In front the chambers of the dome. In the background the PGF. An ABR is not installed at this site. Within the brick building the chickens are kept.
Type of construction / construction plan	Brick built / no plan available - ABR is not installed
Commissioning	October 2005
Household size	7 people
Volume biogas dome / Area PGF	≈ 18 m^3 / ≈ 5 m^2
Waste water source household	toilet, bathroom, kitchen, laundry
Live stock	30 - 35 pigs, 300 chicken
Waste water source open stable	pig waste water
Feedstock manually fed	pig, chicken and dog waste (about 14 kg/day)
Effluent reuse	surface irrigation of garden
Effluent COD content: outlet dome / PGF	1’489 mg/l / 1’318 mg/l
COD removal efficiency: outlet dome - PGF	11 %, low retention time of waste water
Biogas utilization	used for cooking, boiling bath water, chicken heater lamp
Biogas consumption (interview, assumption)	> 1 m^3 per day (6.4h/day used in stove on half flame*)
Labor cost (including material provided by TED)	16’850 Maluti
Total cost of plant	≈ 30’000 Maluti / ≈ 3’000 U.S. Dollar

* Biogas consumption of an ordinary one flame stove is about 300 liters biogas per hour (PPP TED-Borda). In summer water is boiled without being used, just to release the biogas in order to lower the water level within the digester. Also neighbours come to cook with biogas at Mrs Ntsihele’s place.

7.6. Me Lerato „Flower House“

Picture 11: Dome inlet and outlet (lower left corner) in the front. In the background the open stable for the pigs. Pig waste water is directly flowing into dome inlet chamber. Two bowls of feedstock paper are standing next to the inlet chamber.

Picture 12: In front the storage tank and PGF for treating black water are partly visible. In the background the open pig stables (where the digester is located). There is no connection between digester and PGF.

Type of construction	Brick built / digester and PGF are not connected
Commissioning	August 2008
Household size	5 people (3 adults, 2 children)
Volume biogas dome	≈ 9 m^3
Live stock	12-20 pigs, 14 chicken
Waste water source	pig waste water
Feedstock manually fed	pig, chicken waste, paper
Effluent reuse	surface irrigation of garden
Effluent COD content: outlet dome / PGF	6’342 mg/l / 6’528 mg/l
COD removal efficiency: outlet dome - PGF	retention time is to low, no COD decrease dedectable
Biogas utilization	used for cooking
Biogas consumption (interview, assumption)	≈ 800 liters per day (2.6 h/day used in stove*)
Biogas methane content	unknown
Fresh water consumption	≈ 920 liters per day (household and animals)
Total cost of plant	≈ 16’000 Maluti / ≈ 1’600 U.S. Dollar

* Biogas consumption of an ordinary one flame stove is about 300 liters biogas per hour (PPP TED-Borda).

7.7. Mazenod

Picture 13: Dome inlet, gas outlet, and dome outlet chamber in front of the ABR and PGF.

Picture 14: Biogas system in front of maize field that gets irrigated with effluent. On the right hand site part of the owners building where biogas is used.

Type of construction	Brick built
Commissioning	February 2008
Household size	6 people (2 adults, 4 children)
Volume biogas dome / ABR / Area PGF	≈ 6 m^3 / ≈ 3 m^3 / ≈ 5 m^2
Waste water source	toilet, bathroom, kitchen
Feedstock manually fed	bought cow dung (≈ 8 kg/day), garden weeds
Effluent reuse	surface irrigation of garden
Effluent COD content: outlet dome / PGF	687 mg/l / 546 mg/l (average values)
COD removal efficiency: outlet dome - PGF	20 %
Biogas utilization	used for cooking
Biogas consumption (interview, assumption)	≈ 600 liters per day (2.1 h/day used in stove*)
Biogas methane content	unknown
Fresh water consumption	unknown
Total cost of plant	≈ 16'000 Maluti / ≈ 1'600 U.S. Dollar

* Biogas consumption of an ordinary one flame stove is about 300 liters biogas per hour (PPP TED-Borda).

7.8. Mrs Nthama

 **Picture 15:** Dome inlet, gas outlet, and dome outlet chamber and an expansion chamber (in front). Expansion chambers have been installed in older systems, for agricultural purposes.	 **Picture 16:** Expansion chamber outlet, it overflows automatically as soon as a certain water level is reached, then enters the distribution canal and irrigates the garden.
Type of construction	Brick built
Commissioning	May 2004
Household size	9 people (7 adults, 2 children)
Volume biogas dome / expansion chamber	≈ 9 m^3 / unknown
Waste water source	toilet, bathroom, kitchen
Live stock	140 chicken
Feedstock manually fed	4 wheelbarrows of chicken waste in a month
Effluent reuse	surface irrigation of garden
Effluent COD content: outlet dome / PGF	no measurements
Biogas utilization	used for cooking, boiling bath water
Biogas consumption (interview, assumption)	≈ 1'000 liters per day (3.4 h/day used in stove*)
Biogas methane content	unknown
Fresh water consumption	unknown
Total cost of plant	≈ 16'000 Maluti / ≈ 1'600 U.S. Dollar

* Biogas consumption of an ordinary one flame stove is about 300 liters biogas per hour (PPP TED-Borda).

8. Summary of Results

8.1. Treatment Performance of ABR and PGF

In this context, the “treatment performance” means the difference in COD concentration between water samples from the dome outlet and the PGF outlet. It cannot be seen equivalent to the COD removal rate of a plant. Within the PGF rainwater can enter leading to dilution of water samples. That means that the reduction of the COD concentration between the dome outlet and the PGF outlet is not only due to COD removal, but can also be influenced through entering rainwater (dilution) or evaporation (accumulation).

The “treatment performance” is only based on values from dome outlet and PGF outlet. The dome itself is not considered in this context. But COD removal is also happening right from the beginning when bacteria start to decompose the organic matter. Decomposition already takes place in the sewage pipe that enters the inlet chamber.

The “treatment performance” is calculated based on dissolved organic matter. Thus, the non-dissolved organic matter that enters the system is not measured. Non-dissolved organic matter that settles down and gets slowly decomposed within the digester is not detected when taking samples from the inlet chamber. Thus, an input-output-analysis over the digester is not possible.

Within the digester outlet, most of the organic material is supposed to be dissolved and can thus be measured. Therefore, the “treatment performance” in this context is only considering the reduction in COD concentration between dome outlet and PGF outlet. Thus, the values presented in Table 4 do not represent the efficiency of the whole treatment system, but show the efficiency of ABR and PGF (in case there is an ABR and PGF installed).

Table 4: Reduction of COD concentration between dome outlet and PGF oulet.

		Feedstock (amount is not known)	**COD (dome outlet)** mg/l	**COD (PGF)** mg/l	**Reduction of COD concentration ABR and PGF**
1	**Garden site**	black water (bw)	303	134	55%
2	**Me Palesa**	bw, kitchen waste, grass	2’293	373	83%
3	**Childrens Home**	bw	1’048	350	66%
4	**Mr Monethi**	bw	472	267	43%
5	**Mrs Ntsihele**	bw, pig waste	1’489	1’318	11%
6	**Me Lerato**	chicken + pig waste, paper	6’342*	6’528*	-3%
7	**Mazenod**	bw, cow dung	687	546	20%
8	**Mrs Nthama**	bw, chicken waste	not measured		

* PGF is not installed (Samples are taken from dome inlet and outlet).

The treatment performance of ABR and PGF is very differing. One plant achieves a performance of about 83%, whereas another plant is not noticeable able to reduce the COD concentration. TED-Borda tries to achieve COD-values in the PGF outlet of about 120 mg COD/l. But these values are only approached at one plant.

The “treatment performance” of the whole system including the biogas digester could not be measured. The COD removal rate within the digester can only be calculated based on the biogas production of the plant. Organic matter that is decomposed produces biogas, thus the biogas production rate directly depends on the COD removal rate. According to Murali Mohan G.[2] around 0.345 m^3 biogas is produced when one kg COD is destroyed.

In order to know the “treatment performance” of the entire system, the feedstock (black water and additional material) has to be analyzed for several months. In addition, waste water volume and composition (organic load) have to be measured. Accumulation of organics within the digester needs to be considered.

Furthermore, it is important to know that if conditions are changing, the “treatment performance” can vary within a short period of time. It depends mainly on the following factors:

- **Feedstock material:** Can the organic material be decomposed by anaerobic bacteria? How fast can it be decomposed? Are there toxic materials harming the decomposition process? Is there continuity in feeding regarding amount and composition of feedstock (adaption of bacteria)?
- **Components and dimension of system:** What components are installed (digester, ABR and PGF)? What is the retention time of the system? Is there enough time for the bacteria to decompose the material or is the system overloaded?
- **Age of plant:** Are the bacteria already adapted?
- **Climate / Weather condition:** High temperatures enhance the treatment performance, whereas low temperatures reduce the biological activity. Rain enables a dilution of the effluent within PGF (decrease in COD concentration). Hot, dry weather leads to high evaporation rates (increase in COD concentration).

[2] http://cgpl.iisc.ernet.in/site/Portals/0/Publications/Presentations/Bio-Energy/Liquid%20&%20Solid%20Waste%20Mgmt.pdf

8.2. Biogas Production & Consumption

Table 6 reveals that the agricultural plants (No. 5, 6, 7 and 8) that are fed with animal dung generate much more biogas than plants mainly fed with black water. The biogas is used for cooking and boiling bath water. Agricultural plants provide biogas that covers 100% of the cooking energy demand in summer and 20-40% in winter.

Agricultural plants generate a lot of biogas, but do not achieve the same treatment performance as household plants (see Table 5). Basically, these systems are overloaded, thus the achieved COD concentration (around 120 mg/l) can by far not be met.

The values measured show that the longer the time span between two measurements, the lower the average daily gas production (see Appendix Biogas Production). Most probably, the reasons for this are gas losses (automatic release or leakages in the upper digester part). The longer the gas gets stored the higher the gas pressure resulting in higher gas losses. Therefore, values for the biogas production are calculated in two ways. First the average value is taken. Secondly, a trend line is fit trough all values giving a specific equation. Based on this equation the daily biogas production is calculated (see value in brackets).

Table 6: Biogas production and consumption.

		Feedstock	**Gas Production** average (without losses*) l/day	**Gas Consumption** (Interview) lday	**Methane-Content**
1	**Garden site**	black water (bw)	62 (70*)		65-75%
2	**Me Palesa**	bw, kitchen waste, grass	108 (139*)		60-65%
3	**Childrens Home**	bw	62 (79*)		unknown
4	**Mr Monethi**	bw	193 (226*)		70-76%
5	**Mrs Ntsihele**	pig waste, bw		> 1000**	unknown
6	**Me Lerato**	chicken + pig waste, paper		~ 800**	unknown
7	**Mazenod**	bw, cow dung		~ 600**	unknown
8	**Mrs Nthama**	chicken waste, bw		~ 1000**	unknown

* Values of gas production according to trend line (equation see Appendix Biogas Production) for x=24 hours. These values could be the average biogas production without losses.

** Values are derived from interview. They can only be seen as approximate values. Biogas consumption of an ordinary one flame stove is about 300 liters biogas per hour (PPP TED-Borda).

8.3. Harmful Substances in Effluent

In order to evaluate the effluent quality, samples from four different plants were taken and analyzed. In addition, a fresh water sample (tap water) was taken as a reference. All samples were analyzed regarding toxic substances, basically metals and semimetals. The results are summarized in Table 7.

Table 7: Harmful substances in effluent (samples taken from PGF outlet).

Samples	Chromium (Cr) µg / l	Nickel (Ni) µg / l	Cadmium (Cd) µg / l	Lead (Pb) µg / l
Garden site	0.1	0.28	< 0.1	0.36
Me Palesa	0.33	11.11	< 0.1	0.53
Mr. Monethi	0.09	3.75	< 0.1	0.23
Mrs. Ntsihele	4.07	25.81	0.12	1.97
Tap Water Maseru*	0.1	1.47	< 0.1	0.28

* Tap water was taken from a guesthouse in Maseru (Lower Prison Gardens)

Further analyses revealed the following concentrations for all samples:

- Copper (Cu) < 0.1 µg / l
- Zinc (Zn) < 10 µg / l
- Arsenic (As) < 10 µg / l
- Selenium (Se) < 1 µg / l
- Tin (Sn) < 2 µg / l
- Thallium (Tl), thorium (Th) and uranium (U) are not traceable.
- Molybdenum (Mo) and wolfram (W) do not exist

8.4. Economical Aspects

When looking at the economical aspects of the biogas systems implemented by TED-Borda, the alternative waste water treatment option has to be taken into consideration. In the case of Maseru, the storage tank is seen as the alternative. Storage tanks with soak-away are either not allowed by authorities or do not work due to the ground texture. Regular emptying of the storage tanks is expensive and the commercial utility can hardly serve the demand. Thus many private households, landlords of rental houses and institutions invest in a Biogas/DEWATS system provided by TED-BORDA.

Storage tanks have to be emptied regularly (about twice a month). The municipal Water and Sewerage Authority (WASA) is responsible for tank emptying. Emptying a tank load is charged by about 250 Maluti. This comes up to about 500 Maluti per month for a household, means about 6'000 Maluti per year. In comparison, it is assumed that a biogas plant has to be emptied approximately every 5 years (accumulation of settled solids within the digester).

The biogas systems have higher investment costs than storage tanks, but operational costs are far lower. In addition, biogas is produced that can replace bottled gas or other energy sources (for cooking). In Table 8 the economics of the biogas systems are presented. The work for feeding and operating the plant is not considered.

Table 8: Economics of waste water treatment systems on household level (Childrens Home is excluded). Comparison of storage tank and biogas systems (approximate values).

		Investment costs	Capital costs Annuity (2%, 15 year)	Operation costs	Savings bottled gas*	Result
	Storage tank	~ 5'000 M	390 M/year	6'000 M/year	0	-6'390 M/year
1	**Garden site**	~ 16'000 M	1'200 M/year	50 M/year	~ 140 M/year**	- 1110 M/year
2	**Me Palesa**	~ 16'000 M	1'200 M/year	50 M/year	~ 250 M/year**	- 1'000 M/year
3	**Childrens Home**					-
4	**Mr Monethi**	~ 16'000 M	1'200 M/year	50 M/year	~ 440 M/year**	- 860 M/year
5	**Mrs Ntsihele**	~ 30'000 M	2'300 M/year	50 M/year	~ 2'500 M/year	+ 150 M/year
6	**Me Lerato**	~ 16'000 M	1'200 M/year	50 M/year	~ 1'800 M/year	+550 M/year n
7	**Mazenod**	~ 16'000 M	1'200 M/year	50 M/year	~ 1'300 M/year	+ 50 M/year
8	**Mrs Nthama**	~ 16'000 M	1'200 M/year	50 M/year	~ 2'300 M/year*	+ 1'050 M/year

* based on a bottled gas (19kg) prize of 250 Maluti.

** Biogas is not yet used. Digester is not connected to the kitchen. Thus, values represent potential savings.

8.5. Current Problems & Open Questions

- **Gas tightness**: Plastering, curing and waxing of the fixed-dome digester have to be done carefully in order to prevent gas leakages. Most of the digesters where gas measurements were taken seem to have gas leakages.

What is the best mixture of candle wax and oil in order to achieve optimal gas tightness?

- **Inoculation with active sludge:** The function of the ABR depends on activated sludge at the bottom of the chambers. Currently, the performance of most of ABR's is not satisfying. Build up of activated sludge is taking too much time (some times several months).

What is the best way to inoculate an ABR (technical and economical feasible)?
How can the efficiency of an ABR be enhanced?

- **Water leakages:** If the plastering is not properly done water leakages can occur in digester, ABR and PGF (for example PGF at Children's Home).
- **Gas valve out of brass**: Brass contains cupper and zinc, whereas cupper reacts with biogas (H_2S) leading to corrosion of the valve. Some of the new plants are built with valves out of brass that are thought to be used for water connections, not for an atmosphere with biogas. The valve is supposed to be of chromium steel that is resistant against H_2S. The brass valves will be replaced.
- **Overflow of effluent:** If the plant does not cope with the high amount of feedstock or/and rainwater is entering the system effluent can overflow. At Me Palesa site, the PGF is overflowing due to a leakage/hole in the PGF wall. At Mrs Ntsihele site, the PGF is sometimes overflowing, but also back flow through dome inlet chamber happens (when biogas is produced water is displaced).
- **Manhole cover:** These covers can break into two parts (Me Palesa). Rectangular covers can fall into dome inlet or outlet (Me Lerato). Removal is uncomfortable and time consuming.
- **Neighbors complaining:** Overflow can cause problems with neighbors (mess and smell).
- **pH value in inlet chamber:** The pH value within the inlet chamber of Me Palesa site decreased towards 5.11 on 18.12.2008 due to the hydrolysis[3] of the additional feedstock. Based on the gas measurements this low pH value could have harmed the biogas production process. Detailed analysis could give more information (measurement of VFA/TIC[4]).

[3] Hydrolysis; first step of anaerobic decomposition of organic matter. Volatile fatty acids are produced. Thus, pH value goes down.
[4] Ratio between volatile fatty acids (VFA) and alkalinity (TIC)

9. Conclusions

Based on the research question asked in chapter 3 the following conclusions can be made:

1) What is the treatment performance of the biogas plant regarding COD removal?

Basically, only the treatment performance of the ABR and PGF could be measured. As only COD was measured the samples from the heterogeneous dome inlet chamber with a lot of non-dissolved organic matter could not be considered as representative for the organic content.

The treatment performance of ABR and PGF from various plants is very differing. Agricultural plants (a lot of manure as feedstock) have a high load of organic input and seem to be optimized towards high biogas yields. High biogas yields represent a high COD removal. But these agricultural plants mostly are overloaded. Thus, effluent quality does not strongly change in respect to COD concentrations.

Biogas plants mainly based on black water have a better treatment performance, but can still be improved. The space loading (amount of dry organic material per volume of digester per time) is far lower than within agricultural plants. Especially, the performance of the ABR seems to be weak in comparison with the PGF. The efficiency of activated sludge is mostly missing. The organic load might even be too low to let the bacteria settle down within the ABR chambers. A detailed analysis could help answering this question.

2) How much biogas is produced? What is it used for?

The amount of biogas produced by the biogas plants is also very differing. Agricultural plants generate a lot of biogas that covers most of the cooking energy demand (100% in summer, 20-40% in winter). Biogas plants that are mainly fed with faecal sludge generate less biogas. The main focus is in waste water treatment and not in biogas production.

3) Are the plants feasible to treat organic solid waste, such as kitchen waste and animal dung?

The biogas plants are feasible to treat organic solid waste. But when implementing such a biogas system the objective has to be defined, either the system serves as a waste water treatment system, solid waste disposal system or biogas production system. Based on the feedstock composition and the aspired effluent quality, the systems design (dimensions of components), operation and effluent reuse might look different.

The space loading in biogas plants is limited. That means that the amount of dry organic matter that can be treated within a biogas system is limited. If the space loading exceeds its limits the process can be harmed till it stops working. The process is harmed by the production of volatile fatty acids (hydrolysis) resulting in low pH values inside the digester. The space loading can be exceeded with materials that have a relatively high content of dry organic matter (for example kitchen waste). Black water in contrast consists of a lot of water and thus helps to stabilize the process. The combination of a relatively small waste water treatment site (economics) and a waste disposal site (including biogas production) does only work to a certain extent.

4) What are the advantages and disadvantages concerning the operation of a biogas plant?

Most of the biogas plants from TED-Borda do replace storage tanks. Compared to storage tanks there are several advantages. Having a biogas plant releases the owner from regular emptying of a storage tank. This saves lot of money (around 250 Maluti per load) and problems related to a delayed tank emptying. In addition the biogas systems provide biogas that replaces expensive bottled gas or other energy sources, as well as an effluent that can be used for irrigation.

Disadvantages can be seen when the system (mainly PGF) is overflowing (can also happen with storage tank) or when a digester or a PGF is clogging.

10. Outlook

The study gives an overview over the plants that are installed by TED-Borda. The plants analysed differ a lot regarding COD treatment performance, biogas production, feedstock etc. Focusing on the feasibility of treating organic solid waste, some of the system could be selected in order to conduct a detailed analysis. The analysis could be done at a plant already fed with organic solid waste (for example kitchen waste at Me Palesa) or at a plant where manually feeding has to be started. Controlled feeding over a long period of time could give more precise data about the feasibility of treating organic solid waste:

What is the upper limit of solid waste respectively organic load to be fed in before the process collapse?

In summer, some of the plants generate more biogas than the current demand for cooking.

What options are there to use the biogas in low- and middle income countries?

11. Contacts

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13. Appendix

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Picture Series: Garden Site

Picture 1: Overview of biogas plant (date picture taken, 19.11.2008).

Picture 2: Inlet, gas outlet and dome outlet, as well as part of ABR in the front (18.12.2008).

Picture 3: Effluent water is not yet used for irrigating the garden (14.1.2009).

Picture 4: Gas meter gets installed. Pipes are cut (19.11.2008).

Picture 5: Gas meter is fixed installed (19.11.2008).

Picture 6: Biogas burns with a high flame (19.11.2008).

Picture 7: View into dome inlet chamber (4.12.2008).

Picture 8: Feedstock manually fed (05.12.2008).

Picture 9: Feedstock manually fed (11.12.2008).

Picture10: Feedstock manually fed (16.12.2008).

Picture 11: Feedstock manually fed (16.12.2008).

Picture 12: Feedstock manually fed (18.12.2008).

Picture 13: View into dome inlet after feeding (18.12.2008)

Picture 14: Decomposition of organics is taking place (6.1.2009)

Picture 15: Decomposition has proceeded (12.1.2009).

Picture 16: PGF covered with a few dry plants (19.11.2008).

Picture 17: Plants seem to be growing (4.12.2008).

Picture 18: Plants have grown (14.1.2009).

Picture 19: Water collection tank in PGF (1.12.2008).

Picture 20: Plants are growing on gravel stones (6.1.2009).

Picture 21: Cleary visible plant growth (12.1.2009).

Picture 22: Water meter. Freshwater consumed by the household is measured.

Picture 23: In order to reach the sites a car is required. At the left lower corner of the picture the cover of the water meter is visible.

Picture 24: The feedstock material is weighed with a hanging balance before put into the inlet chamber.

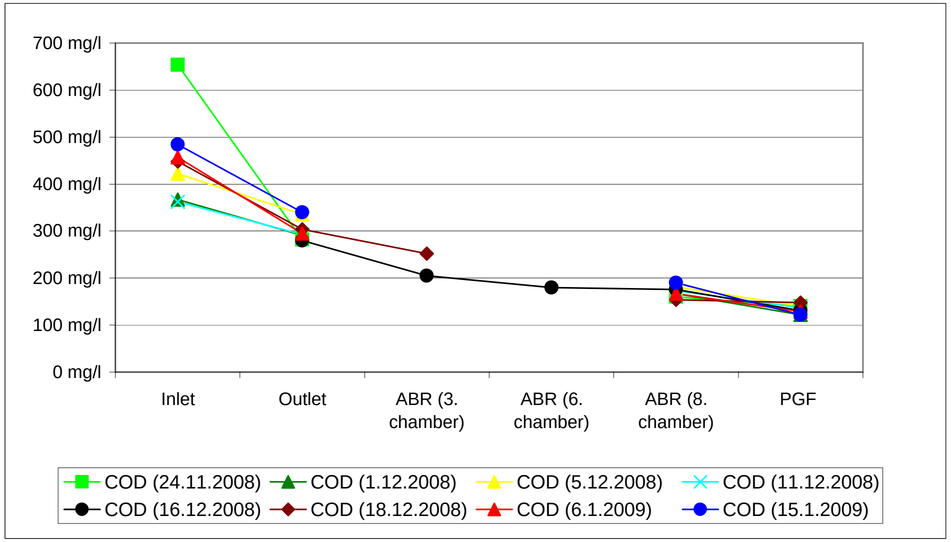
Garden Site

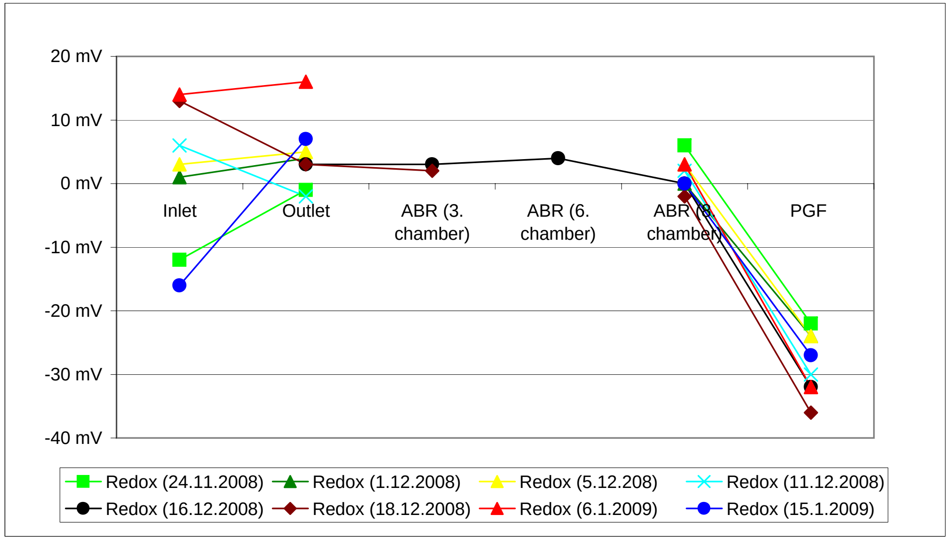
Effluent Analysis

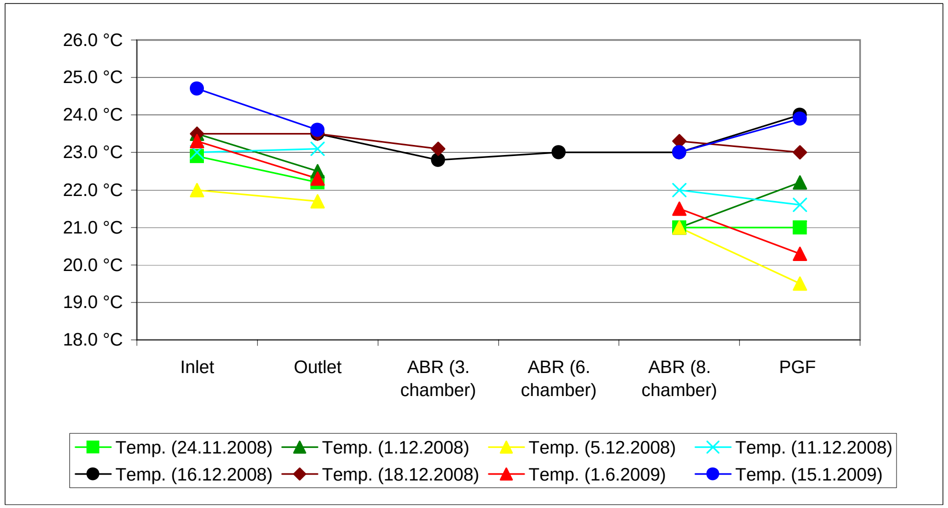
Date	Sampling time	Time of chemical analysis	Plant		Inlet	Outlet	ABR (3. chamber)	ABR (6. chamber)	ABR (8. chamber)	PGF	Remarks
21.06.2008			Garden site	COD		459 mg/l					Analysed by TED-Borda
24.11.2008	10:15		Garden site	pH	7.25	7.03			6.97	7.43	Layer of scum in the inlet
				Redox- Potential	-12 mV	-1 mV			6 mV	-22 mV	
				Temperature	22.9 °C	22.2 °C			21.0 °C	21.0 °C	
		14:30		COD	654 mg/l	282 mg/l			160 mg/l	140 mg/l	
01.12.2008	12:40		Garden site	pH	6.89	6.83			6.91	7.31	
				Redox- Potential	1 mV	4 mV			0 mV	-24 mV	
				Temperature	23.5 °C	22.5 °C			21.0 °C	22.2 °C	
		16:00		COD	367 mg/l	291 mg/l			167 mg/l	122 mg/l	
05.12.2008	09:00		Garden site	pH	6.84	6.83			6.86	7.31	1.6 kg of organics fed
				Redox- Potential	3 mV	5 mV			3 mV	-24 mV	
				Temperature	22.0 °C	21.7 °C			21.0 °C	19.5 °C	
		13:00		COD	422 mg/l	336 mg/l			181 mg/l	140 mg/l	
11.12.2008	10:45		Garden site	pH	6.78	6.92			6.87	7.4	3.0 kg of organics fed
				Redox- Potential	6 mV	-2 mV			2 mV	-30 mV	
				Temperature	23.0 °C	23.1 °C			22.0 °C	21.6 °C	
		15:00		COD	362 mg/l	293 mg/l			173 mg/l	137 mg/l	
16.12.2008	12:40		Garden site	pH		6.85	6.84	6.82	6.87	7.45	3.2 kg of organics fed
				Redox- Potential		3 mV	3 mV	4 mV	0 mV	-32 mV	
				Temperature		23.5 °C	22.8 °C	23.0 °C	23.0 °C	24.0 °C	
		14:30		COD		280 mg/l	205 mg/l	180 mg/l	176 mg/l	131 mg/l	
18.12.2008	11:00		Garden site	pH	6.61	6.8	6.82		6.9	7.47	2.3 kg of organics fed
				Redox- Potential	13 mV	3 mV	2 mV		-2 mV	-36 mV	
				Temperature	23.5 °C	23.5 °C	23.1 °C		23.3 °C	23.0 °C	
		14:30		COD	448 mg/l	304 mg/l	252 mg/l		154 mg/l	148 mg/l	
06.01.2009	09:30		Garden site	pH	6.72	6.67			6.91	7.51	
				Redox- Potential	14 mV	16 mV			3 mV	-32 mV	
				Temperature	23.3 °C	22.3 °C			21.5 °C	20.3 °C	
		15:30		COD	457 mg/l	295 mg/l			167 mg/l	129 mg/l	
15.01.2009	11:30		Garden site	pH	7.13	6.73			6.87	7.33	
				Redox- Potential	-16 mV	7 mV			0 mV	-27 mV	
				Temperature	24.7 °C	23.6 °C			23.0 °C	23.9 °C	
		13:00		COD	484 mg/l	340 mg/l			190 mg/l	122 mg/l	

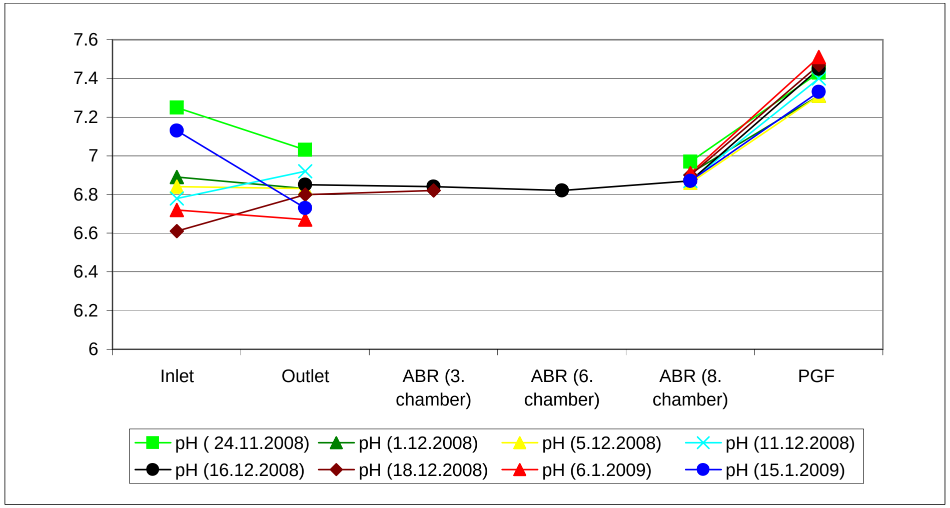
Average	pH	6.9	6.8			6.9	7.4	
Average	Redox- Potential	1 mV	4 mV			2 mV	-28 mV	
Average	Temperature	23.3 °C	22.8 °C			22.0 °C	21.9 °C	
Average	COD	456 mg/l	303 mg/l			171 mg/l	134 mg/l	

Effluent Analysis







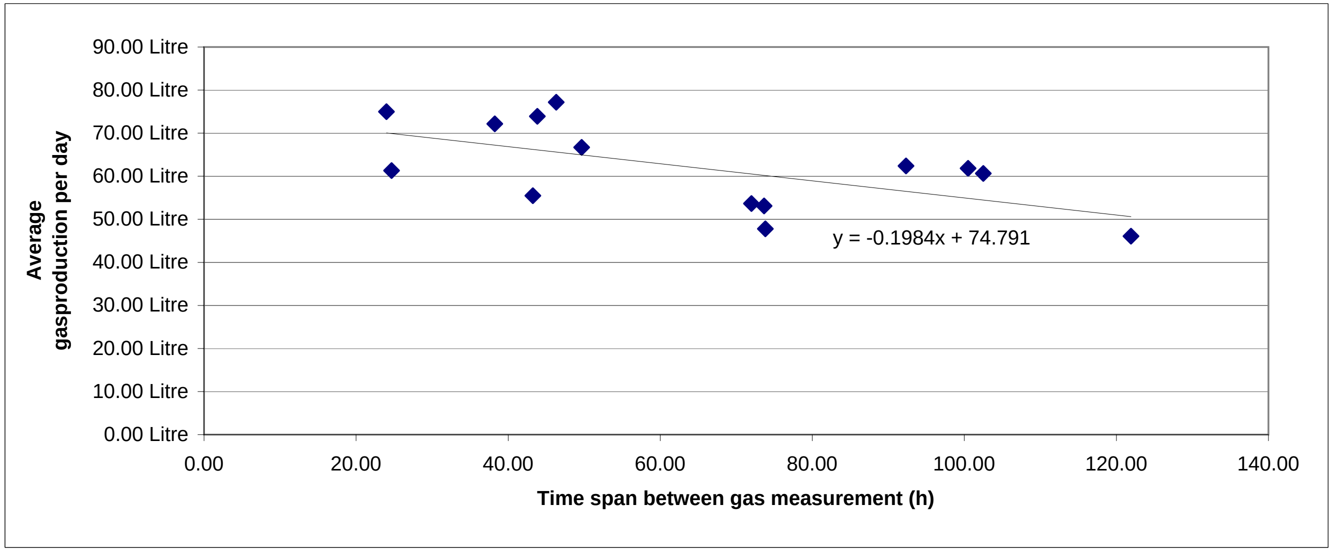


Biogas-Plants in Lesotho
Garden Site

Biogas Production and Water Consumption

Date	Time	Time span (h)	Display gas meter (m3)	Gas production (per time span)	Gas production (per day)	Number of people	Gas production / day and person	Gas composition (CO2-content)
Mid of 2007	00:00:00	0	14268.495	0 Litre				
19.11.2008	18:15:00	00:00	14268.731	236 Litre				
21.11.2008	08:30:00	38.25	14268.846	115 Litre	72.16 Litre	4	18.04 Litre	
24.11.2008	10:10:00	73.67	14269.009	163 Litre	53.10 Litre	4	13.28 Litre	
25.11.2008	10:50:00	24.67	14269.072	63 Litre	61.30 Litre	4	15.32 Litre	
28.11.2008	12:40	73.83	14269.219	147 Litre	47.78 Litre	4	11.95 Litre	12%
01.12.2008	12:40	72.00	14269.38	161 Litre	53.67 Litre	4	13.42 Litre	
05.12.2008	09:00	92.33	14269.62	240 Litre	62.38 Litre	4	15.60 Litre	17%
09.12.2008	15:30	102.50	14269.879	259 Litre	60.64 Litre	4	15.16 Litre	13%
11.12.2008	10:45	43.25	14269.979	100 Litre	55.49 Litre	4	13.87 Litre	14%
16.12.2008	12:40	121.92	14270.213	234 Litre	46.06 Litre	4	11.52 Litre	14%
18.12.2008	11:00	46.33	14270.362	149 Litre	77.18 Litre	4	19.29 Litre	14%
06.01.2009	*09:30*	*454.50*	*14270.559*	*197 Litre*	*10.40 Litre*	*4*	*2.60 Litre*	*16%*
08.01.2009	11:10	49.67	14270.697	138 Litre	66.68 Litre	4	16.67 Litre	
12.01.2009	15:40	100.50	14270.956	259 Litre	61.85 Litre	4	15.46 Litre	13%
14.01.2009	11:30	43.83	14271.091	135 Litre	73.92 Litre	4	18.48 Litre	12%
15.01.2009	11:30	24.00	14271.166	75 Litre	75.00 Litre	4	18.75 Litre	12%
				Average	61.9 Litre		15.5 Litre	13%
				x=24h	70.0 Litre			

Dislay prepaid water meter (m3)	Water consumption (prepaid)	Water consuption per person / day
374.5899		
376.1201	1530 Litre	124.35 Litre
377.935	1815 Litre	151.24 Litre
380.5575	2623 Litre	170.42 Litre
382.775	2217 Litre	129.80 Litre
383.6272	852 Litre	118.22 Litre
386.2996	2672 Litre	131.52 Litre
388.5959	2296 Litre	297.36 Litre
395.1626	6567 Litre	86.69 Litre
395.8975	735 Litre	88.78 Litre
397.3539	1456 Litre	86.95 Litre
398.0457	692 Litre	94.70 Litre
398.4586	413 Litre	103.22 Litre
	Average	131.94 Litre



Picture Series: Me Palesa

Picture 1: Overview of the biogas plant (date picture taken, 1.12.2008)

Picture 2: Inlet, gas outlet and dome outlet, as well as ABR (12.1.2009).

Picture 3: The ABR connects the dome outlet with the PGF (8.1.2009).

Picture 4: Gas plug valve (closed) is connected with plastic pipe (8.12.2008).

Picture 5: The plastic pipe is connected to the gas meter. (8.12.2008).

Picture 6: The pipe is gas tightly connected. Sealing wax is attached (8.12.2008).

Picture 7: During gas flaming the iron plate protects the pipe (18.12.2008).

Picture 8: Dome inlet, food leftovers were fed (24.11.2009)

Picture 9: Sampling effluent from dome outlet (24.11.2008).

Picture 10: Feedstock; food leftovers mixed with water (10.12.2008)

Picture 11: Dome inlet, layer of grass under food leftovers (8.1.2009)

Picture 12: Dome outlet, organic solids remain within the digester and get decomposed (8.1.2009).

Picture 13: Dome inlet, grass layer and food leftovers (12.1.2009)

Picture 14: Grass is collected and fed into inlet chamber (12.1.2009).

Picture15: Dome inlet, additional grass layer is added (15.1.2009).

Picture 16: PGF covered with a few dry plants (1.12.2008).

Picture 17: Plants do not seem to grow within the PGF (12.1.2009).

Picture 18: Taking effluent samples from ABR (24.11.2008).

Picture 19: Connections for gas meter are soldered. Prefabricated connection pieces that fit to gas meter were missing.

Picture 20: Soldered connections on top of the gas meter. This gas meter was used for gas measurements at several plants.

Picture 21: Testoryt device to measure the CO_2-content of gas. CO_2 gets absorbed by the liquid. Thus the volume of the liquid increases correspondingly.

Me Palesa

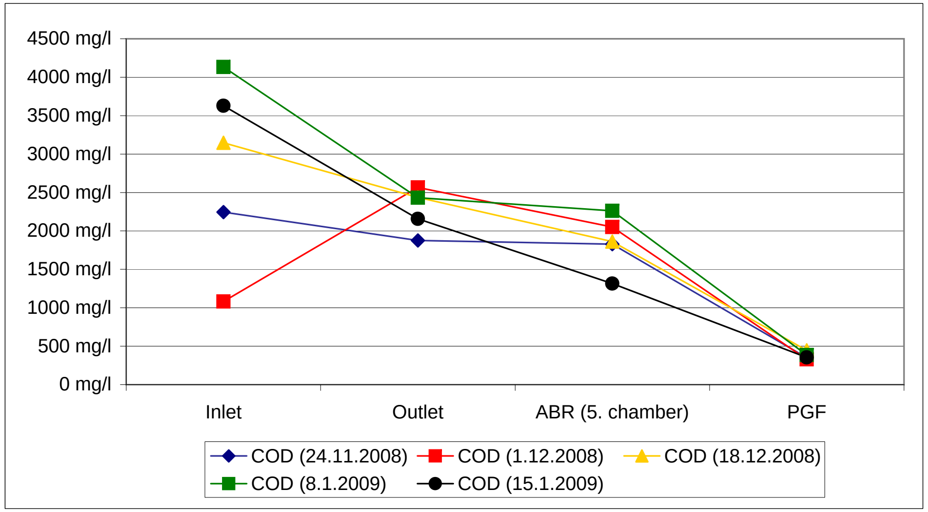
Effluent Analysis

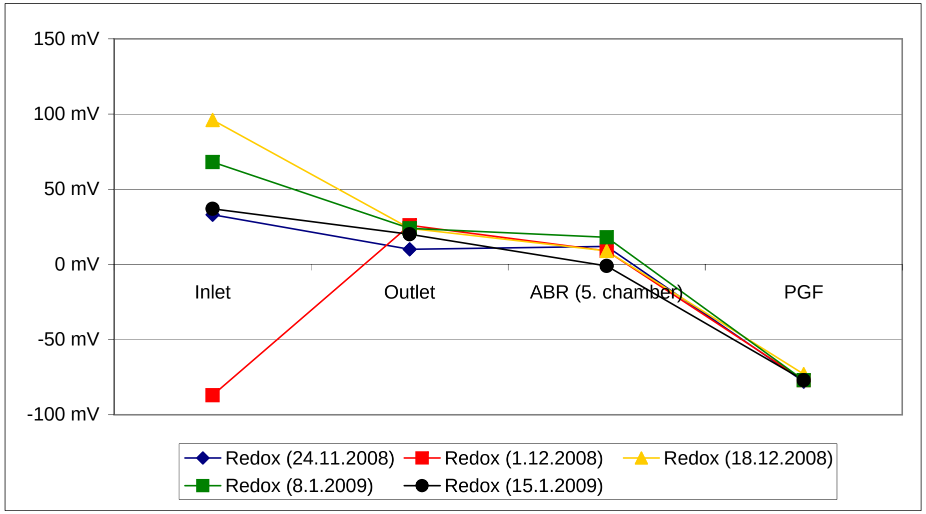
Date	Sampling time	Time of chemical analysis	Plant		Inlet	Outlet	ABR (5. chamber)	PGF	Remarks
14.06.2008	10:00		Me Palesa	COD		2908 mg/l		631 mg/l	Analysed by TED-Borda
11.09.2008	11:00		Me Palesa	pH		6		7	Analysed by TED-Borda
12.09.2008				COD		2837 mg/l		526 mg/l	part of sample was frozen
02.10.2008			Me Palesa	Temperature		18.5 °C		16.5 °C	Analysed by TED-Borda
				COD		1991 mg/l		340 mg/l	
24.11.2008	12:10		Me Palesa	pH	6.5	6.87	6.85	8.36	A lot of kitchen waste is fed.
				Redox- Potential	33 mV	10 mV	12 mV	-78 mV	
				Temperature	23.5 °C	23.4 °C	23.6 °C	24.3 °C	
		14:30		COD	2245 mg/l	1876 mg/l	1827 mg/l	350 mg/l	
01.12.2008	14:00		Me Palesa	pH	8.36	6.45	6.74	8.21	
				Redox- Potential	-87 mV	26 mV	9 mV	-77 mV	
				Temperature	23.9 °C	21.9 °C	22.7 °C	23.0 °C	
		16:00		COD	1082 mg/l	2566 mg/l	2050 mg/l	330 mg/l	
18.12.2008	13:30		Me Palesa	pH	5.11	6.43	6.7	8.1	
				Redox- Potential	96 mV	24 mV	9 mV	-73 mV	
				Temperature	24.6 °C	23.2 °C	23.5 °C	26.3 °C	
		14:30		COD	3147 mg/l	2436 mg/l	1861 mg/l	445 mg/l	
08.01.2009	10:00		Me Palesa	pH	5.64	6.44	6.55	8.2	
				Redox- Potential	68 mV	24 mV	18 mV	-77 mV	
				Temperature	26.0 °C	24.3 °C	24.4 °C	24.1 °C	
09.01.2008		15:00		COD	4134 mg/l	2432 mg/l	2261 mg/l	386 mg/l	
15.01.2009	10:15		Me Palesa	pH	6.77	6.5	6.88	8.18	A lot of grass is fed.
				Redox- Potential	37 mV	20 mV	-1 mV	-77 mV	
				Temperature	25.2 °C	23.4 °C	24.2 °C	26.0 °C	
		13:00		COD	3629 mg/l	2157 mg/l	1316 mg/l	355 mg/l	

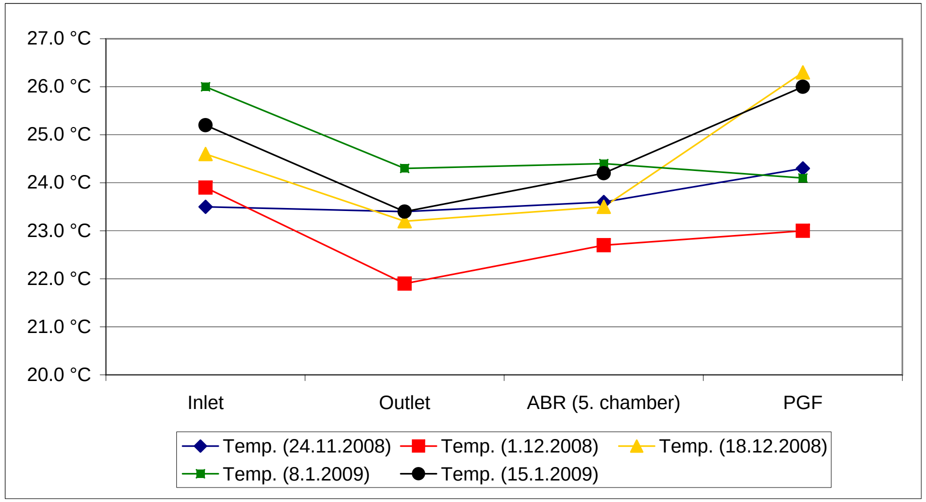
Average	pH	6.5	6.5	6.7	8.2	
Average	Redox- Potential	29 mV	21 mV	9 mV	-76 mV	
Average	Temperature	24.6 °C	23.2 °C	23.7 °C	24.7 °C	
Average	COD	2847 mg/l	2293 mg/l	1863 mg/l	373 mg/l	

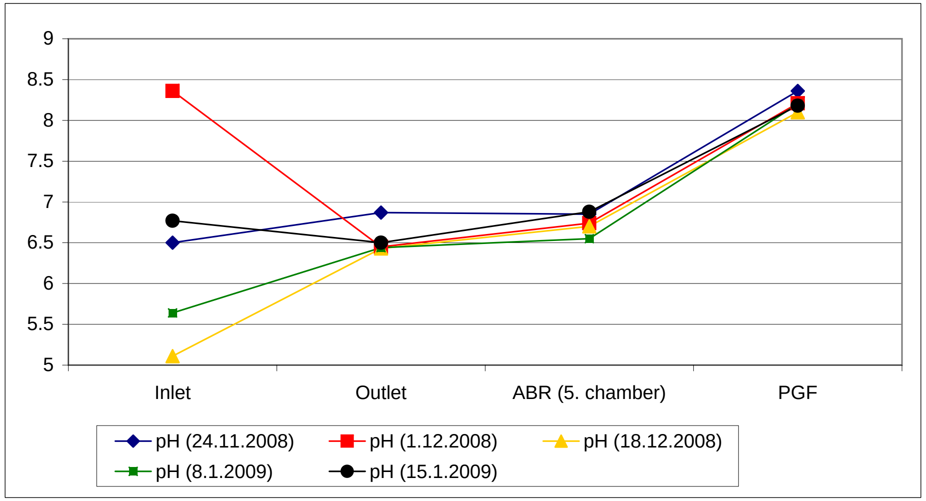
Me Palesa

Effluent Analysis







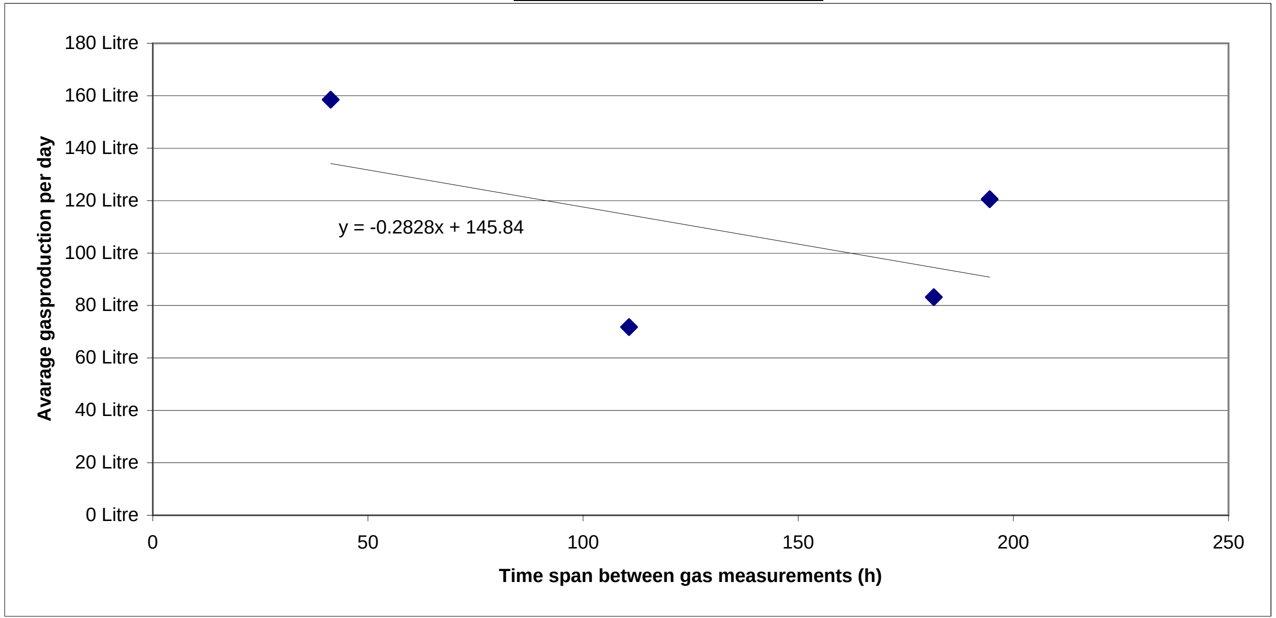


Me Palesa

Biogas Production and Water Consumption

Date	Time	Time span (h)	Display gas meter (m3)	Gas production (per time span)	Gas production (per day)	Number of people	Gas production/day and person	Gas composition (CO2-content)
01.12.2008	14:00:00		12450.354					
09.12.2008	16:30:00	194.50	12451.331	977 Litre	120.56 Litre	4	30.14 Litre	
09.12.2008	16:30:00		12451.332					
11.12.2008	09:50:00	41.33	12451.605	273 Litre	158.52 Litre	4	39.63 Litre	26%
11.12.2008	09:50:00		12452.374					
18.12.2008	13:30:00	181.50	12453.003	629 Litre	83.17 Litre	4	20.79 Litre	24%
08.01.2009	10:00:00		12455.32					
12.01.2009	14:40:00	110.67	12455.651	331 Litre	71.78 Litre	4	17.95 Litre	30%
12.01.2009	*14:40:00*		*12456.496*	*Leakage in measuing device*				
15.01.2009	*10:15:00*	*82.25*	*12456.623*	*127 Litre*	*37.06 Litre*	*4*	*9.26 Litre*	*28%*
				Average	108.5 Litre		27.1 Litre	27%
				x=24h	139.1 Litre			

Dislay prepaid water meter (m3)	Water consumption (prepaid)	Water consumption per person / day
216.1827		
219.1776	2995 Litre	92.39 Litre
219.1776		
219.984	806 Litre	117.06 Litre
219.984		
222.844	2860 Litre	94.55 Litre
227.609		
228.4358	827 Litre	44.83 Litre
228.4358		
228.8519	416 Litre	30.35 Litre
	Average	75.83 Litre



Me Palesa

Additional Feedstock

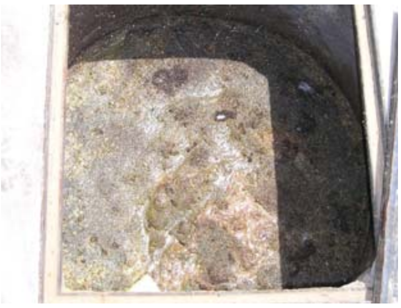
Date	Time	Amount of water	Amount organics	Composition / remarks
		is fed in with organics		
10.12.2008	11:00	3.0 kg	1.0 kg	meat, papa, vegetables
13.12.2008	14:20	1.0 kg	4.0 kg	papa, vegetables
15.12.2008	13:00	1.0 kg		
16.12.2008	15:20	10.0 kg	5.5 kg	papa, vegetables
17.12.2008	16:30	10.0 kg	2.0 kg	starchy waste food
18.12.2008	10:30	9.0 kg	2.0 kg	grass
19.12.2008	08:00	10.0 kg	5.0 kg	papa, grass
20.12.2008	10:00	15.0 kg	2.0 kg	food leftovers
21.12.2008	09:00	10.0 kg	1.5 kg	food leftovers
22.12.2008	11:00	20.0 kg	5.0 kg	grass
23.12.2008	10:00	10.0 kg	2.0 kg	grass and vegetables
24.12.2008	10:00	10.0 kg	3.0 kg	grass
25.12.2008	09:00	10.0 kg	2.0 kg	food leftovers
26.12.2008	09:30	5.0 kg	1.0 kg	food leftovers
27.12.2008	11:00	10.0 kg	2.0 kg	food leftovers
28.12.2008	10:00	15.0 kg	1.0 kg	grass
29.12.2008	12:00	20.0 kg	3.0 kg	grass
30.12.2008	08:30	10.0 kg	1.0 kg	grass
31.12.2008	09:00	10.0 kg	2.0 kg	food leftovers
01.01.2009	08:00	15.0 kg	0.5 kg	food leftovers
02.01.2009	09:30	10.0 kg	2.0 kg	grass
04.01.2009	10:00	20.0 kg	1.0 kg	grass
06.01.2009	12:00	15.0 kg	4.0 kg	papa and vegetables
07.01.2009	18:45	1.9 kg	1.9 kg	papa, egg shells, meat banana pulp, vegetables
10.01.2009	09:33	5.5 kg	5.5 kg	papa, tea bags, egg shells,
10.01.2009	10:15	4.5 kg	4.5 kg	meat, vegetables
		260.9 kg	**64.4 kg**	**Total waste manually fed**
		8.4 kg/day	**2.1 kg/day**	**Average waste manually fed**

Picture Series: Childrens Home

Picture 1: Overview of the biogas plant (Nov. 2008)

Picture 2: ABR with 12 chambers (4.12.2008).

Picture 3: PGF in series; different size of crashed stones (Nov. 2008).



Picture 4: Dome inlet with dry layer, before mixing (Nov. 2008).

Picture 5: Dome inlet, after mixing with stick (Nov. 2008)

Picture 6: Dome outlet, soup water in entering (4.12.2008)

Picture 7: First chamber of ABR (Nov. 2008).

Picture 8: Two chambers of ABR. Two pipes that lead to water to the bottom of the chamber (Nov. 2008).

Picture 9: Last chamber of ABR; effluent is entering the connection pipe to PGF (Nov. 2008).

Picture 10: Second PGF outlet chamber; effluent is used for irrigation (Nov. 2008).

Picture 11: Gas valve at the wall and gas stove, not yet modified for biogas applications (Nov. 2008)

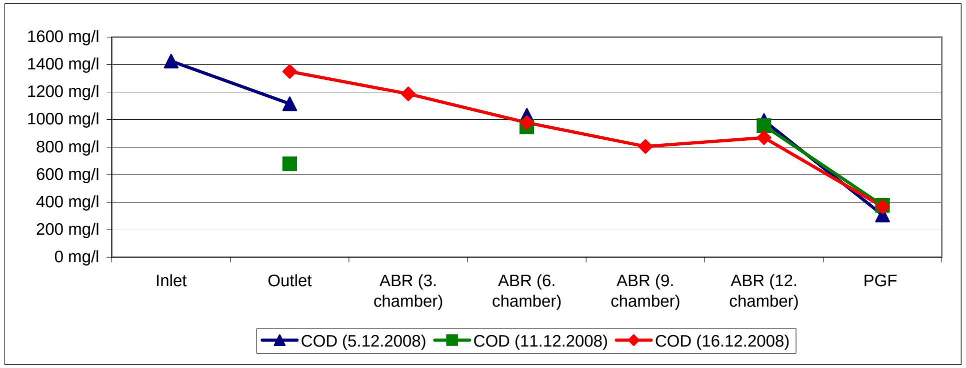
Picture 12: Gas measurement; biogas is flamed. Plastic pipe is protected (4.12.2008)

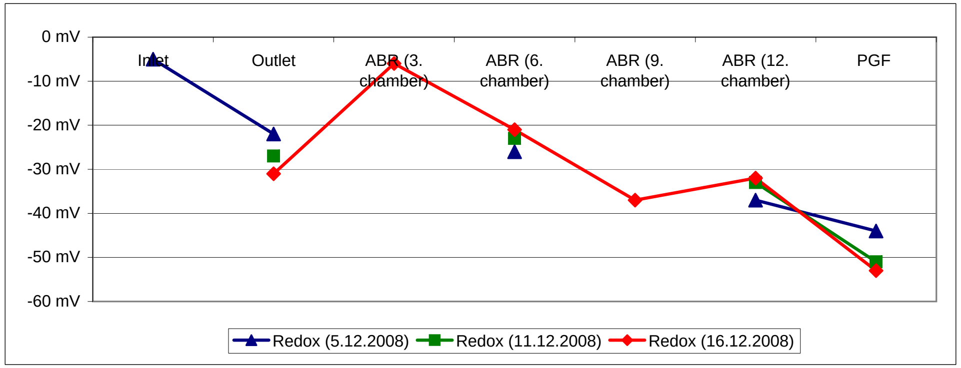
Biogas-Plants Lesotho

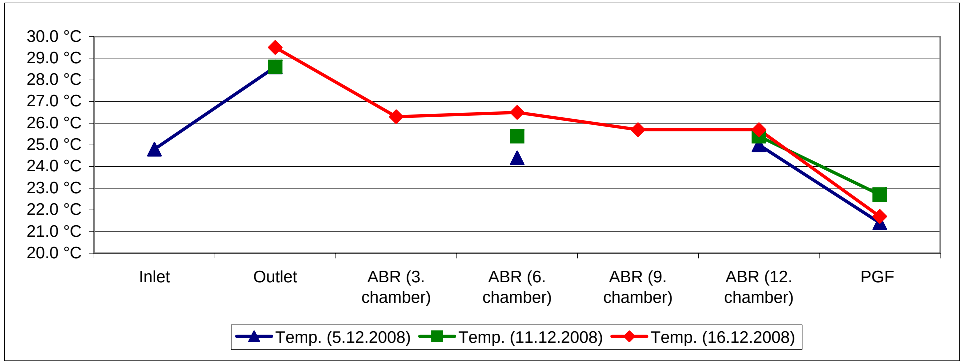
Childrens Home

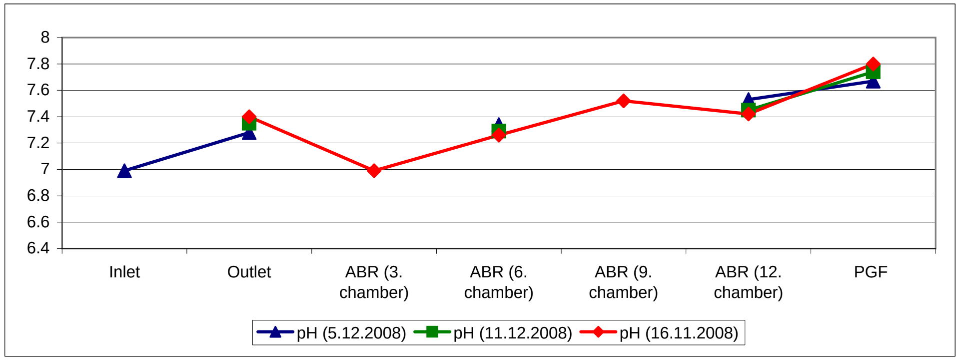
Effluent Analysis

Date	Sampling time	Time of chemical analysis	Plant		Inlet	Outlet	ABR (3. chamber)	ABR (6. chamber)	ABR (9. chamber)	ABR (12. chamber)	PGF
05.12.2008	11:00		Childrens Home	pH	6.99	7.28		7.34		7.53	7.67
				Redox- Potential	-5 mV	-22 mV		-26 mV		-37 mV	-44 mV
				Temperature	24.8 °C	28.6 °C		24.4 °C		25.0 °C	21.4 °C
		13:00		COD	1426 mg/l	1115 mg/l		1032 mg/l		993 mg/l	307 mg/l
11.12.2008	13:30		Childrens Home	pH		7.35		7.29		7.45	7.74
				Redox- Potential		-27 mV		-23 mV		-33 mV	-51 mV
				Temperature		28.6 °C		25.4 °C		25.4 °C	22.7 °C
		15:00		COD		678 mg/l		947 mg/l		956 mg/l	377 mg/l
11.12.2008	13:30		Childrens Home	pH		7.4	6.99	7.26	7.52	7.42	7.8
				Redox- Potential		-31 mV	-6 mV	-21 mV	-37 mV	-32 mV	-53 mV
				Temperature		29.5 °C	26.3 °C	26.5 °C	25.7 °C	25.7 °C	21.7 °C
		15:00		COD		1350 mg/l	1187 mg/l	978 mg/l	805 mg/l	869 mg/l	367 mg/l
				COD	Average	1048 mg/l					350 mg/l





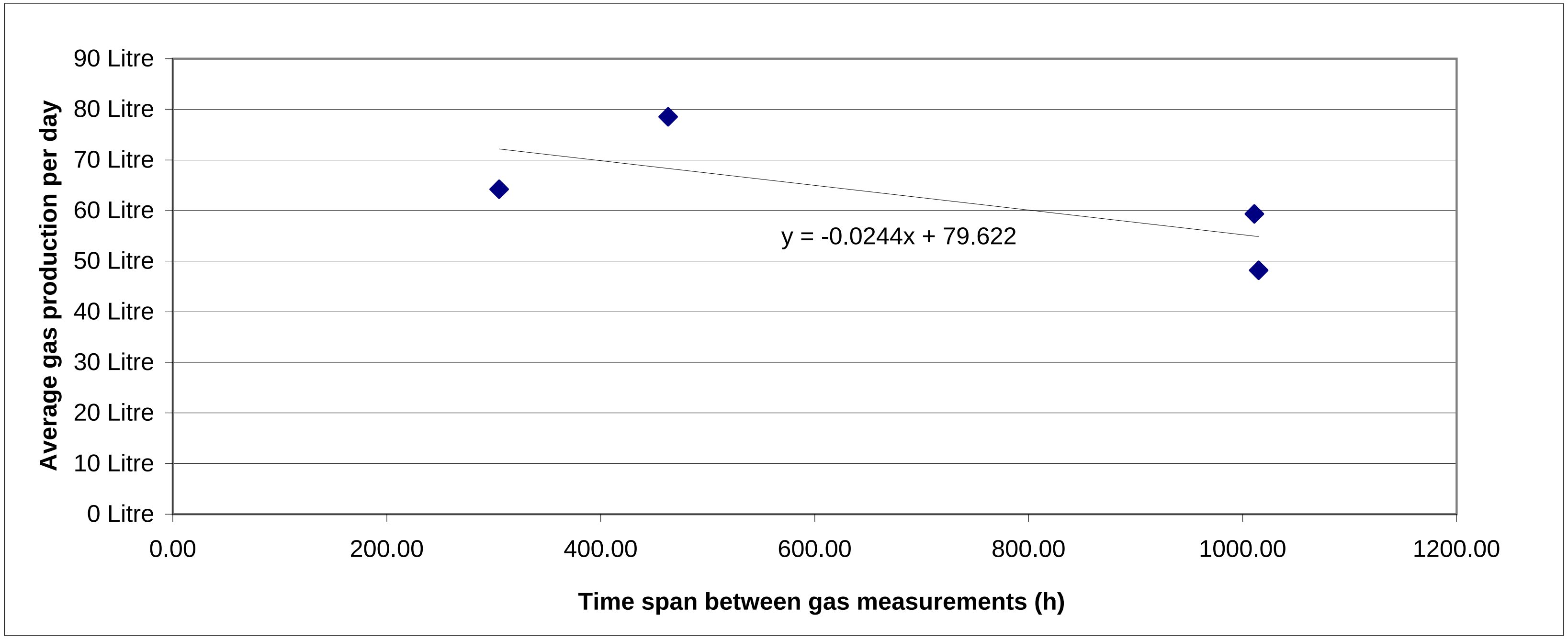




Biogas-Plants in Lesotho
Childrens Home

Biogas Production

Date	Time	Time span (h)	Display gas meter (m3)	Gas production (per time span)	Gas production (per day)	Number of people
18.11.2008	15:00:00		12449.3400 m3			
05.12.2008	16:00:00	409.00	12450.3510 m3	1011.00	59.33 Litre	very fluctuating (around 10 - 30 people)
05.12.2008	16:00:00		12451.6050 m3			
11.12.2008	13:30:00	141.50	12452.0680 m3	463.00	78.53 Litre	very fluctuating (around 10 - 30 people)
11.12.2008	16:00:00		12452.0690 m3			
16.12.2008	10:00:00	114.00	12452.3740 m3	305.00	64.21 Litre	very fluctuating (around 10 - 30 people)
16.12.2008	10:00:00		12453.0030 m3			
06.01.2009	11:20:00	505.33	12454.0180 m3	1015.00	48.21 Litre	very fluctuating (around 10 - 30 people)
				Average	62.6 Litre	
				x=24h	79.0 Litre	



Picture Series: Mr Monethi

Picture 1: Overview of the biogas plant (Nov. 2008)

Picture 2: Chambers of digester, ABR and PGF (left) (Nov. 2008).

Picture 3: PGF in series; different size of crashed stones (13.1.2009).

Picture 4: Dome inlet, use of detergent (Nov. 2008).

Picture 5: Dome outlet, no biogas production (Nov.2008)

Picture 6: Dome inlet, after stopping using detergent (9.1.2009)

Picture 7: Dome inlet, water level goes down when releasing biogas (9.1.2009)

Picture 8: Dome outlet, some sanitary towels passed the digester (9.1.2009).

Picture 9: PGF with some plants (9.1.2009).

Picture 10: Effluent tank in PGF, used for irrigation (1.9.2009).

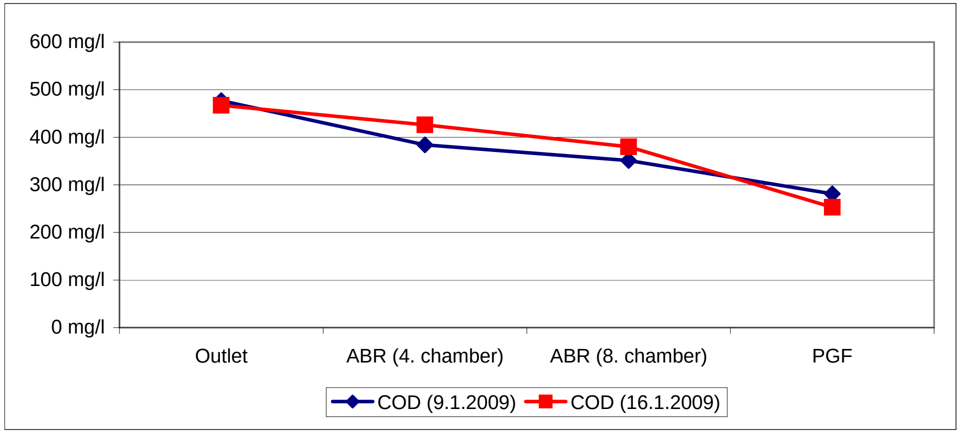
Picture 11: Measurement of biogas production (9.1.2009)

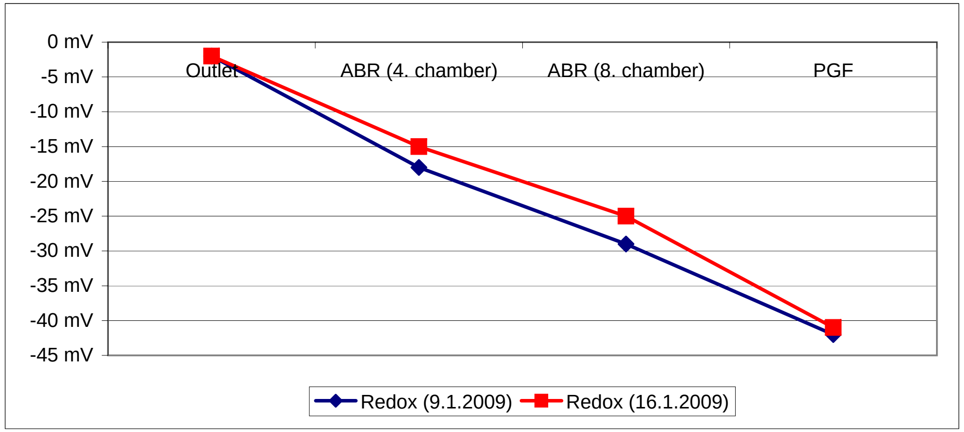
Picture 12: Open gas valve with connection to gas meter (9.1.2009)

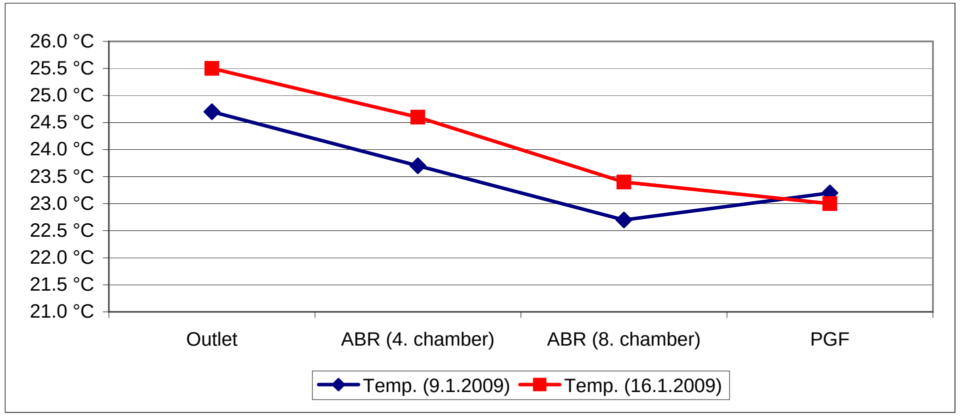
Mr Monethi

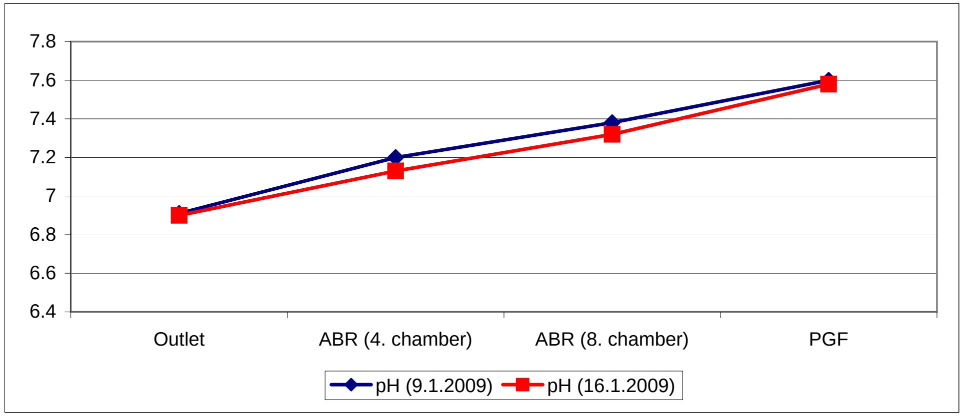
Effluent Analysis

Date	Sampling time	Time of chemical analysis	Plant		Inlet	Outlet	ABR (4. chamber)	ABR (8. chamber)	PGF	Remarks
02.10.2008			Monethi	Temperature		22.0 °C			17.8 °C	Analysed by TED-Borda
03.10.2008				COD		488 mg/l			420 mg/l	
09.01.2009	13:30		Monethi	pH		6.91	7.2	7.38	7.6	
				Redox- Potential		-2 mV	-18 mV	-29 mV	-42 mV	
				Temperature		24.7 °C	23.7 °C	22.7 °C	23.2 °C	
		15:00		COD		477 mg/l	384 mg/l	351 mg/l	281 mg/l	
16.01.2009	09:30		Monethi	pH		6.9	7.13	7.32	7.58	
				Redox- Potential		-2 mV	-15 mV	-25 mV	-41 mV	
				Temperature		25.5 °C	24.6 °C	23.4 °C	23.0 °C	
		10:30		COD		467 mg/l	426 mg/l	380 mg/l	253 mg/l	
					Average	472 mg/l	405 mg/l	366 mg/l	267 mg/l	





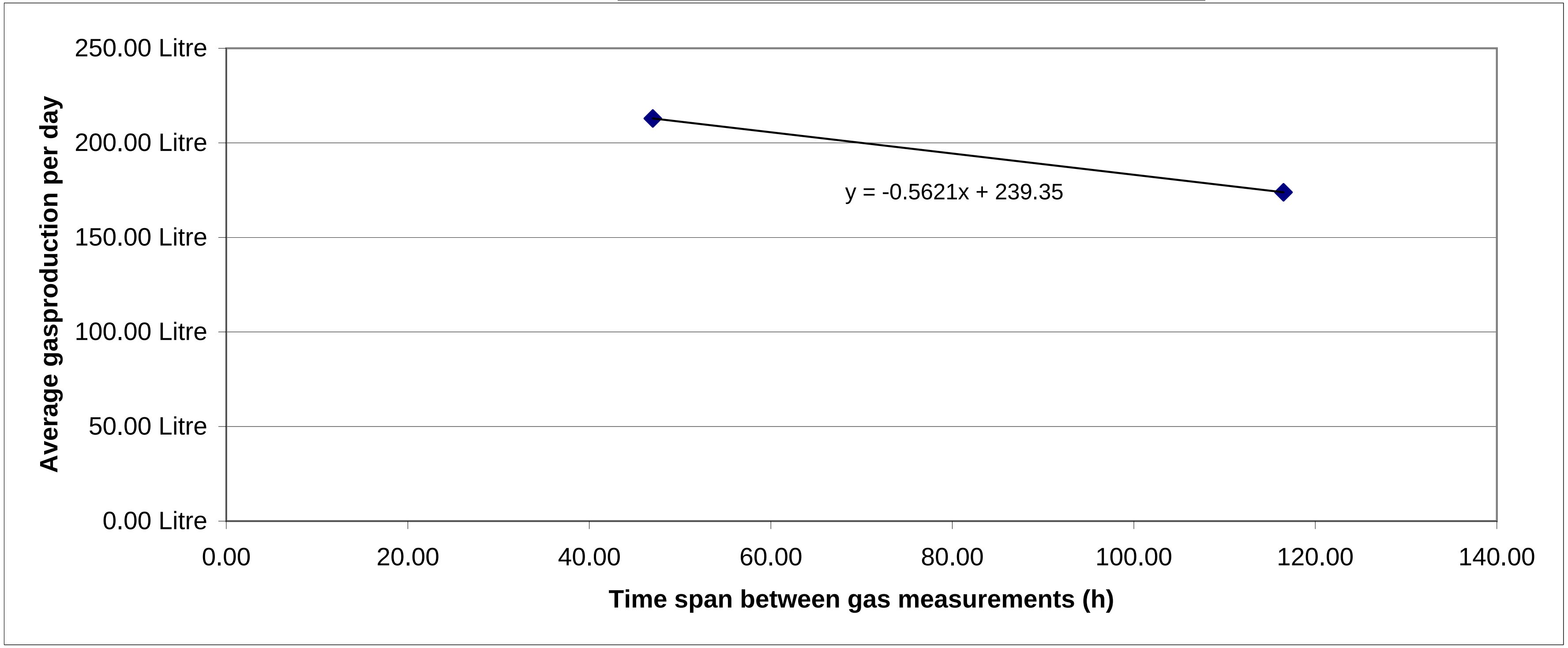




Mr Monethi

Biogas Production

Date	Time	Time span (h)	Display gas meter (m3)	Gasproduction (per time span)	CO2-content in biogas	Gasproduction (per day)	Number of people	Gasproduction / day and person
09.01.2009	13:00:00		12454.018					
09.01.2009	14:00:00	1.00	12455.32	1302 Litre	12%			
09.01.2009	14:00:00		12455.652					
14.01.2009	10:30:00	116.50	12456.496	844 Litre	8%	173.87 Litre	4	43.47 Litre
14.01.2009	10:30:00		12456.703					
16.01.2009	09:30:00	47.00	12457.12	417 Litre	10%	212.94 Litre	4	53.23 Litre
				Average	10%	193.4 Litre		48.4 Litre
				x=24h		225.9 Litre		



Picture Series: Mrs Ntsihele

Picture 1: Overview of the biogas plant (13.1. 2009)

Picture 2: Open stable for pigs (13.1.2009).

Picture 3: PGF with outlet chambers (Nov. 2008).

Picture 4: Young pigs in the stable(13.1. 2009)

Picture 5: Chicken breeding (13.1. 2009).

Picture 6: Gas heater operated with biogas (Nov. 2008).

Picture 7: Open pig stables with waste water channels(13.1.2009).

Picture 8: Regular overflow of waste water (13.1. 2009)

Picture 9: Waste water entering the dome inlet by gravity (Nov. 2008).

Picture 10: Oulet chambers of PGF, effleunt used for irrigation (13.1.2009).

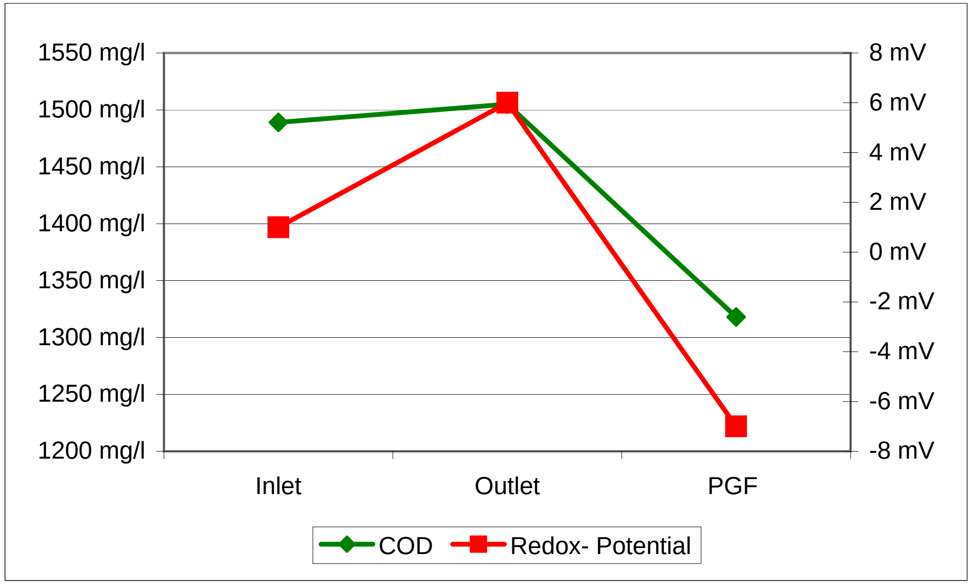
Picture 11: The garden where effluent is applied (13.1.2009)

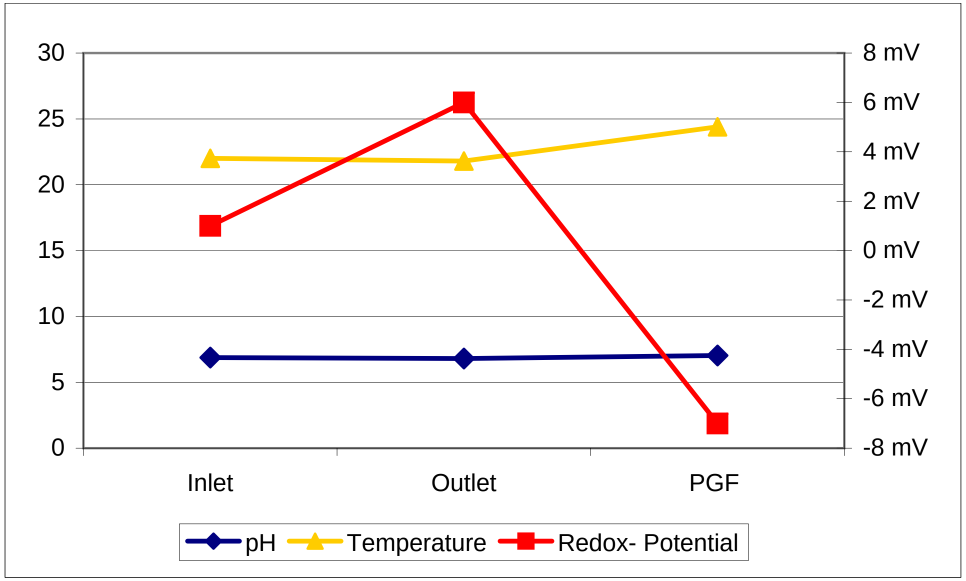
Picture 12: Chicken dung is fed manually into inlet chamber (13.1.2009)

Biogas-Plants in Lesotho
Mrs Ntsihele

Effluent Analysis

Date	Sampling time	Time of chemical analysis	Plant		Inlet	Outlet	ABR (last chamber)	PGF	Remarks
01.12.2008	11:40		Mrs Ntsihele	pH	6.88	6.8		7.03	A lot of pig manure
				Redox- Potential	1 mV	6 mV		-7 mV	
				Temperature	22.0 °C	21.8 °C		24.4 °C	
		16:00		COD	1489 mg/l	1505 mg/l		1318 mg/l	





Mrs Ntsihele

Biogas consumption

Date	Time	Duration	Purpose of gas use / Remarks	Date	Time	Duration	Purpose of gas use / Remarks
11.12.2008	05:30	315 min	Bath water, porridge, soup	25.12.2008	05:00		boiling water without using it
11.12.2008	11:30	135 min	Porridge, Water, Meat, Vegetables	25.12.2008	06:30		boiling water without using it
11.12.2008	04:30	360 min	Beans, porridge, bath water	25.12.2008	05:30		boiling water without using it
12.12.2008	05:30	255 min	Bath water, soup, eggs	26.12.2008	05:30		boiling water without using it
12.12.2008	11:00	300 min	no gas avaiable (rain)	26.12.2008	11:00		Papa, vegetables, mutton
12.12.2008	06:30	90 min	Papa, water	26.12.2008	19:00	325 min	Water, bread
13.12.2008	05:30	90 min	Porridge, water	27.12.2008	05:30		boiling water without using it
13.12.2008	07:00	90 min	no gas avaiable (rain)	27.12.2008	06:30		boiling water without using it
13.12.2008	12:30	120 min	Beans, porridge, bath water	28.12.2008	05:30		boiling water without using it
13.12.2008	05:00	285 min	Water, samp, beet root, carrots	28.12.2008	19:30		boiling water without using it
14.12.2008	05:30	310 min	Water, rice, vegetables, beef	29.12.2008	06:30		Water, soup, eggs
14.12.2008	12:00	60 min	Samp, Vegetables, water	29.12.2008	12:00		Water, papa, meat
14.12.2008	06:00	80 min	Water	29.12.2008	06:30		boiling water without using it
15.12.2008	05:30	210 min	Water, porridge, eggs	30.12.2008	05:00		Water, porridge, milk
15.12.2008	12:00	220 min	Porridge, spinarch	31.12.2008	05:30	180 min	Water, soup, eggs
15.12.2008	17:30	180 min	Meat, papa, water	31.12.2008	14:00		Water, vegetables, papa
16.12.2008	05:30	210 min	Water, soup, eggs	31.12.2008	19:30	300 min	Water
16.12.2008	11:00	210 min	Papa, water, vegetables	01.01.2009	09:00	180 min	Water
17.12.2008	05:00	270 min	Fish, vegetables, water	01.01.2009	18:30	240 min	Water
17.12.2008	11:30	60 min	Vegetables, papa, meat, water	02.01.2009	05:30	315 min	Water, porridge
17.12.2008	06:30	60 min	Water, fish, beans	02.01.2009	03:45	215 min	Water, Dumpkin
18.12.2008	05:00	420 min	Water, meat, papa	03.01.2009	05:30		Water
18.12.2008	06:30	60 min	Water	03.01.2009	18:30		Water
19.12.2008	05:00	330 min	Water, soup, eggs	04.01.2009	05:30		Water
19.12.2008	12:30	105 min	Samp, beef, potatoes	05.01.2009	07:00	180 min	Water, soup
19.12.2008	06:00	60 min	Water, papa, spinarch	05.01.2009	18:30		Water
20.12.2008	05:00	165 min	Water, soup	06.01.2009	05:30	495 min	Water, porridge, meat, samp
20.12.2008	11:30	120 min	Porridge, vegetables, meat, water	06.01.2009	07:00		Water
20.12.2008	06:30	60 min	Water	07.01.2009	05:30	480 min	Water, samp, papa
21.12.2008	05:00	330 min	Water, rice, vegetables	07.01.2009	07:00		Water
21.12.2008	13:00	60 min	Water	08.01.2009	05:30		Water
21.12.2008	18:30	30 min	Water	08.01.2009	11:30	195 min	Water, papa, vegetables, mutton
22.12.2008	05:00	180 min	Water, soup, eggs	08.01.2009	19:00	255 min	Water
22.12.2008	10:30	240 min	Samp, chicken, vegetables	09.01.2009	05:30	180 min	Water, soup
22.12.2008	06:30	60 min	Water	09.01.2009	12:00	150 min	Water, papa, moroho, nama
23.12.2008	05:00	310 min	Bread, water, meat	09.01.2009	07:00	240 min	Water
23.12.2008	11:00	240 min	Water, vegetables, papa	10.01.2009	05:30	240 min	Water, porridge
23.12.2008	06:30	75 min	Water	10.01.2009	18:30	240 min	Water
24.12.2008	05:00	225 min	Water, soup, bread	11.01.2009	06:00	225 min	Water, vegetables, meat, rice
24.12.2008	09:00		boiling water without using it	11.01.2009	19:00	270 min	Water, samp, moroho, nama
24.12.2008	05:30		boiling water without using it			**11885 min**	
						6.4 h/day	**Average time of gas use**

Mrs Ntsihele

Additional Feedstock

Date	Time	Amount	Composition / remarks (Assumption: 1 spade = 1 kg)
11.12.2008		> 15 kg	pig waste, 15 spades, waste from toilet house
12.12.2009	11:30	> 46 kg	30 kg chicken waste; pig waste, 16 spades; waste from toilet house
13.12.2008	09:30	> 16 kg	pig waste, 16 spades, waste from toilet house
14.12.2008		> 1 kg	waste from toilet house
15.12.2008	11:00	~36 kg	pig waste, 35 spades; dog waste, 1 spade
16.12.2008	11:00	~38 kg	20 kg chicken waste, pig waste, 18 spades
17.12.2008	11:50	~18 kg	pig waste, 18 spades
18.12.2008	11:00	~35 kg	20kg chicken waste, pig waste, 15 spades
19.12.2008	11:00	> 2 kg	pig waste, dog waste
20.12.2008	11:00	~20 kg	pig waste, 20 spades
21.12.2008	11:30	~9 kg	pig waste , 9 spades
23.12.2008	11:00	> 10 kg	10 kg chicken waste, pig waste, dog waste
29.12.2008		~50 kg	50 kg pig waste
02.01.2009	10:30	~18 kg	pig waste, 18 spades
05.01.2009	14:00	~18 kg	pig waste, 18 spades
06.01.2009	10:30	~15 kg	pig waste, 14 spades; dog waste, 1 spade
09.01.2009	10:00	~35 kg	pig waste, 35 spades
10.01.2009	17:00	~45 kg	45 kg chicken waste
		> 427 kg	**Total waste manually fed (inflow by gravitiy is not measured)**
		> 14 kg/day	**Average waste manually fed**

Picture Series: Mazenod

Picture 1: Overview of the biogas plant (27.11.2008)

Picture 2: Situation a few days later (10.12.2008)

Picture 3: Maize crops have grown for 1.5 months (14.1.2009).

Picture 4: Cow dung is bought and fed into digester (27.11.2008)

Picture 5: Dome inlet, black waster and cow dung mixed (27.11. 2008).

Picture 6: Dome outlet (27.11.2008).

Picture 7: Dome outlet (16.12.2008).

Picture 8: ABR, tanking effluent samples (16.12.2008)

Picture 9: PGF, only covered with a few plants (14.1.2009).

Picture 10: PGF outlet, effluent tank - effluent is used for irrigation (10.12.2008)

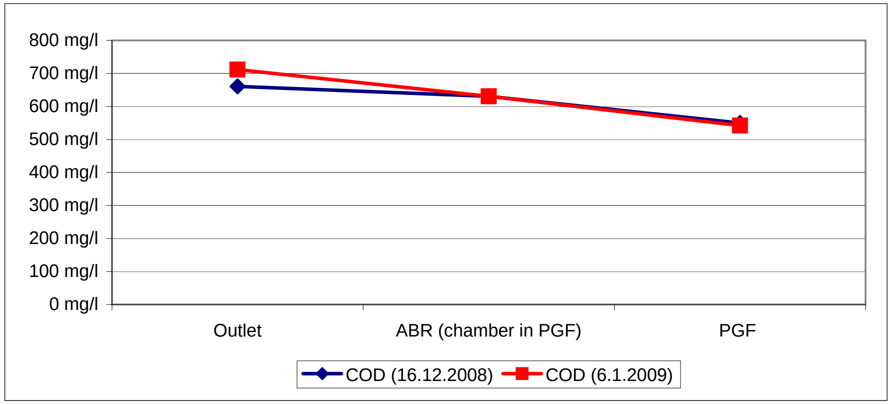
Picture 11: Biogas stove in the kitchen (10.12.2008)

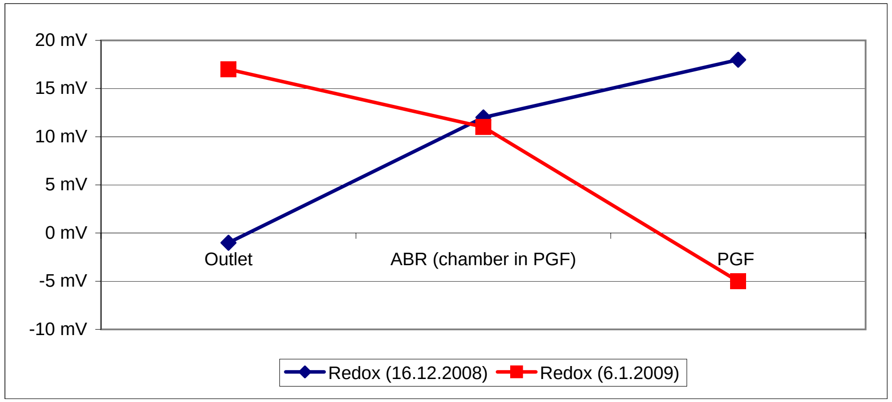
Picture 12: Family member in front of biogas stove (14.1.2009)

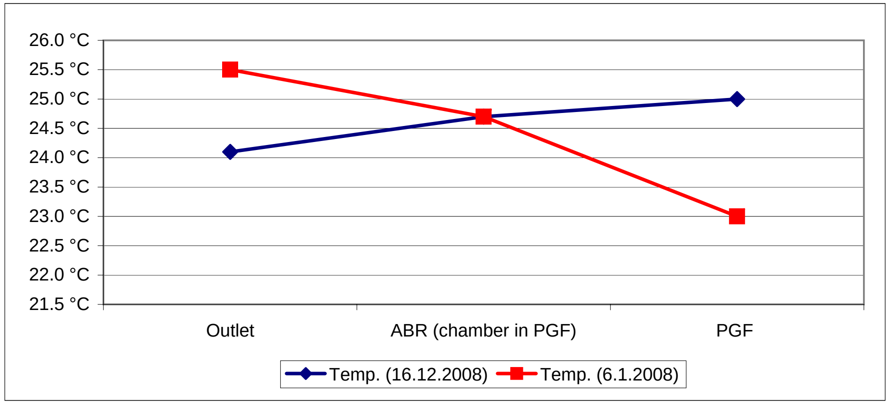
Mazenod

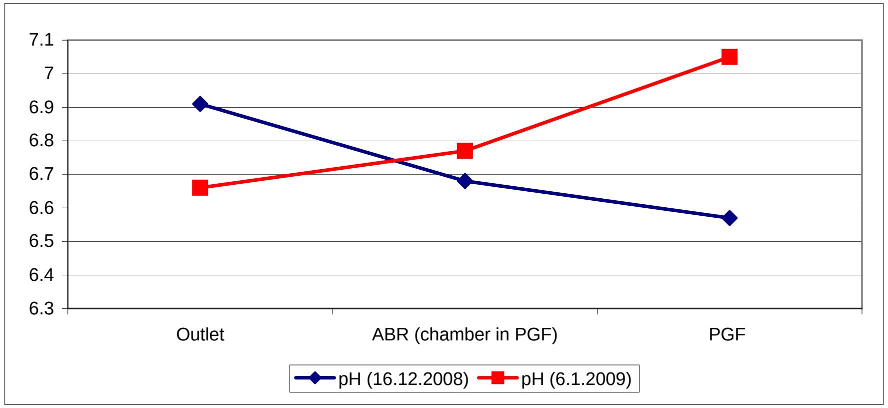
Effluent Analysis

Date	Sampling time	Time of chemical analysis	Plant		Inlet	Outlet	ABR (chamber in PGF)	PGF	Remarks
14.06.2008	10:00		Mazenod	COD		899 mg/l		800 mg/l	Analysed by TED-Borda
11.09.2008	11:00		Mazenod	pH		7		7	Analysed by TED-Borda
12.09.2008				COD		804 mg/l		549 mg/l	
16.12.2008	11:20		Mazenod	pH		6.91	6.68	6.57	
				Redox- Potential		-1 mV	12 mV	18 mV	
				Temperature		24.1 °C	24.7 °C	25.0 °C	
		14:30		COD		911 mg/l	637 mg/l	550 mg/l	
17.12.2008		14:30		COD		661 mg/l	631 mg/l	550 mg/l	
06.01.2009	13:00		Mazenod	pH		6.66	6.77	7.05	
				Redox- Potential		17 mV	11 mV	-5 mV	
				Temperature		25.5 °C	24.7 °C	23.0 °C	
		15:30		COD		712 mg/l	631 mg/l	542 mg/l	
					Average	687 mg/l	631 mg/l	546 mg/l	







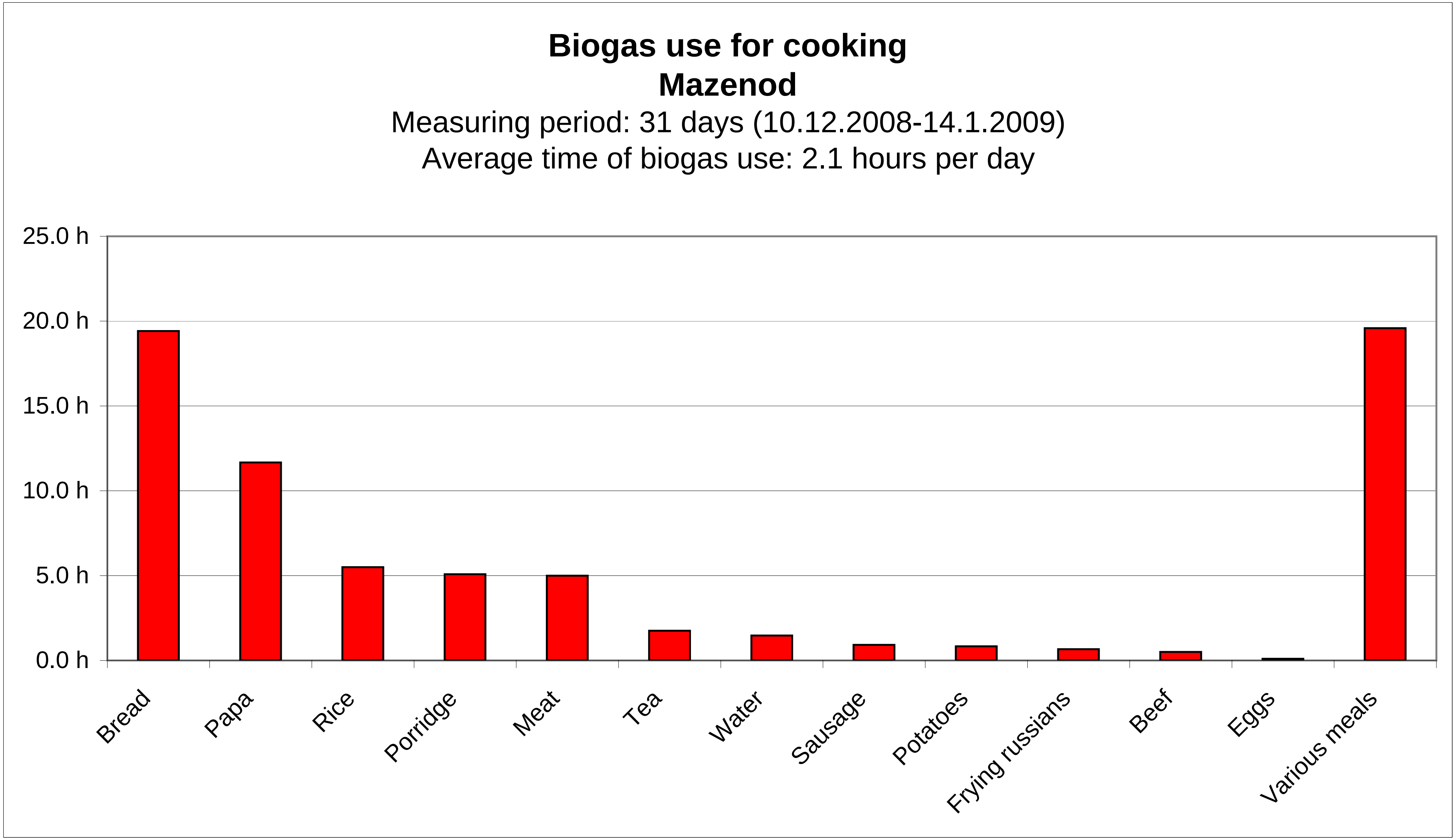


Mazenod

Biogas Consumption

Date	Time	Duration	Purpose of gas use / Remarks	Date	Time	Duration	Purpose of gas use / Remarks
10.12.2008	*06:00*	*6 min*	*tea*	*25.12.2008*	*08:40*	*110 min*	*meat*
10.12.2008	*14:31*	*6 min*	*eggs*	*26.12.2008*	*08:00*	*20 min*	*water*
10.12.2009	*17:02*	*11 min*	*tea*	*26.12.2008*	*08:45*	*15 min*	*porridge*
11.12.2008	*08:00*	*20 min*	*porridge*	*26.12.2008*	*18:00*	*90 min*	*bread*
11.12.2008	*12:00*	*120 min*	*rice & meat*	*27.12.2008*	*09:50*	*5 min*	*sausage*
11.12.2008	*19:50*	*10 min*	*tea*	*27.12.2008*	*10:00*	*15 min*	*tea*
12.12.2008	*12:30*	*150 min*	*bread*	*27.12.2008*	*12:00*	*90 min*	*beans*
13.12.2008	*15:00*	*180 min*	*beans*	*28.12.2008*	*05:45*	*75 min*	*porridge*
13.12.2008	*16:40*	*60 min*	*papa*	*28.12.2008*	*14:05*	*130 min*	*bread*
14.12.2008	*08:00*	*20 min*	*fish and polony*	*29.12.2008*	*18:00*	*60 min*	*papa*
14.12.2008	*12:40*	*60 min*	*rice*	*30.12.2008*	*12:50*	*60 min*	*rice*
14.12.2008	*13:00*	*30 min*	*sausage*	*31.12.2008*	*18:15*	*75 min*	*porridge*
14.12.2008	*13:30*	*180 min*	*bread*	*01.01.2009*	*07:33*	*23 min*	*water*
15.12.2008	*12:00*	*120 min*	*chicken and papa*	*02.01.2009*	*11:35*	*70 min*	*rice*
16.12.2008	*06:00*	*120 min*	*porridge*	*02.01.2009*	*09:50*	*80 min*	*papa*
16.12.2008	*17:00*	*120 min*	*rice & frying russians*	*02.01.2009*	*16:00*	*195 min*	*bread*
17.12.2008	*08:00*	*6 min*	*tea*	*06.01.2009*	*13:30*	*70 min*	*papa*
17.12.2008	*15:00*	*120 min*	*papa & meat*	*06.01.2009*	*16:00*	*120 min*	*bread*
18.12.2008	*08:00*	*6 min*	*tea*	*07.01.2009*	*08:30*	*45 min*	*water*
18.12.2008	*12:00*	*90 min*	*rice & frying russians*	*08.01.2009*	*08:00*	*15 min*	*tea*
19.12.2008	*07:00*	*11 min*	*tea*	*08.01.2009*	*08:15*	*20 min*	*sausage*
22.12.2008	*11:00*	*60 min*	*papa*	*08.01.2009*	*12:00*	*150 min*	*rice and pork*
22.12.2008	*11:00*	*10 min*	*frying russians*	*09.01.2009*	*08:00*	*10 min*	*tea*
22.12.2008	*14:00*	*180 min*	*bread*	*09.01.2009*	*15:00*	*75 min*	*papa*
22.12.2008	*18:00*	*60 min*	*meat*	*10.01.2009*	*12:00*	*60 min*	*rice*
23.12.2008	*13:00*	*60 min*	*rice*	*10.01.2009*	*18:00*	*120 min*	*papa*
23.12.2008	*14:00*	*10 min*	*frying russians*	*10.01.2009*	*20:00*	*30 min*	*beef*
23.12.2008	*19:00*	*10 min*	*frying russians*	*11.01.2009*	*12:00*	*80 min*	*rice*
23.12.2008	*19:10*	*10 min*	*frying russians*	*11.01.2009*	*14:00*	*90 min*	*meat*
24.12.2008	*14:10*	*95 min*	*papa*	*12.01.2009*	*16:00*	*80 min*	*papa*
24.12.2008	*14:10*	*40 min*	*meat*	*13.01.2009*	*06:00*	*45 min*	*frying chips*
24.12.2008	*09:00*	*15 min*	*tea*	*13.01.2009*	*06:45*	*50 min*	*potatoes*
				13.01.2009	*16:00*	*120 min*	*bread*
				14.01.2009	*06:00*	*60 min*	*frying chips*
						4349 min	
						2.1 h/day	**Average time of use**

Biogas Consumption



Picture Series: Me Lerato

Picture 1: Overview of the biogas plant (Nov. 2008)

Picture 2: Dome inlet (right) and gas outlet (left, Nov. 2008).

Picture 3: Open stables for pigs (Nov. 2008).

Picture 4: Pigs in the stable(Nov. 2008)

Picture 5: Chicken breeding next to the plant (13.1. 2009).

Picture 6: Paper as feedstock for digester (Nov. 2008).

Picture 7: Gas outlet and dome outlet chamber covered with plants (13.1.2009).

Picture 8: Dome inlet with scum layer (Nov. 2008)

Picture 9: Dome outlet with scum layer (Nov. 2008).

Picture 10: Biogas stove in the kitchen on the right side (13.1.2009)

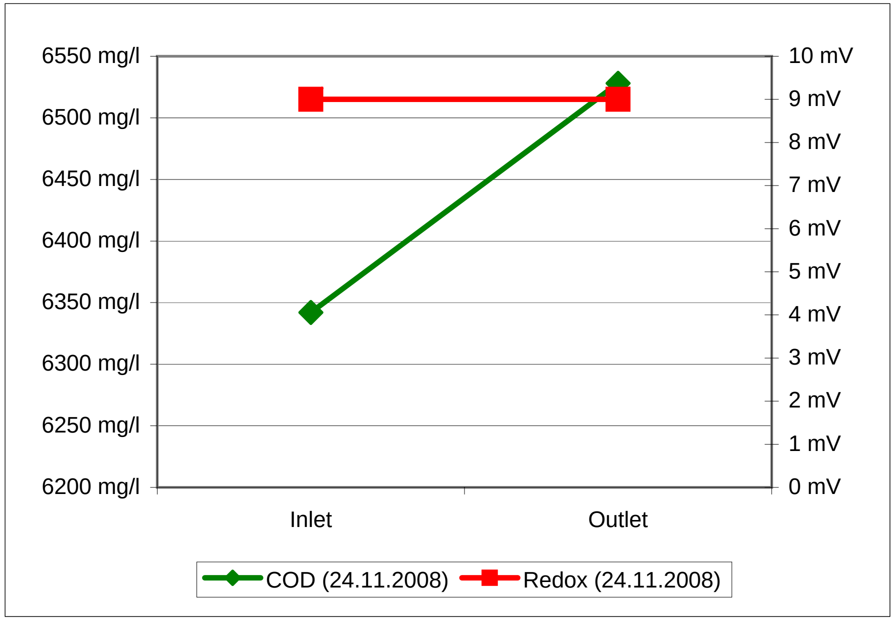
Picture 11: Septic tank and PGF for black water from household (13.1.2009)

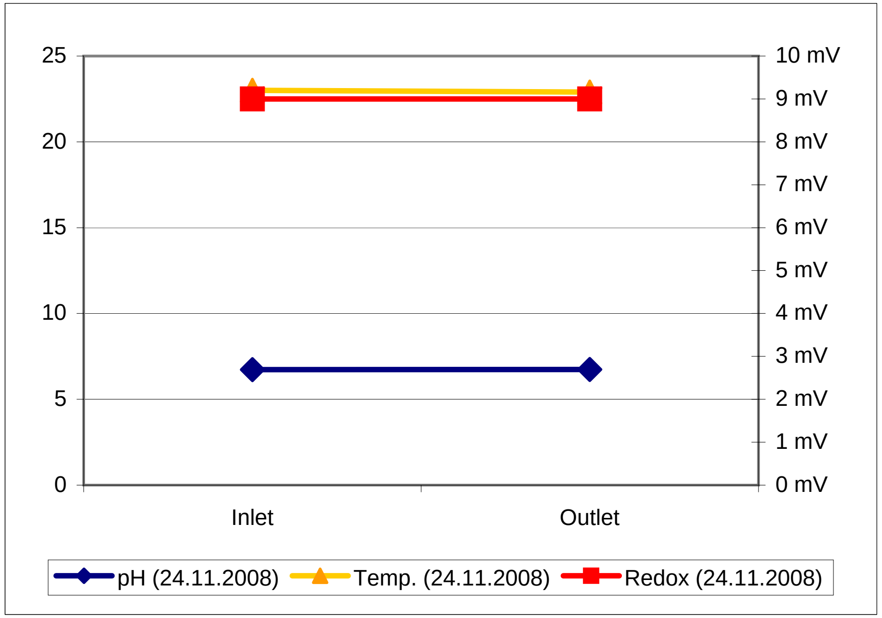
Picture 12: PGF is not connected with digester, only to septic tank (13.1.2009)

Biogas-Plants in Lesotho
Me Lerato "Flower House"

Effluent Analysis

Date	Sampling time	Time of chemical analysis	Plant		Inlet	Outlet	Remarks
11.12.2008	11:40		Me Lerato	pH	6.73	6.74	
				Redox- Potential	9 mV	9 mV	
				Temperature	23.0 °C	22.9 °C	
		15:00		COD	6342 mg/l	6528 mg/l	Samples cooled in the frigde after 12:30 till analysed





Me Lerato

Biogas Consumption

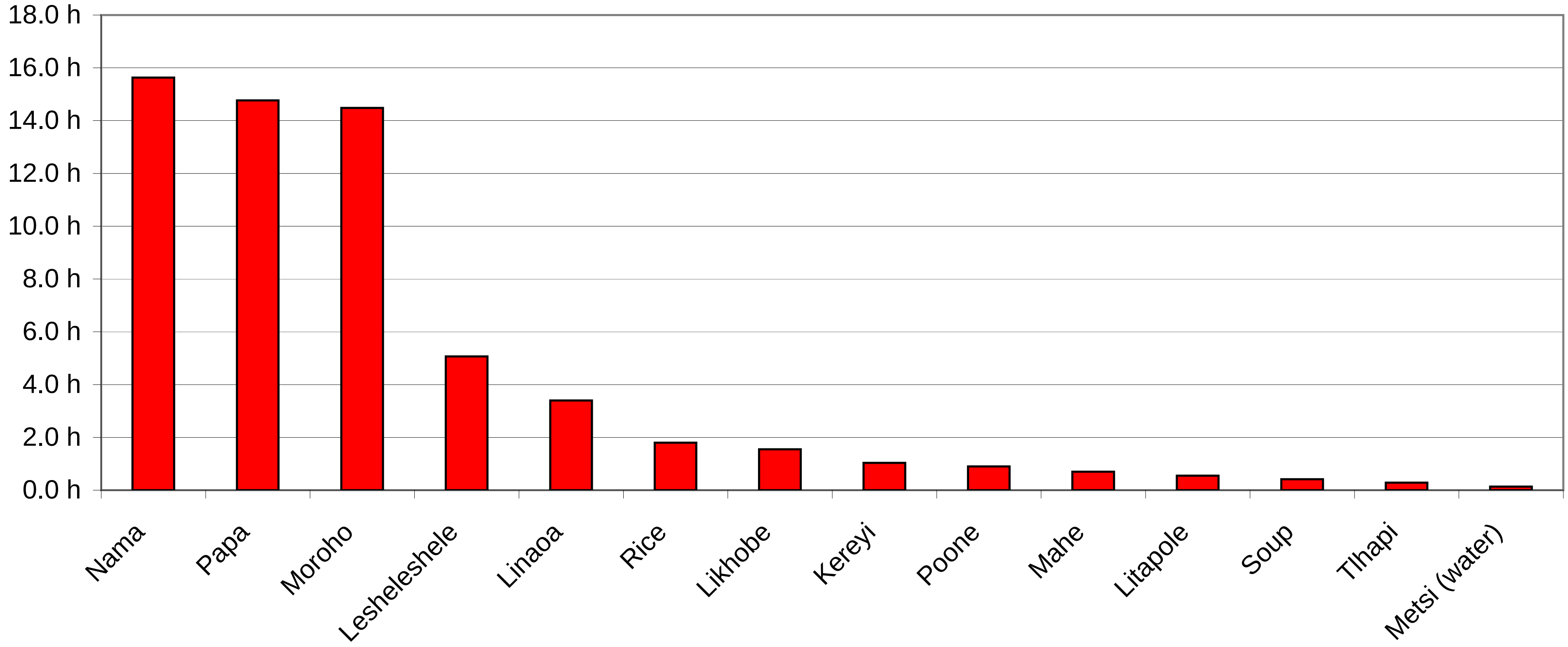
Date	Time	Duration	Purpose of gas use / Remarks	Date	Time	Duration	Purpose of gas use / Remarks
10.12.2008	16:30	41 min	Nama	22.12.2008	06:20	15 min	Lesheleshele
10.12.2008	16:59	9 min	Moroho	22.12.2008	12:43	37 min	Papa
11.12.2008	05:47	12 min	Lesheleshele	22.12.2008	12:25	25 min	Soup
11.12.2008	08:50	130 min	Linaoa	23.12.2008	06:15	17 min	Lesheleshele
11.12.2008	12:30	60 min	Papa	06.01.2009	05:49	10 min	Lesheleshele
12.12.2008	05:43	9 min	Lesheleshele	06.01.2009	11:44	45 min	Papa
12.12.2008	12:42	55 min	Papa	06.01.2009	14:20	42 min	Nama
12.12.2008	16:16	38 min	Nama	06.01.2009	14:20	4 min	Moroho
12.12.2008	16:55	10 min	Moroho	06.01.2009	15:47	9 min	Kereyi
13.12.2008	05:43	10 min	Lesheleshele	07.01.2009	11:22	67 min	Papa
13.12.2008	11:48	34 min	Nama	07.01.2009	12:14	16 min	Moroho
13.12.2008	11:48	21 min	Papa	07.01.2009	12:29	17 min	Tlhapi
14.12.2008	05:43	11 min	Lesheleshele	08.01.2009	05:28	16 min	Lesheleshele
14.12.2008	05:52	41 min	Papa	08.01.2009	11:06	47 min	Papa
14.12.2008	06:14	67 min	Nama	08.01.2009	12:19	51 min	Nama
14.12.2008	09:18	6 min	Moroho	08.01.2009	13:12	8 min	Moroho
15.12.2008	05:38	10 min	Lesheleshele	08.01.2009	09:13	4 min	Mahe
15.12.2008	11:11	70 min	Papa	08.01.2009	10:59	54 min	Poone
15.12.2008	16:42	15 min	Moroho	08.01.2009	11:59	20 min	Moroho
15.12.2008	17:38	10 min	Nama	08.01.2009	15:50	34 min	Nama
15.12.2008	18:47	22 min	Nama	09.01.2009	05:38	52 min	Lesheleshele
16.12.2008	05:25	35 min	Nama	09.01.2009	11:15	55 min	Papa
16.12.2008	05:38	16 min	Lesheleshele	09.01.2009	12:10	112 min	Nama
16.12.2008	11:44	59 min	Papa	09.01.2009	05:58	650 min	Moroho
16.12.2008	12:11	8 min	Metsi	10.01.2009	10:21	10 min	Lesheleshele
16.12.2008	16:13	8 min	Moroho	10.01.2009	06:00	21 min	Mahe
17.12.2008	05:12	10 min	Lesheleshele	10.01.2009	10:45	32 min	Nama
17.12.2008	11:31	53 min	Papa	10.01.2009	12:23	8 min	Moroho
17.12.2008	16:07	8 min	Moroho	10.01.2009	17:48	28 min	Papa
17.12.2008	16:07	23 min	Nama	11.01.2009	05:55	18 min	Lesheleshele
17.12.2008	18:13	17 min	Kereyi	11.01.2009	06:13	46 min	Rice
18.12.2008	05:17	10 min	Lesheleshele	11.01.2009	07:00	19 min	Kereyi
18.12.2008	11:35	38 min	Papa	11.01.2009	07:29	12 min	Litapole
18.12.2008	13:48	52 min	Linaoa	11.01.2009	07:58	22 min	Linaoa
18.12.2008	17:21	68 min	Nama	12.01.2009	09:41	32 min	Nama
19.12.2008	05:27	10 min	Lesheleshele	12.01.2009	05:27	13 min	Lesheleshele
19.12.2008	12:22	28 min	Moroho	12.01.2009	11:52	47 min	Papa
19.12.2008	12:22	58 min	Papa	12.01.2009	11:52	69 min	Nama
19.12.2008	13:20	40 min	Nama	12.01.2009	15:58	10 min	Moroho
20.12.2008	06:32	17 min	Lesheleshele	12.01.2009	12:15	33 min	Rice
20.12.2008	12:38	51 min	Papa	13.01.2009	05:29	13 min	Lesheleshele
20.12.2008	12:52	42 min	Nama	13.01.2009	11:40	45 min	Moroho
21.12.2008	05:46	16 min	Lesheleshele	13.01.2009	11:52	54 min	Papa
21.12.2008	05:48	42 min	Nama	13.01.2009	12:20	47 min	Nama
21.12.2008	06:14	29 min	Rice	14.01.2009	05:38	9 min	Lesheleshele
21.12.2008	10:58	8 min	Moroho	14.01.2009	05:49	57 min	Nama
21.12.2008	11:22	17 min	Kereyi	14.01.2009	10:10	93 min	Likhobe
21.12.2008	11:38	21 min	Litapole	14.01.2009	11:43	17 min	Mahe
				14.01.2009	12:00	16 min	Moroho
						3643 min	
						2.6 h/day	**Average time of use**

Biogas Consumption

Biogas use for cooking
Me Lerato

Measuring period: 23 days (10.12.2008-14.1.2009, with interruption)

Average time of biogas use: 2.6 hours per day



Picture Series: Mrs Nthama

Picture 1: Overview of the biogas plant (Nov. 2008)

Picture 2: Gas outlet and dome outlet in the back (Nov. 2008)

Picture 3: Drying bed on top of expansion chamber (10.12.2008).

Picture 4: Drying bed, effluent is put on top to be dried (Nov. 2008)

Picture 5: Dome inlet, black waster mixed with chicken waste (Nov. 2008).

Picture 6: Dome outlet (Nov. 2008).

Picture 10: Oulet of expansion chamber, effluent enters the water canal (Nov. 2008)

Picture 11: Water canal is distributing the effluent (Nov. 2008)

Picture 12: Overview of garden (Nov. 2008)

Picture 7: Maize crops have been growing (12.1.2009).

Picture 8: Chicken breeding (10.12.2008)

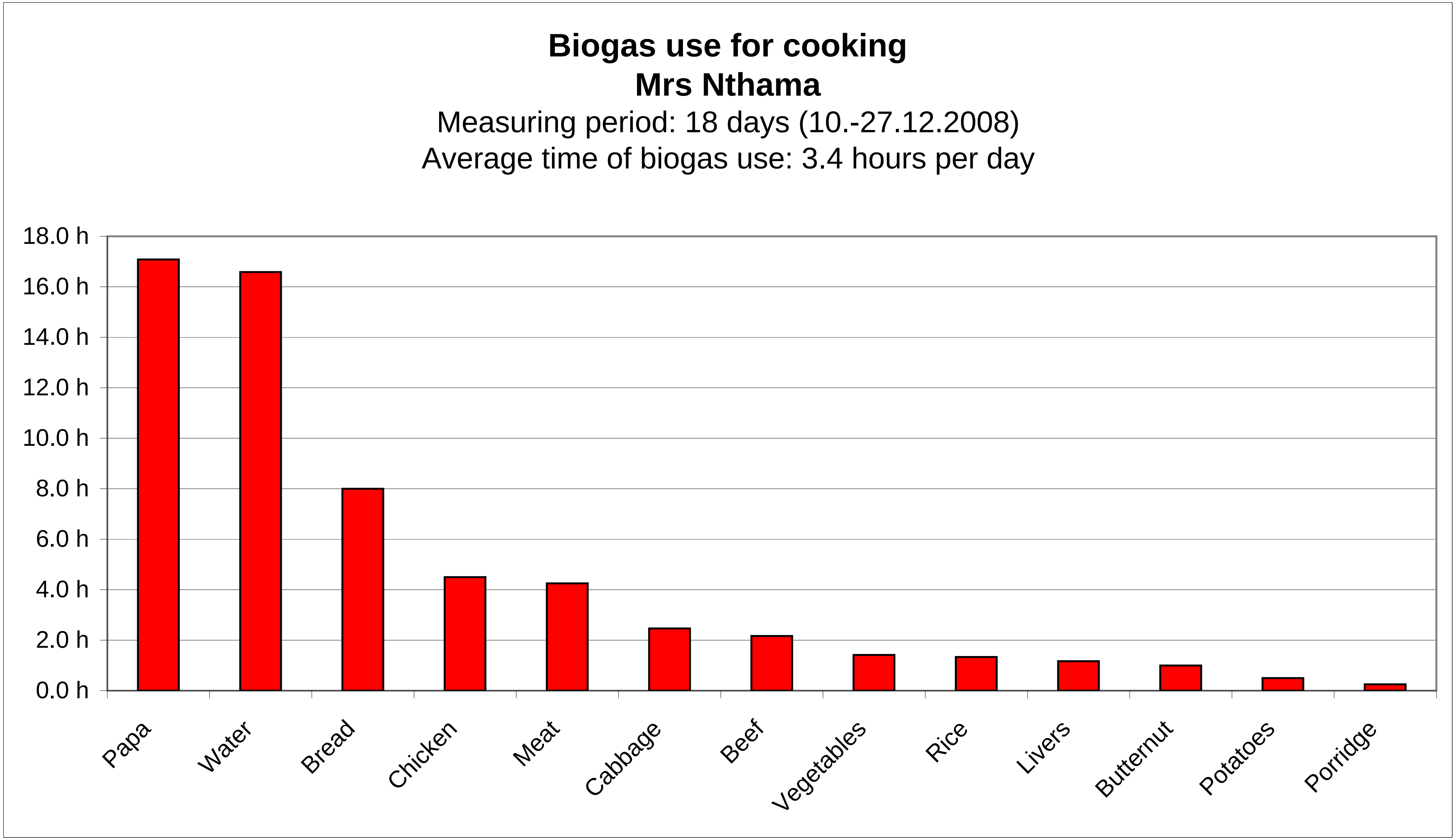
Picture 9: Wheelbarrow for chicken waste collection (14.1.2009).

Mrs Nthama

Biogas Consumption

Date	Time	Duration	Purpose of gas use / Remarks	Date	Time	Duration	Purpose of gas use / Remarks
10.12.2008	*20:30*	*10 min*	*Beef*	*18.12.2008*	*05:00*	*90 min*	*Water*
11.112.08	*10:50*	*150 min*	*Papa*	*18.12.2008*	*10:33*	*23 min*	*Cabbage*
11.12.2008	*06:00*	*120 min*	*Bread*	*18.12.2008*	*08:05*	*120 min*	*Papa*
12.12.2008	*07:00*	*10 min*	*Livers*	*18.12.2008*	*06:00*	*45 min*	*Meat*
13.12.2008	*11:05*	*60 min*	*Papa*	*19.12.2008*	*05:30*	*90 min*	*Water*
13.12.2008	*12:39*	*40 min*	*Vegetables*	*19.12.2008*	*09:40*	*140 min*	*Papa*
14.12.2008	*08:00*	*120 min*	*Meat*	*19.12.2008*	*09:40*	*20 min*	*Cabbage*
14.12.2008	*10:00*	*60 min*	*Water*	*20.12.2008*	*12:21*	*120 min*	*Bread*
14.12.2008	*10:00*	*50 min*	*Rice*	*20.12.2008*	*06:30*	*150 min*	*Chicken*
14.12.2008	*08:45*	*30 min*	*Butternut*	*21.12.2008*	*05:00*	*60 min*	*Water*
14.12.2008	*09:30*	*30 min*	*Potatoes*	*21.12.2008*	*10:30*	*30 min*	*Butternut*
15.12.2008	*09:28*	*140 min*	*Papa*	*21.12.2008*	*11:30*	*30 min*	*Rice*
15.12.2008	*09:00*	*120 min*	*Water*	*22.12.2008*	*05:30*	*90 min*	*Water*
15.12.2008	*12:52*	*20 min*	*Cabbage*	*22.12.2008*	*07:30*	*45 min*	*Papa*
15.12.2008	*07:00*	*120 min*	*Bread*	*22.12.2008*	*09:00*	*60 min*	*Livers*
16.12.2008	*09:29*	*150 min*	*Papa*	*22.12.2008*	*07:00*	*60 min*	*Water*
16.12.2008	*11:47*	*20 min*	*Cabbage*	*23.12.2008*	*08:30*	*15 min*	*Porridge*
16.12.2008	*11:47*	*20 min*	*Water*	*24.12.2008*	*10:00*	*60 min*	*Water*
16.12.2008	*04:00*	*120 min*	*Chicken*	*24.12.2008*	*06:45*	*45 min*	*Cabbage*
16.12.2008	*05:00*	*120 min*	*Bread*	*25.12.2008*	*09:30*	*120 min*	*Beef*
17.12.2008	*06:00*	*120 min*	*Water*	*25.12.2008*	*01:00*	*120 min*	*Water*
17.12.2008	*12:50*	*130 min*	*Papa*	*26.12.2008*	*05:00*	*105 min*	*Water*
17.12.2008	*02:50*	*20 min*	*Cabbage*	*26.12.2008*	*07:30*	*45 min*	*Papa*
				26.12.2008	*08:15*	*45 min*	*Vegetables*
				27.12.2008	*10:00*	*90 min*	*Meat*
				27.12.2008	*11:30*	*45 min*	*Papa*
						3643 min	
						3.4 h/day	***Average time of use***

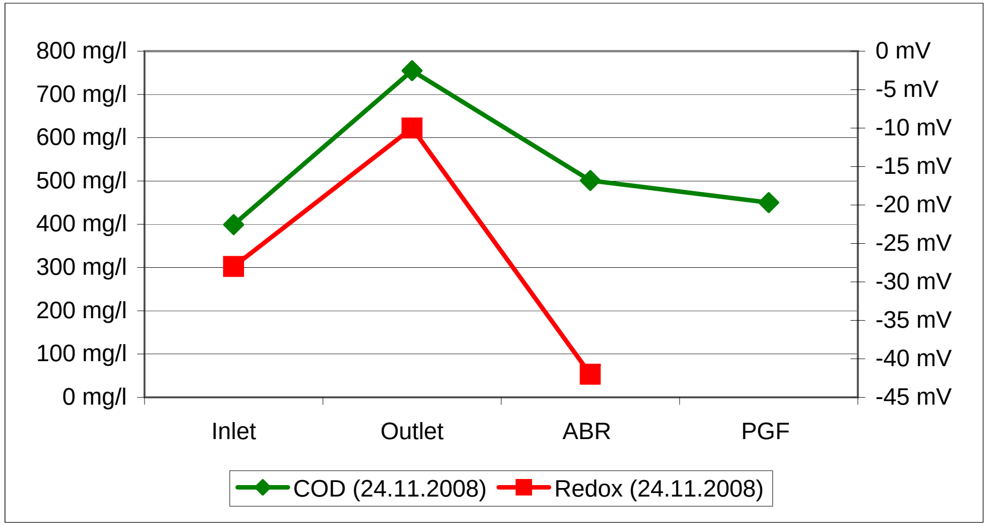
Biogas Consumption

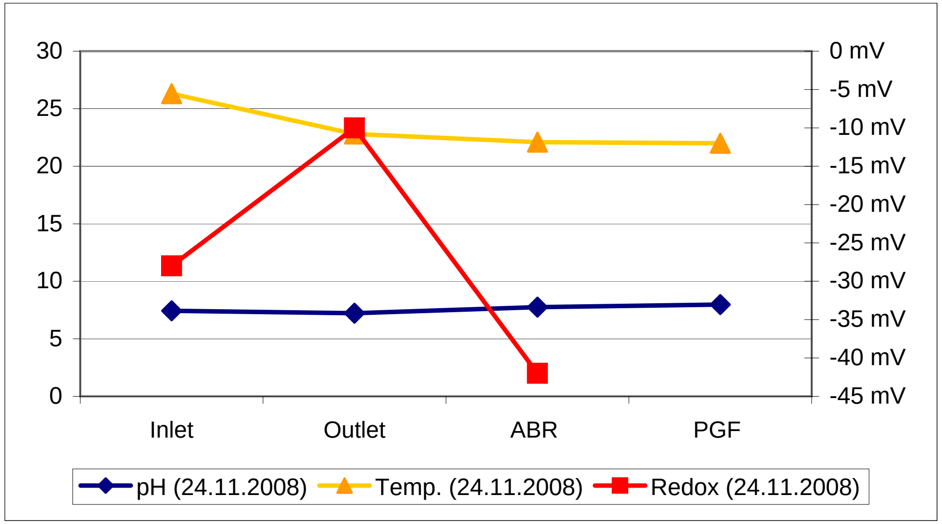


Swampi Site

Effluent Analysis

Date	Sampling time	Time of chemical analysis	Plant		Inlet	Outlet	ABR	PGF	Remarks
21.06.2008			Swampi site	COD		615 mg/l		303 mg/l	Analysed by TED-Borda
24.11.2008	11:00		Swampi site	pH	7.44	7.23	7.75	7.98	
				Redox- Potential	-28 mV	-10 mV	-42 mV		
				Temperature	26.3 °C	22.8 °C	22.1 °C	22.0 °C	
		14:30		COD	399 mg/l	755 mg/l	501 mg/l	450 mg/l	Samples cooled in the frigde after 12:30 till analysed

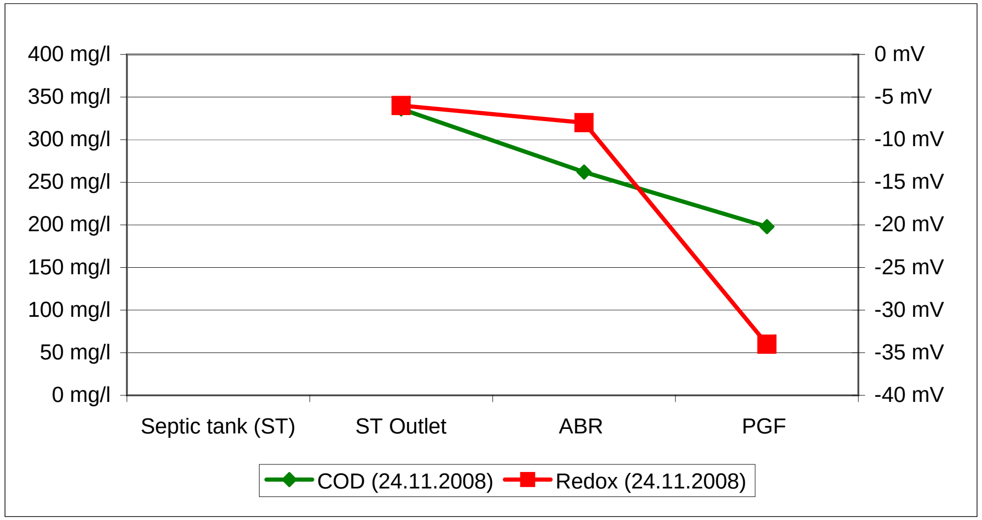


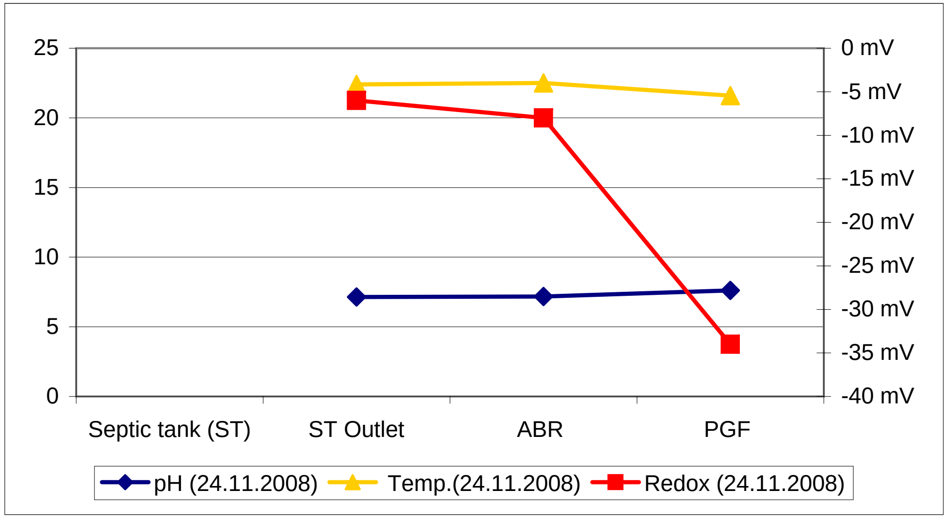


Biogas-Plants in Lesotho
Yellow Shop
(no biogas dome, but septic tank with ABR and PGF)

Effluent Analysis

Date	Sampling time	Time of chemical analysis	Plant		Septic tank (ST)	ST Outlet	ABR	PGF	Remarks
11.09.2008			Yellow shop	pH				7	Analysed by TED-Borda
				Temperature				14.0 °C	
12.09.2008				COD				204 mg/l	
02.10.2008			Yellow shop	Temperature				16.6 °C	Analysed by TED-Borda
03.10.2008				COD				220 mg/l	
24.11.2008	11:30		Yellow shop	pH		7.14	7.18	7.61	
				Redox- Potential		-6 mV	-8 mV	-34 mV	
				Temperature		22.4 °C	22.5 °C	21.6 °C	
		14:30		COD		336 mg/l	262 mg/l	198 mg/l	Samples cooled in the frigde after 12:30 till analysed





Picture Series: St. Angelas

In the following the construction of a fixed dome digester of TED-Borda will be illustrated. The pictures where taken at the construction site of St. Angelas, a school for handicapped children, Maseru.

Picture 1: After locating the site the soil is dug out according to the project plans. In the foreground the hole for the digester and the ABR is visible, in the background for the PGF (17.11.2008).

Picture 2: The foundation for the digester is already casted while the one for the ABR is still in preparation. Final digging and soil removal has to be done manually (21.11.2008).

Picture 3: The first rows of the digester are built. The circular form is made with a lath that is attached in the middle of the foundation (radius, 25.11.2008).

Picture 4: The wooden lath got a rectangular cut in order to easily keep the bricks in the right position (25.11.2008).

Picture 5: The positions of inlet and outlet chamber depend on the existing sewage pipe and the available space for ABR and PGF (25.11.2008).

Picture 6: When the wall reaches a certain height respectively a certain slope hooks are required to hold the bricks in position (25.11.2008).

Picture 7: Hooks weighted with additional brick (hanging on the wall) keep the placed bricks in position (2.12.2008).

Picture 8: Besides finalizing the digester the ABR is built up (foundation and first brick rows can be seen in the front, 2.12.2008).

Picture 9: Before closing the upper part of the digester it gets smoothly plastered and partly covered with soil (8.12.2008).

Picture 10: The chambers of the ABR are visible. The walls are reinforced with steel rods that are put into the brick holes and then filled with plaster (8.12.2008).

Picture 11: The digester is closed by installing a gas plug valve where the gas can be released. The inlet chamber is going to be finalized (10.12.2008).

Picture 12: The digester is smoothly plastered from inside from the top to the bottom. Afterward the curing process starts (12.12.2008)

Picture 13: Inlet and outlet chamber, as well as ABR are going to be finalized (7.1.2009).

Picture 14: The PGF is build up in order to provide a post-treatment of the effluent (7.1.2009).

Picture 15: Inlet chamber gets connected with waste water pipe from school (12.1.2009).

Picture 16: In order to protect the plaster from sunlight it gets covered. To much sunlight causes a fast drying of the plaster resulting in generating breaks (leakages, 13.1.2009).

Picture Series: Fixing Gas Leakages

Fixed dome digesters if not properly build can have gas leakages. In this case gas is penetrating the digesters wall and gets released in the upper part, thus only a small gas pressure can be build up within the gas storage chamber. As a result biogas can not be used by the plant owner. In the following the detection and fixing of gas leakages is presented.

The pictures were taken at a biogas plant in Mopateng, Lesotho on the 19. Nov. 2008.

Picture 1: The site gets inspected. On the right the toilet being the waste water source is partly visible. Gas pressure meter gets installed.

Picture 2: Gas tightness is first controlled in the gas piping system that goes from the digester outlet to the end users (for example stove).

Picture 3: Secondly the gas tightness is tested on the top of the digester within the brick chamber. This is done by filling in soap water that enables the identification of leakages (when soap bubbles occur). In order to see any leakage a certain gas pressure has to be build up within the digester.

Picture 4: Here the gas pressure was build up manually by blowing air into the digester. This could also be done with exhaust gas of the car. Filling the inlet with water also increases the gas pressure to a certain extent (the higher the pressure the easier the detection is).

Picture 5: The next step consists of testing the surface of the gas storage chamber. Therefore part of the digester has to be dug free.

Picture 6: Testing is also done with soap water. Again air has to be blown regularly into the digester in order facilitate the detection.

Picture 7: After detecting the leakages the leakage points have to be marked. Then the surface gets dried and then sealed with hot (melted) candle wax that enters the capillary tubes.

Picture 8: After the wax gets dried the soil can be shoveled back.

The control of success of this method is possible after a certain periode of time. If gas pressure increases to a certain extent the digester is supposed to be gas tight.

If not the digesters content has to be taken out (pumping) in order to enable an proper sealing from inside.

Picture Series: Equipment Effluent Analysis

Picture 1: Effluent sampling stick. This sticks enables to samples through the tight cover holes of the ABR.

Picture 2: A bottle is cut into half and attached to stick.

Picture 3: Room in TED-Borda-Office. In the back the place where COD analysis is conducted (laboratory).

Picture 4: Sampling bottles on top of table.

Picture 5: Effluent is filtered and stored in small plastic cases.

Picture 6: Differences in effluent quality are obvious.

Picture 10: Filtering process. Duration depends on solid content within effluent (filters can clog).

Picture 11: Hach Lange test cubes in the front (COD TNT822 and TNT823 were used).

Picture 12: Test cube heater (on the left) and photospectro-meter (on the right).