eawag
aquatic research

Sandec
Water and Sanitation in
Developing Countries

Appropriate Rural Technology
Institute Tanzania (ARTI-TZ)

Anaerobic Digestion of Canteen Waste at a Secondary School in Dar es Salaam, Tanzania

Tenzing Gyalpo, March 2010

Supervised by Yvonne Vögeli (Eawag), Prof. G. Kassenga and Dr. S. Mgana (both Ardhi University)



Tenzing Gyalpo
gyalpot@student.ethz.ch

Eawag (Swiss Federal Institute of Aquatic Science and Technology)
Sandec (Department of Water and Sanitation in Developing Countries)
P.O. Box 611
8600 Dübendorf
Switzerland
Tel. +41 (0)44 823 52 86
Fax +41 (0)44 823 53 99
Internet: www.eawag.ch; www.sandec.ch

Bibliographic reference:
Gyalpo T (2010). Anaerobic digestion of canteen waste at a secondary school in Dar es Salaam, Tanzania. Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf, Switzerland.

Cover pictures: Project information (top left), Institutional ARTI biogas plants (top right), Open dumping site at the school (bottom left), Biogas stove with stiff maize paste (bottom right)
(Pictures: Tenzing Gyalpo)

Table of Content

Summary

Inadequate solid waste management is gaining importance as one of the most important threats to public health and environmental quality in economically developing countries. As the organic fraction accounts for the larger part of the municipal solid waste, anaerobic digestion thereof would be an appropriate solution to reduce the amount of waste dumped and/or landfilled.

After the evaluation of the suitability of the ARTI Compact biogas system for kitchen waste on household level by Lohri (2009), this study focuses on the technical and operational aspects of institutional biogas plants. Azania is the first secondary school in Tanzania which is equipped with three ARTI biogas plants to treat their food waste (digester tank 4000 L, gas holder 3000 L). These plants as well as the training of the operators and cooks were funded by Costech (8'850'000 TShs, 6'404 US Dollars, 18.03.10).

The unstirred floating-dome digesters were fed with the canteen waste (26% TS, 92% VS). Two biogas plants (plant 2 and 3) were fed with 8 kg food waste per day whereas for one biogas plant (plant 1) the daily load should be increased from 8 kg/d to 20 kg/d. Though, 20 kg/d could not be reached due to lack of food waste. The analysis showed that the reduction in organic waste for both, plant 1 and plant 2, was very high. The effluent contained around 90% less TS, VS, and COD compared to the influent. The ammonium and phosphate concentrations in the effluent were on average 280 mg/L and 33 mg/L, respectively. The anaerobic bacterial decomposition resulted in a mean gas production of 426 L/kg VS (= average of plant 1 and plant 2). This refers only to the gas which finally is used for cooking. Gas losses occurred due to loose fit of the gas holder and the digester tank (about 17.5%) which is not accounted in the daily gas production. The methane contents for plant 1 and 2 were 55 and 58 vol%, respectively. The hydraulic retention times were about 53 and 59 days, the solid retention times 163 and 143 days, and the organic loading rate 0.97 and 0.48 kg VS/(m^{3*}d) digester tank for plant 1 and plant 2 respectively. The average air temperature for the study period (1.10.2009 – 25.01.2010) was 28.8 °C and the average biogas pressure was 2.25 mbar above air pressure in Dar es Salaam. The maximum usable gas amount of one gas holder was found to be about 1800 L. If all three gas holders were full and used simultaneously, the gas lasted for 6 hours of cooking which replaces up to 35 kg charcoal per week. With an average charcoal consumption of 44 kg/d at Azania, the amortisation period is 10.5 years when fed with 8 kg/plant*d. By increasing the feedstock to 16 kg/plant*d, the amortisation period can be reduced to only 4 years.

Visiting other institutional plants in Dar es Salaam and interviews with the responsible persons revealed that the expectations of customers did not correspond with the specifications given by ARTI-TZ. This showed that the burning duration announced depend on several factors which have to be considered individually from institution to institution. Also, a lack of canteen waste for a constant feeding at high level reduces both the optimal biological and economical performance for a biogas plant.
This study showed that the recommended feeding rate by ARTI-TZ given for the Azania plants can be doubled without impairing the digester activity. Though, this amount of food waste is not available at Azania. Therefore, new sources of food waste, e.g. from other schools or restaurants, have to be considered in order to increase the performance of the plants and finally reduce the charcoal consumption significantly. The willingness of

the cooks for using biogas is present, though the time for cooking is slightly longer and the gas supply not always guaranteed. For future projects, emphasis has to be put on the estimation of daily available food waste, design of the gas burner and gas stove and intensive trainings of the people working with the biogas plants in order to use a biogas plant to its full capacity. Tough it seems yet a big challenge to fully change from charcoal to biogas, it is certainly a very good option for a partial substitution which finally will lead to a successful organic waste management and reduction in unsustainable energy consumption.

Acknowledgement

I would like to express my sincere thanks to my supervisors Yvonne Vögeli from Sandec, Prof. Gabriel Kassenga and Dr. Shaaban Mgana from Ardhi University for their valuable and constructive advices and comments to my work.

I would like to thank Costech for their permission of conducting this research.

Further I am grateful to Prof. Urs Baier form ZHAW, Dr. Mbuligwe and Minza Selele from Ardhi University for their helpful suggestions and support during the work. It is a pleasure to thank Mr. Ndimbo and Mr. Ramadhani for their support in the laboratory works.

Without the help of the six Azania students, namely Aby, Edgar, Abel, Aminiel, Allen and Levocatus, who volunteered themselves to feed the biogas plants at their school, this project would not have been possible. I would like to thank them very much. This also holds true for the cooks, namely Margret, Rose, Antony and Stella. Their readiness to cook with biogas made it possible to collect data. Also, I would like to thank Mr. Ayubu, teacher and patron of the students, and Mr. Ngozye, the head of Azania Secondary School.

Also, I would like to show my gratitude towards ARTI Tanzania, its employees and especially its directors Dennis Tessier and Nachiket Potnis for welcoming me to Dar es Salaam, for interesting discussions about biogas and for being open to improvements and realizing them at the Azania plants.

Many thanks go to Christian Lohri for his help in the beginning of the work and sharing his experience in the field.

Moreover, I wish to thank the Swiss Agency for Development and Cooperation (SCD), the NCCR North-South research programme, the Swiss Federal Institute of Aquatic Science and Technology (Eawag) as well as the Swiss Federal Institute of Technology Zurich (ETH Zürich) for their financial support.

Finally, I am indebted to many others which I have not mentioned but nevertheless every one of them contributed to this work in their own way and made my stay in Dar es Salaam unforgettable.

List of Figures

List of Tables

Abbreviations

AD	Anaerobic Digestion
ARTI	Appropriate Rural Technology Institute
A/TIC	Acids/Total Inorganic Carbon
C	Carbon
CBS	Compact Biogas System
CH_4	Methane
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
COD_{dis}	Dissolved Chemical Oxygen Demand
COD_{tot}	Total Chemical Oxygen Demand
Costech	Tanzania Commission of Science and Technology
DSM	Dar es Salaam
DW	Dry weight
Eawag	Swiss Federal Institute of Aquatic Science and Technology
FW	Food Waste
H_2S	Hydrogen Sulphide
HRT	Hydraulic Retention Time
MC	Moisture content
NH_3	Ammonia
NH_4^+	Ammonium
NH_4^+-N	Ammonium-Nitrogen
NL	Norm Litre
O_2	Oxygen
OLR	Organic Loading Rate
PO_4^{3-}	Phosphate
PO_4^{3-}-P	Phosphate-Phosphorus
P_{total}	Phosphorus total
Sandec	Department of Water and Sanitation in Developing Countries
SRT	Solid Retention Time
SW	Solid Waste
SWM	Solid Waste Management
TKN (N_{total})	Total Kjeldahl Nitrogen
TS	Total Solids
TZ	Tanzania
$VS_{(tot)}$	(Total) Volatile Solids
ww	Wet Weight

1 Introduction

Inadequate solid waste management is gaining importance as one of the most important threats to public health and environmental quality in economically developing countries. To a great extent, the composition of household waste in economically developing countries consists of biodegradable material. This is also the case in Dar es Salaam, where organic matter accounts for around 71% of the total amount of municipal solid waste generated (Mbuligwe and Kassenga, 2004). Institutional solid waste constitutes 56–64% organic waste (Mbuligwe, 2002). Biomethanation at a decentralized level is seen as an ideal option to treat organic waste as it minimizes transport costs and provides renewable energy and organic fertilizer. The Indian organisation known as Appropriate Rural Technology Institute (ARTI) developed in 2003 a small-scale biogas system designed for household level use. This compact biogas system is now being promoted in Tanzania and Uganda by local ARTI branches (ARTI-Tanzania, ARTI-Uganda) and has been adapted on a wider scale for institutions such as schools and restaurants.

From July to December 2008, a study on the performance of the ARTI compact biogas plant was conducted by Sandec in collaboration with the Ardhi University of Dar es Salaam. To get more precise information about this rather new treatment option for organic solid waste, a household-scale biogas plant was monitored at the University campus. The evaluation showed that this system can be recommended as an appropriate treatment option for organic solid waste in developing countries. A detailed description of the ARTI system as well as the results regarding gas production and composition, effluent quality, user friendliness and economic aspects can be found in Lohri (2009).

The same biogas system, but with bigger digester size, has been implemented by ARTI-Tanzania (ARTI-TZ) at institutional level. Different lodges and schools in Dar es Salaam have installed such biogas systems, benefiting from the biogas to substitute charcoal and firewood as the traditional cooking fuel. Although these biogas plants have been in operation for about one year, there is no data that can prove its technical reliability or cost effectiveness. If this technology is to be effectively disseminated in Tanzanian schools and other African countries, scientific evidence is needed regarding the performance of the system.

This follow-up project is, therefore, focusing on the technical and operational aspects at the first secondary school in Tanzania which has three biogas plants in operation. The study has again been conducted in collaboration with the Ardhi University of Dar es Salaam, with field work taking place between October 2009 and January 2010.

1.1 Objectives

The main objective of this study is to evaluate a biogas plant at a secondary school using canteen waste as feedstock. The specific objectives are to:

1. quantify daily average gas production and composition,
2. determine the treatment efficiency of the biogas plant (decomposition of organic material), and
3. evaluate the overall suitability of the system for treatment of organic solid wastes in schools/canteens pertaining to technical, and economic aspects.

1.2 Compact biogas systems at Azania Secondary School

Costech (Tanzania Commission of Science and Technology) is an organization responsible for coordinating and promoting research and technology for sustainable development in Tanzania. Convinced of the advantages of the design and affordability of the ARTI Compact Biogas System (CBS), Costech donated three CBS (digester size: 4 m^3, gas holder size: 3 m^3) for a pilot project at Azania Secondary School in Dar es Salaam (Figure 1). The aim of this project is to promote biogas technology at institutional level. Selection criteria for the institution were based on energy consumption, accessibility, free area for the placement of the plants, and the interest of the institution itself. Among several institutions, Azania Secondary School fulfilled all these criteria. Due to its location in the city centre, the school is well accessible for other head of institutions, students from different schools and further interested people. As these plants serve as demonstration objects, different events were organized to promote this technology. For example, Azania students organized a sport event at their Azania compound where many students from different schools participated and were informed about biogas. Further, Costech funded a training of trainers on CBS and research on the CBS performance (feeding, gas production). Seeing its potential, Costech awarded ARTI-TZ with the Award for Science and Technology for introducing the CBS in Tanzania (for more information, see www.costech.or.tz).

The biogas plants have been in operation for approximately one year when this monitoring project was started. Before the installation of the biogas plants, the food waste was dumped and burned on the school compound (Figure 2).

Figure 1: Three ARTI Compact Biogas Systems at Azania Secondary School

Figure 2: Open dumping of waste produced at Azania Secondary School

2 Materials and Methodologies

2.1 Operation of the biogas plants at Azania Secondary School

For the daily feeding of the biogas plants, six Azania students were responsible. During the monitoring period, the feeding took place from Monday to Saturday under controlled conditions by measuring the weight of feedstock and the volume of added fresh water. The students were responsible of the regular feeding. They were provided with a feeding plan, a spring balance (max. 20kg), two 10 L and four 20 L plastic buckets and four pairs of gloves. The feeding was conducted twice a day, from 6-7 am and 5-7 pm. Further, a 50 L plastic bucket was provided for a distinct food waste collection.
At the beginning of the study, the three plants were numbered. Biogas plant 1 was the test plant which was characterized by an increased feeding during the observed period (Table 1). The other two biogas plants (plant 2 and 3) were fed according to the recommendations given by ARTI-TZ. Therefore, they are regarded as control plants, although their behaviour might be different. The intended feeding plan could not be followed through the whole study period. Reasons are explained in chapter 3.1.

Table 1: Intended feeding plan for the Azania biogas plants

	Plant 1			Plant 2 and Plant 3		
Week	**Food waste [kg ww/d]**	**Fresh water [L/d]**	**Overflow [L/d]**	**Food waste [kg ww/d]**	**Fresh water [L/d]**	**Overflow [L/d]**
1	**8**	60	80	**8**	60	80
2	**8**	60	80	**8**	60	80
3	**12**	60	80	**8**	60	80
4	**12**	60	80	**8**	60	80
5	**16**	60	80	**8**	60	80
6	**16**	60	80	**8**	60	80
7	**16**	60	80	**8**	60	80
8	**20**	60	80	**8**	60	80
9	**20**	60	80	**8**	60	80
10	**20**	60	80	**8**	60	80
11	**20**	60	80	**12**	60	80
12	**20**	60	80	**12**	60	80

2.2 Gas Production and Composition

In order to measure the gas production a scale on the gas holders was marked as it was done by Lohri (2009). After every fifty litres of biogas, measured by the gas meter, a line was drawn using a permanent marker pen (Figure 3).
The gas composition (content of CH_4, CO_2, O_2, NH_3, H_2S) was measured 4 times per week (2 times after feeding the plants in the morning, 2 times randomly during the week) using the Dräger X-am 7000 measurement device, provided by Sandec.

Figure 3: Scaling of the gas amount in the gas holder

2.3 Sample collection

The food waste samples were taken from the same bucket as the waste was collected by the students to feed the plants. Effluent samples were taken after the feeding procedure while the excess water was overflowing from the digester tank. The sampling took place twice per week (Monday and Thursday) in the early morning after feeding. Approximately 400 g of mixed food waste sample and 3.5 dL of effluent samples in PET bottles were taken for the analysis to the laboratory of the Environmental Engineering Department of Ardhi University. Before the feeding, the pH, redox potential and temperature of the digester tank was measured at the water table using HQ40d multi meter.

2.4 Analysis of food waste and effluent

Table 2 lists the analyzed parameters of feedstock and effluent. All the analysis was conducted at Ardhi University apart from the TKN which was measured at the University of Dar es Salaam.

Table 2: Parameter analyzed

Parameters	Feedstock	Effluent	Method
Total Solids (TS)	x	x	Standard Methods[1]
Volatile Solids (VS)	x	x	Standard Methods
Total Chemical Oxygen Demand (COD_{tot})	x	x	Standard Methods
Dissolved Chemical Oxygen Demand (COD_{dis})	x	x	Standard Methods
Ammonium (NH_4^+)	x	x	Standard Methods
Total Kjeldahl Nitrogen (TKN)	x	x	Standard Methods
Total Phosphorus (P_{tot})	x	x	USEPA Acid Persulfate Digestion Method
Phosphate (PO_4^{3-})	x	x	USEPA PhosVer® 3 Method
Ratio of Volatile Fatty Acids to Total Inorganic Carbon (A/TIC)		x	Kapp titration (Lohri, 2009)
Heavy Metals (Cd, Cu, Pb)		x	Atomic Absorption Spectrophotometer
pH		x	HQ40d multi meter
Temperature		x	HQ40d multi meter
Redox Potential		x	HQ40d multi meter

[1] Standard methods for the examination of water and wastewater (Clesceri et al. 1998)

2.5 Monitoring of the cooking practice

The monitoring of the cooking practice should give information about:
- cooking time and charcoal consumption per meal/per day
- cooking time and biogas consumption per meal
- amount of food waste produced
- number of charcoal stoves and biogas stoves used

The charcoal consumption and the amount of food waste produced were measured by help of a 20 L plastic bucket and a spring balance (max. 20 kg). The biogas consumption was measured with the gas meter provided by Erdgas Zurich (Figure 4).

Figure 4: Gas meter provided by Erdgas Zurich (left), gas meter connected to the biogas stove (right)

2.6 Cost-benefit analysis

Based on the data on gas production, average charcoal consumption, investment costs, and operation and maintenance costs of the biogas system, a cost-benefit analysis was conducted.

2.7 Interviews with other institutions with ARTI biogas plants

Three institutions having ARTI biogas plants other than Azania are WIPHAS Secondary School, Dogo Dogo Centre (orphanage), and Bethsiada Secondary School. Interviews were conducted with the head master, cooks, and the operators of each institution. All are located in Dar es Salaam (Questionnaires in Appendix C).

3 Results

As the biogas plants at Azania are located at a school which has a character of a public place, and were operated under real conditions, not all factors could be controlled and results are not always comparable with studies under laboratory conditions. Many external factors existed which could not be eliminated and therefore may have influenced the results obtained.

3.1 Operation of the Azania plants

The feeding plan as presented in chapter 2.1 could not be realized thoroughly because the availability of food waste was limited and fluctuated strongly day by day. The increase in feedstock for plant 1 could be more or less assured up to 16 kg/d (up to week 7). The feeding amount of 8 kg/d for plant 2 and 3 could be provided for the same time period (up to week 7). Later on, with the beginning of the Christmas holiday (week 9, decrease in number of students and therefore less food waste) and the special occasion of fish donation by the government in the beginning of January 2010, the feeding plan for all plants could not be followed anymore. Besides, the feeding amount for plant 1 was not increased on Saturdays (i.e. it was always 8 kg/d). Further, periods of water shortage occurred frequently during the monitoring period which effected the dilution of the food waste. Instead the food waste was diluted with the effluent water or with less amount of fresh water than recommended. The food waste was analyzed regarding its composition. The mean values of the chemical characterisation are listed in Table 3.

Table 3: Waste characterization

Components	Mean value
Dry weight [%]	26.3
Moisture content [%]	73.7
Density [kg/L]	~0.9[1]
TS [g/kg]	263.7
VS [g/kg]	242.5
VS [% TS]	91.9
COD_{tot} [g/kg]	427.9
COD_{dis} [g/kg]	149.1
%C	51.1
C [g/kg]	123.9
C/N ratio	26

[1] For all calculations, a density of 1 kg/L was assumed.

3.2 Gas Composition, Production, and Availability

3.2.1 Biogas composition

Figure 5 shows the development of the methane content of each plant in volume percentage of the total biogas volume throughout the monitoring period. As apparent, there were elevated methane concentrations in all plants at the beginning of the measurement period. Due to school holidays, the biogas plants were not fed and the gas not used during two months when the measurements started. This resulted in higher methane content due to the fact that CO_2 dissolved back into the digester water. The

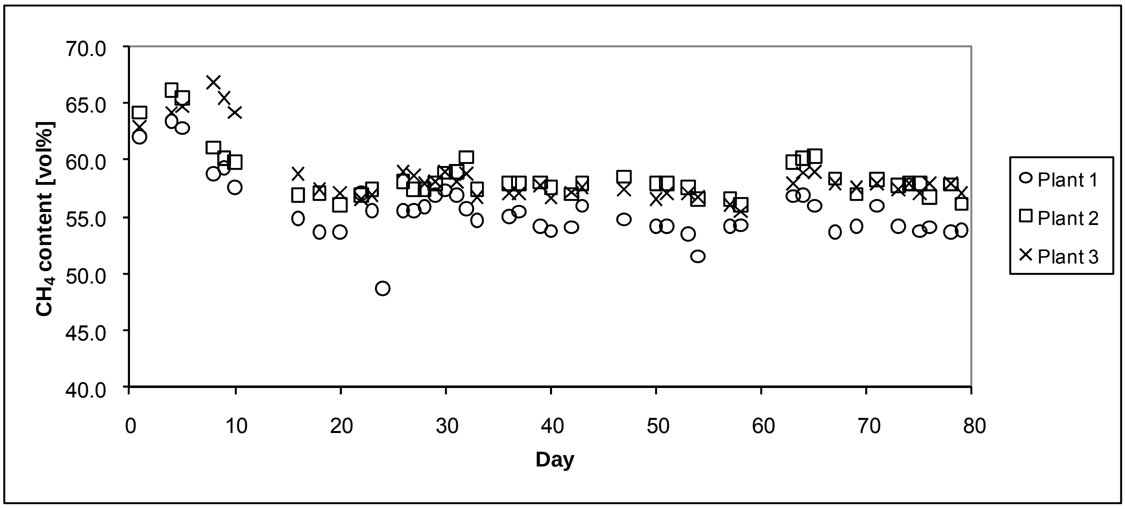


Figure 5: Development of the methane content of plant 1, 2, and 3 during the whole monitoring period

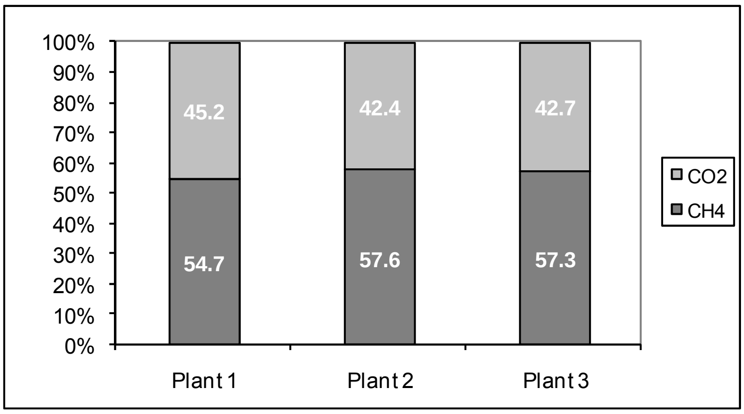


Figure 6: Mean gas compositions of plant 1, 2, and 3. O_2, H_2S and NH_3 accounted for less than 1 vol% of the gas volumes.

methane contents stabilized after two weeks for all plants. The mean methane content of plant 2 and 3 were with 57 vol% slightly higher than of plant 1 with 55 vol% (Figure 6).

3.2.2 Biogas production

Figure 7: Biogas loss due to loose fit of the tanks

The measured gas productions were extrapolated in order to get a 24h gas production rate. Reliable data could be obtained for plant 1 fed with 16 kg/d (week 5-7) and for plant 2 fed with 8 kg/d (week 1-10). The feedstock was analyzed in terms of wet weight, TS, VS, and COD_{tot}. The mean values and the corresponding measured gas productions are shown in Table 4. The specific gas production in terms of the different input loads is shown in Table 5. Gas volumes were also adjusted to norm conditions (0°C and 1013 bar). Due to the loose fit of the gas tank and the digester tank, biogas loss occurred through the gap which accounted for about 17.5% of the biogas production (Figure 7).

Table 4: Mean values of daily TS, VS, and COD_{tot} input and the biogas production with and without loss respectively (value adjusted to norm litres in brackets)

Biogas unit	FW [kg/d]	TS [kg/d]	VS [kg/d]	COD_{tot} [kg/d]	Gas production excl. loss (extrapolated) [L/d]	Gas production incl. loss (extrapolated) [L/d]
plant 2	8	1.84	1.76	3.68	791 (716)	959 (868)
plant 1	16	4.07	3.86	9.20	1557 (1410)	1887 (1709)

Table 5: Specific gas production in dependence to daily wet weight (ww), TS, VS, and COD_{tot} for plant 1 and 2 (value adjusted to norm litres in brackets)

Biogas unit	Gas production (excl. loss) according to input load			
	[L/kg ww]	[L/kg TS]	[L/kg VS]	[L/kg CODtot]
plant 2	98.8	430.1	449.9	214.8
plant 1	97.3	382.1	402.8	169.2
Average	98 (89)	406 (367)	426 (386)	192 (174)

Approximate maximum biogas yield

In order to compare the real performance of the biogas plants with the theoretical optimal performance, the maximal biogas potential can be calculated by help of these approximations:

- 123.9g C/kg FW
- % C = % VS/1.8
- 1g C = 1.87 NL biogas (50% CH_4, 50% CO_2)
- mean temperature 28.8°C (November 2009 - January 2010)
- mean biogas pressure 101419 Pa (November 2009 - January 2010)

The mean biogas yield was 426 L/kg VS excl. loss and 516 L/kg VS incl. loss (Table 5). The theoretical biogas yield is twice as high, namely averaged 1072 L/kg VS (Table 6).This could be due to the lack of mixture of the digester content. Accumulation of sludge on the bottom of the tank reduces the bacterial capacity to decompose the organic material (see Figure 19 and 20).

Table 6: Theoretical maximal biogas potential (adjusted to norm litres in brackets)

Biogas unit	FW [kg/d]	C input [kg/d]	C output [kg/d]	C red [kg/d]	Approx. max. biogas production [L/d]	Biogas yield [L/kg]
plant 2	8	0.99	0.05	0.94	1934 (1751)	1100
plant 1	16	1.98	0.03	1.95	4031 (3650)	1043

3.2.3 Biogas availability

If the gas holder (3000 L volume) was at its maximum height, the volume filled with biogas was approximately 2300 L, but only about 1800 L biogas were available for cooking (Figure 8). This resulted in 5400 L biogas if all the three gas holders were full. As the gas burners used at Azania had an average flow rate of 15 L/min, there was gas for 6 h continuous cooking. However, as soon as the gas holders descended, the pressure and the flow rate were not sufficient anymore at a certain level. The flame went out when there was still about 500 L biogas left in the gasholder (Figure 9). At this point, care had to be taken that the gas stove was closed in order to prevent the escape of the remaining gas.

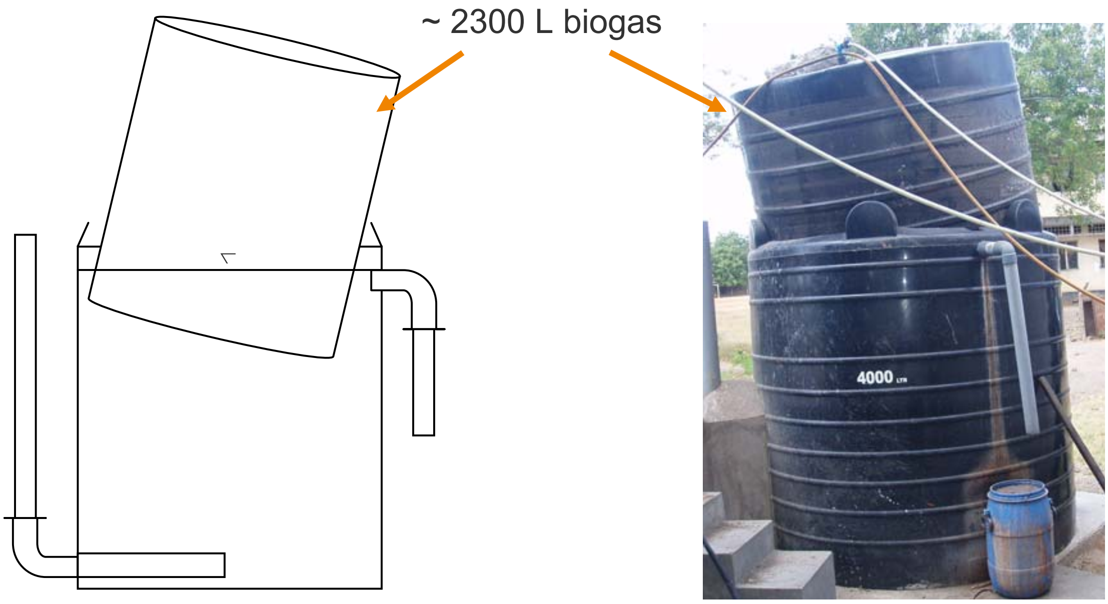


Figure 8: Gas holder at its full capacity

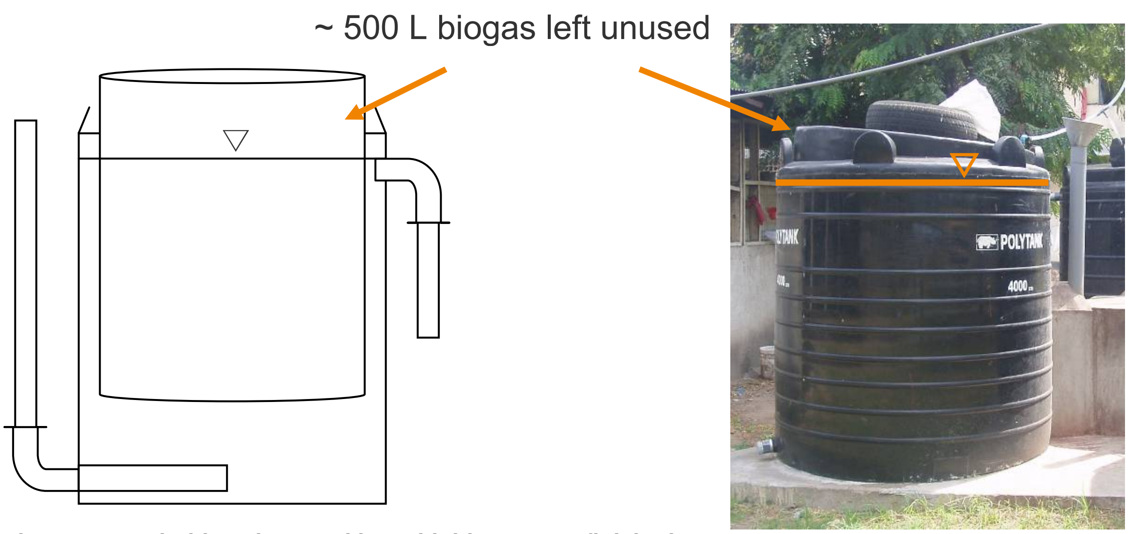


Figure 9: Gas holder when cooking with biogas was finished.

3.3 Monitoring of the cooking practice in the kitchen

Menu plan

Meals prepared for the boarding students in the canteen at Azania Secondary School consisted of tea, uji (maize soup), ugali (stiff maize paste), rice, beans, makande (beans maize soup), cabbage, and meat stew (Table 7). The amount of food prepared was adjusted to the number of students present (Table 8).

Table 7: Menu plan of the Azania canteen

	Breakfast	Lunch	Dinner
Monday	Tea, Toast	Ugali, Beans, Cabbage	Ugali, Beans
Tuesday	Tea, Toast	Ugali, Beans, Cabbage	Makande
Wednesday	Tea, Toast	Ugali, Beans, Cabbage	Rice, Beans
Thursday	Tea, Toast	Ugali, Beans, Cabbage	Makande
Friday	Tea, Toast	Ugali, Beans, Cabbage	Rice, Beans
Saturday	Uji	Ugali, Beans, Cabbage	Makande
Sunday	Uji	Ugali, Beans, Cabbage	Rice, Meat, Banana

Table 8: Food rations per student per day

Food	Amount per student/d
Beans	125 g
Ugali	250 g
Cabbage	variable (8-10 pieces for 110 students)
Rice	250 g
Makande	250 g (125g beans + 125g maize)

Number of students

The dormitories for the boarding students have a capacity of max. 180 students. This year the number of the students was 110. During the Christmas holiday the number decreased to 70 students. The students spending their holiday at home started returning to school after the 4th of January 2010.

Cooking practice

The kitchen was equipped with three charcoal stoves, each varying slightly in the design (Figure 10). Whenever only charcoal was used for cooking, all three stoves were used. Depending on the cook and meal to be prepared, they preferred one stove over the other. But in most cases, the food was distributed as shown in Table 9. The cooking procedure is typically described with certain actions and consecutive phases (Figure 11).

Figure 10: Three charcoal stoves in the Azania kitchen

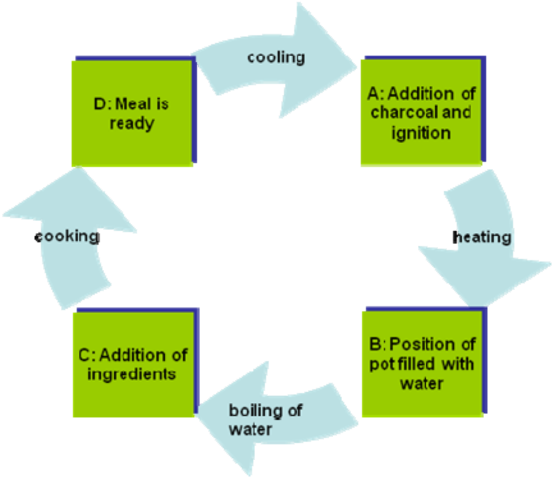


Figure 11: Consecutive phases (blue arrows) interrupted with actions (green boxes) describing the cooking procedure for one charcoal stove

Table 9: Distribution of meals prepared among the three charcoal stoves

	Stove 1	Stove 2	Stove 3
Monday	Tea, Beans	Ugali, Cabbage	Ugali
Tuesday	Tea, Beans	Ugali, Cabbage	Makande
Wednesday	Tea, Beans	Ugali, Cabbage	Rice
Thursday	Tea, Beans	Ugali, Cabbage	Makande
Friday	Tea, Beans	Ugali, Cabbage	Rice
Saturday	Uji, Beans	Ugali, Cabbage	Makande
Sunday	Uji, Beans	Ugali, Cabbage, Meat	Rice
Alternative	Tea, Ugali, Cabbage	Beans	Makande

As shown in Table 9 one stove was used for more than one dish consecutively. Therefore, the cycle (Figure 11) was repeated up to 3 times. The duration of a phase varied to a great extent depending on busyness of the responsible cook. Especially phases 1 and 2 were prone to variations. Depending on several factors (e.g. time, preoccupation with preparations in the staff's room, working alone or in pairs), the heating phase can be less than 5 min or lasts up to 30 min. Usually it lasted between 5-15 min before cooking was started. The same also applied for the time before the food was added to the boiling water. The water was usually boiling for a short time, but sometimes the boiling duration was extended up to 40-60 min. This had great influence on the amount of charcoal consumed and the overall cooking time.

3.3.1 Time and energy consumption

Time and energy consumptions for the preparation of the meals were based on the presence of 110 students.

Time consumption

The cooking time for each meal using charcoal or biogas was observed. The time was measured from the moment when the pot was put on the stove until the pot was taken away or the cooks said it was ready. The cooking times shown in Table 11 are mean values.

Rice was prepared in a special way. If the rice was prepared with biogas, the biogas supply was stopped before the rice was completely ready. Charcoal was thereafter put

on top of the lid in order to finish the rice from the top of the pot whereas the rice on the bottom of the pot was already ready (from the biogas). This was the reason why the time for biogas was shorter than that of charcoal for which the time of this additional heat from the top was included. Also, depending on the cook, rice was made in one or two pots.
The total time consumption would be longer for charcoal as with biogas, because the heat is available immediately, whereas with charcoal the heating phase has to be taken into account.

Energy consumption
The mean daily charcoal consumption without biogas use was 44 kg/d. As one stove was used for more than one dish, the charcoal consumption per meal could not be measured exactly. Rough calculations show the charcoal consumption per meal and the amount of biogas needed for the same meal in Table 10. It can be calculated that 1 m^3 of biogas could substitute 3.2 kg of charcoal.

Table 11: Mean time consumption per meal with charcoal and biogas

Meal	Charcoal [min]	Biogas [min]
Tea	65	-
Uji	75	83
Ugali	100	137
Beans (lunch)	219	245
Beans (lunch + dinner)	271	295
Cabbage	40	55
Makande	340	345
Rice	104	94[1]
Meat	120	155

[1] Biogas stopped but charcoal on top of the lid

Table 10: Mean biogas and charcoal consumption per meal

Meal	Biogas [L]	Charcoal [kg]
Tea	1350[1]	6
Uji	1468	6[2]
Beans (lunch)	4375	13
Ugali	2506	9
Cabbage	824	4
Makande	5641	14
Rice	3193	9
Meat	1985	9

[1] Tea made for 70 students
[2] Assumption same amount as for tea

3.4 Waste production

The feedstock for the plants consisted only of food leftovers that were ugali, beans and makande (Figure 12). Rarely rice was found as part of the feedstock. No organic waste from the preparation of vegetables (i.e. onion peelings, tomatoes and cabbage) and fruit peelings (bananas, mangos) were used because no instruments to cut the waste into small pieces were available. The amount of food waste was fluctuating very much depending on the menu. More food waste was generated from the menu of Mondays, Tuesdays, Thursdays and Saturdays. Little food waste was available when the kitchen staff served rice (with meat). On days without rice (see Table 7), the mean food waste generated was 41 kg/d whereas on the other days approximately 21 kg/d accumulated. This results in a mean food waste generation of 32 kg/d. The amount of organic waste which is not used for feeding the biogas plants was approximately 8kg/d excluding the fruit peelings generated on Sundays. Lack of food waste was also caused by the circumstances that on irregular basis, some children

Figure 12: Food waste bucket near kitchen

outside the school came to collect food waste for their animals, filling a 20 L bucket and taking with them about 20 kg food waste.

3.5 Decomposition of organic waste

The degree of decomposition of organic waste can be expressed by reduction in solid contents (TS, VS) or by reduction in COD comparing influent and effluent concentrations. Table 12 shows the influent and effluent load of TS, VS, and COD_{tot} and the resulting reduction rate for the different feeding rates for plant 1. The same is shown in Table 13 for plant 2. Due to the way of sample collection (effluent sample were taken after 20 L came out already), solid parts of undigested food waste were excluded. Undigested particles were swimming on top after the feeding was finished (Figure 13). Therefore, the real reduction rates have to be considered to be less but still around 85-90%.

Table 12: Mean TS, VS, and COD_{tot} loads per day and their reduction rate for plant 1

Parameter	FW [kg/d]	Influent	Effluent	Reduction [%]
TS [kg/d]	8	2.1	0.1	93.4
	12	3.1	0.2	93.1
	16	4.1	0.3	93.0
VS [kg/d]	8	2.1	0.1	97.1
	12	3.0	0.1	96.4
	16	3.9	0.2	95.7
COD_{tot} [kg/d]	8	1.8	0.1	92.2
	12	5.9	0.2	96.3
	16	9.2	0.1	98.7

Table 13: Mean TS, VS, and COD_{tot} loads per day and their reduction rate for plant 2

Parameter	FW [kg/d]	Influent	Effluent	Reduction [%]
TS [kg/d]	**8**	1.84	0.2	88.8
VS [kg/d]	**8**	1.76	0.1	94.0
COD_{tot} [kg/d]	**8**	3.7	0.1	96.3

Figure 13: Effluent in overflow bucket. Undigested food particles are swimming on top.

3.6 Indicators of process stability

The process stability of the biogas plants is indicated by the pH, temperature, and redox potential of the digester content. An even faster indicator for disturbance in the digester tank is the A/TIC ratio, which is the ratio of volatile fatty acids to total inorganic carbon. The findings are shown in Figure 14 to Figure 17. The measurements were started with the beginning of the operation of the plants. However, because of school holidays, the plants had not been operated for about eight weeks before the measurements began. This might be the reason for the pH drop from 7.3 to 6.8 in the beginning of the measurements. Sudden feeding of the plants led to an increase in volatile acids which triggered a decrease in pH. All three plants showed the same trend throughout the monitoring period. The continuous increase in pH can be explained by an electrode drift. An increase in NH_4^+ did not occur which could have explained the observed increase in pH. The temperature measured at the water table was influenced by the maximum air temperature. Thus, an increase or decrease in the water temperature goes along with an increase or decrease in day air temperature.

The A/TIC ratios were very low (<0.1). Optimal range has been reported to be around 0.3 (Mata-Alvarez, 2003).

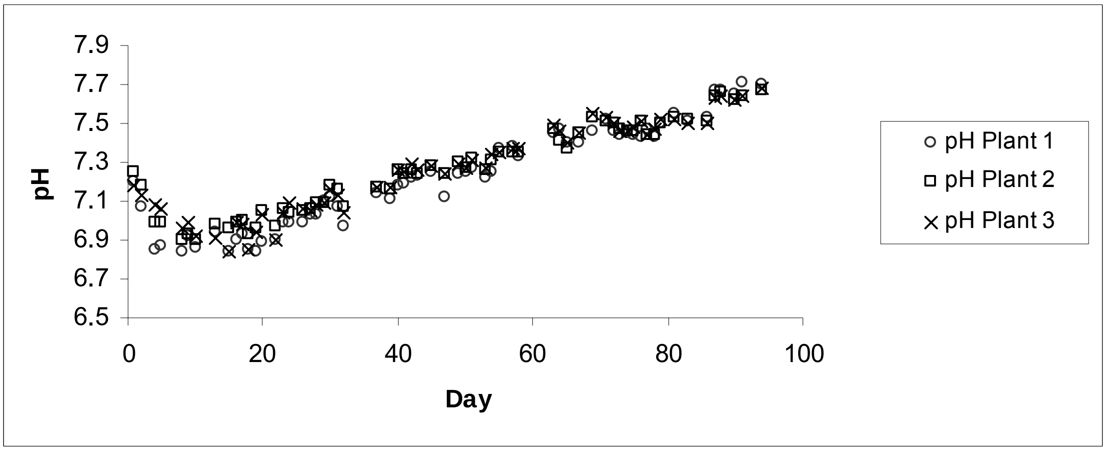


Figure 14: pH development of plant 1, 2, and 3

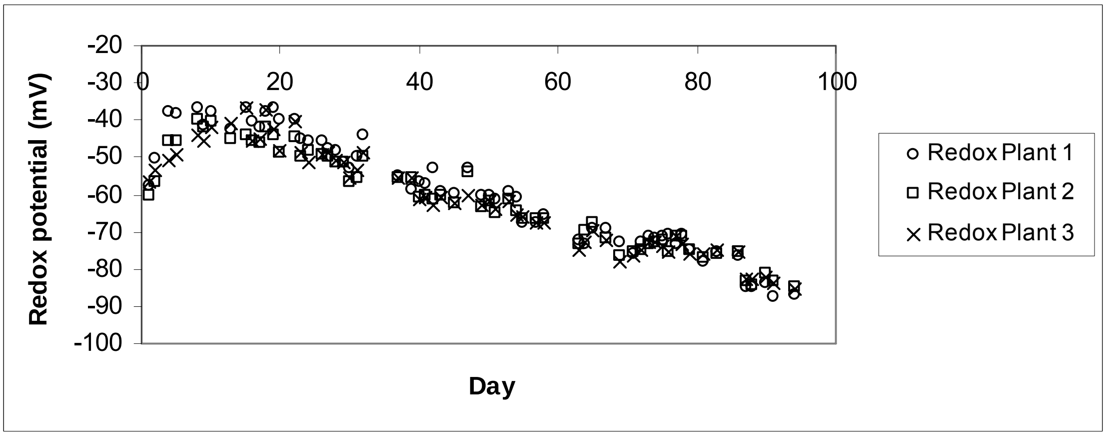


Figure 15: Development of the redox potential plant 1, 2, and 3

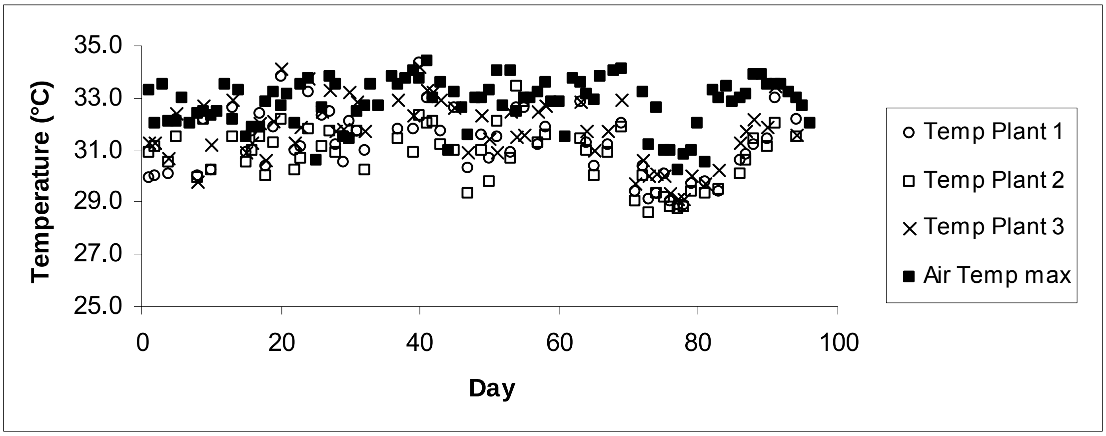


Figure 16: Temperature of the water table of plant 1, 2, and 3

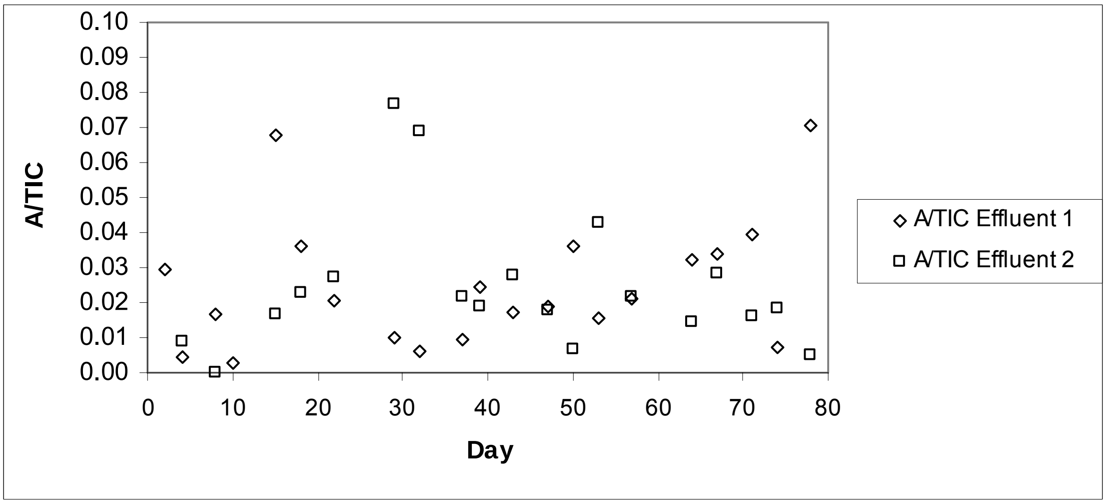


Figure 17: Results of A/TIC Kapp titration

3.7 Effluent quality

Due to the bacterial decomposition of organic waste, nutrients such as NH_4^+ and PO_4^{3-} were released. The effluent was therefore enriched regarding those nutrients and thus the effluent can be used as plant fertilizer (Lohri, 2009). The NH_4^+-N and PO_4^{3-}-P concentration of plant 1 and 2 were very similar even though the feedstock of plant 1 was gradually increased (Figure 18). The gradual increase of the pH shown in Figure 14 cannot be explained by an increase in NH_4^+ as no correlation could be found in Figure 19.

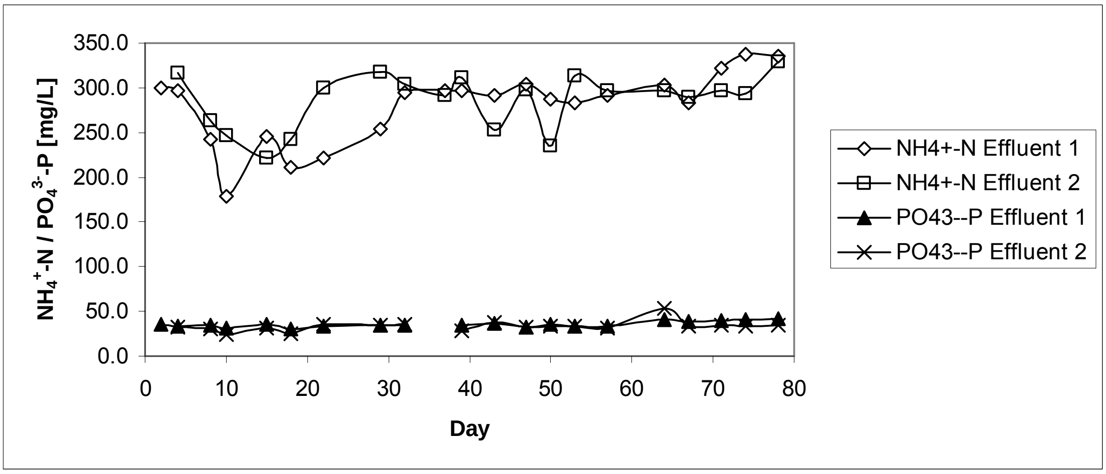


Figure 18: NH_4^+-N and PO_4^{3-}-P concentrations in the effluents of plant 1 and plant 2

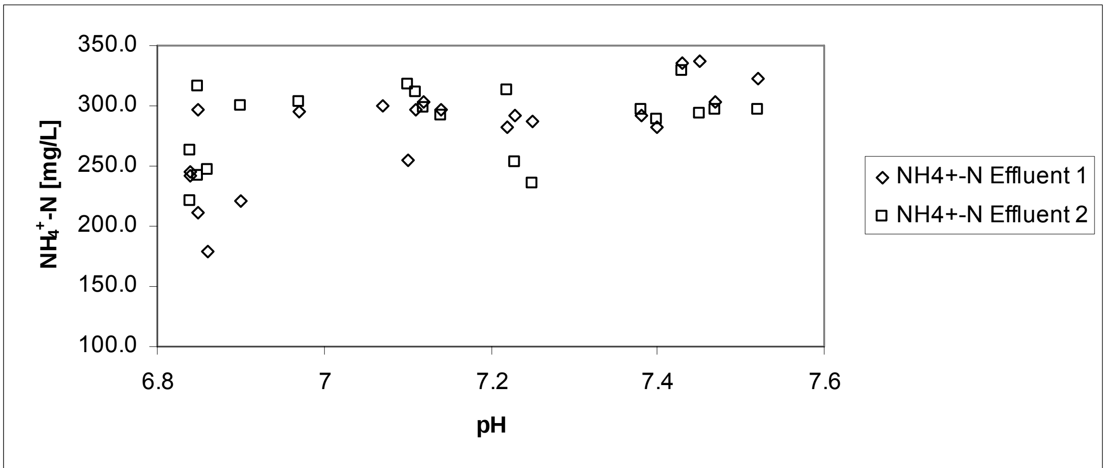


Figure 19: NH_4^+-N concentration in effluents of plant 1 and 2 plotted against pH at top of the digester tanks

Heavy metal concentration

The heavy metals Copper (Cu), Cadmium (Cd), and Lead (Pb) were analyzed by Atomic Absorption Spectrophotometer. The results are shown in Table 14. The measured concentrations were far below the reported inhibition concentrations of Cu, Cd, and Pb (see Lohri (2009)).

Table 14: Heavy metal concentrations in effluents of biogas plant 1 and 2

	Effluent 1			Effluent 2		
	Cu [mg/L]	**Cd [mg/L]**	**Pb [mg/L]**	**Cu [mg/L]**	**Cd [mg/L]**	**Pb [mg/L]**
01.12.2009	0.012	<0.01	0.359	0.019	<0.01	0.191
03.12.2009	0.044	<0.01	<0.01	0.064	<0.01	<0.01
07.12.2009	0.013	<0.01	0.072	<0.01	0.06	0.022
11.12.2009	<0.01	<0.01	<0.01	0.027	<0.01	0.064

3.8 Operational Parameters

The hydraulic retention time (HRT), the solid retention time (SRT), and the organic loading rate (OLR) were calculated by help of the equations given by Mata-Alvarez (2003). The results thereof are shown in Table 15 to Table 17. For the calculation it has to be considered that the total VS content (VS_{tot}) in the digester tank was measured in the end of the monitoring period. Accumulation of organic material could have happened due to the increase in the feeding rate, especially for plant 1.

Table 15: Hydraulic retention time for different feeding amount of plant 1, 2, and 3

Biogas unit	FW [L/d]	Fresh water [L/d]	HRT [d]
plant 1	8	40	**83**
	12	60	**56**
	16	60	**53**
	20	60	**50**
plant 2, 3	8	40	**83**
	8	60	**59**
	12	60	**56**

Table 16: Solid retention time of plant 1, 2, and 3 for different feeding amount

Biogas unit	FW [kg/d]	VS_{tot} in the digester tank [kg]	VS [kg/m^3]	VS [kg/d]	SRT [d]
plant 1	8	27.3[1]	6.81	0.06	**452**
	12	27.3[1]	6.81	0.11	**251**
	16	27.3[1]	6.81	0.17	**163**
plant 2	8	15.55	3.89	0.11	**143**
plant 3	8	22.50	5.63	0.05	**453**

[1] Assumption VS_{tot} valid for the whole study period

Table 17: Organic loading rate of plant 1, 2, and 3 for the different feeding amount

Biogas plant	Food waste [kg/d]	VLR TS [kg TS/m3*d]	VLR VS [kg VS/m3*d]	VLR COD [kg COD/m3*d]
1, 2, 3	8	0.53	0.48	0.86
1	12	0.79	0.73	1.28
1	16	1.05	0.97	1.71

Stratification

At the end of the monitoring period, samples of the digester contents were taken at different levels (A, B, C) by help of a hand pump (Figure 20). These were analyzed regarding TS, VS, dry weight (DW) and moisture content (MC). Table 18 shows the laboratory results of the different sections shown in Figure 20. Further, by means of the VS contents in the digester tank, the solid retention time could be calculated (see Table 16). The laboratory analysis and the sample textures show clearly a stratification of the digester content (Figure 21). The interface between sludge and water was 51, 31, and 38 cm above ground for plant 1, 2, and 3, respectively. If the elevated sludge volume of plant 1 was caused by the increased feeding cannot be stated as these plants have already been in operation for one year. However, a mass balance calculation was performed for the period 9.11.2009 – 13.12.2009 for plant 1 and plant 2. The total carbon fluxes are shown in Figure 22. The values taken for this calculation can be seen in Appendix D. It can be observed now that the calculated $C_{sed,c}$ (= C_{in} – C_{gas} – C_{out}) is almost twice as high as the measured $C_{sed,m}$ (= VS/1.8). It is likely that the approximation of the feeding amount for this calculation was overestimated and/or the bacterial system was not yet in equilibrium.

Table 18: Analysis of the digester contents of plant 1, 2 and 3

Biogas unit	Sample of section	DW [%]	MC [%]	TS [g/L]	VS [g/L]	VS [%]	[kg VS per section[1]]	VS_{tot} in tank [kg]
	A			2.6	1.4	53.1	1.6	
Plant 1	B			4.2	1.4	34.3	2.3	27.3
	C	2.3	97.7	23.0	19.1	82.8	23.4	
	A			2.6	0.5	18.2	0.6	
Plant 2	B			2.9	0.7	25.0	1.5	15.6
	C	2.2	97.8	21.8	18.1	83.0	13.5	
	A			2.8	0.6	22.9	0.7	
Plant 3	B			3.4	1.2	36.5	2.4	22.5
	C	2.5	97.5	25.0	21.2	84.8	19.4	

[1] see Figure 19

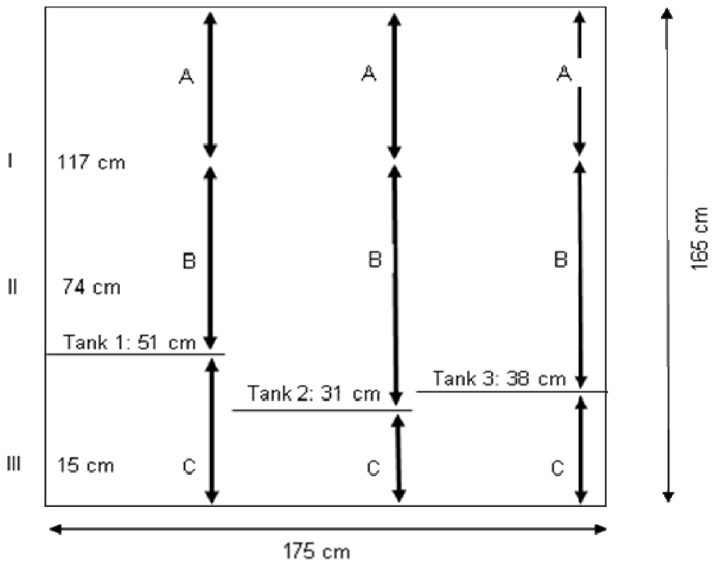


Figure 20: Schematic scheme of the digester tank with the separation line between sludge and water at 51, 31, 38 cm for plant 1, 2, and 3, respectively. One section is indicated by the length of a double arrow.

Figure 21: Three samples of each plant (3, 2, 1) in sequence of C, B, A (from left to right)

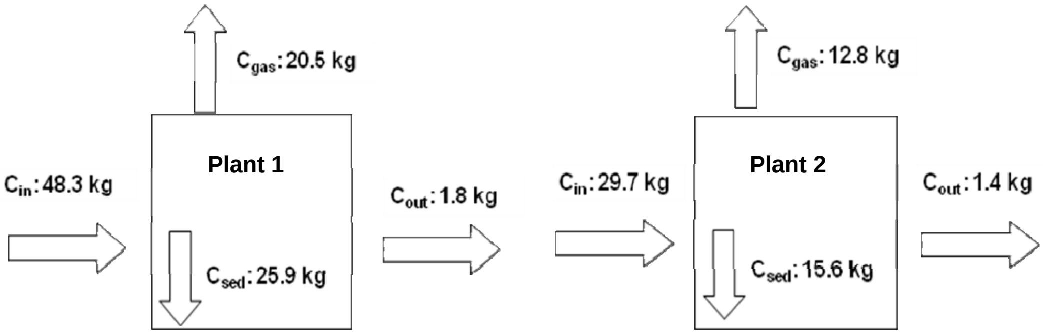


Figure 22: Total carbon fluxes for plant 1 and plant 2 for the period 9.11.09 - 13.12.09

(C_{in} = carbon content in influent, C_{out} = carbon content in effluent, C_{gas} = carbon content in biogas, C_{sed} = carbon content in sediment)

3.9 Cost-Benefit Analysis

The initial cost for the whole set up (three biogas plants, cement platform, three biogas stoves and training) at Azania Secondary School was 8'850'000 TShs (6'404 US Dollars, 18.03.10) and was funded by Costech.

The cost-benefit analysis was based on the following assumptions which resulted from the monitoring period (values used for calculations in italics):

- no operation costs
- negligible maintenance costs
- price of a bag of charcoal ranges between 30'000-35'000 TShs; *30'000 TShs*
- weight of a bag of charcoal ranges between 60-70 kg; *65 kg*
- biogas use if all three gas holders are full (i.e. 6 h of gas for one stove)
- feeding rate of 8 kg food waste per plant and day → on every third day all gas holders are at their limit of capacity and can be used for cooking
- 6 h of gas replace the charcoal amount needed for beans or makande (i.e. substitution of one charcoal stove with one biogas stove; *15kg* of charcoal)

This resulted in a reduction of 1830 kg charcoal per year. Azania could therefore save 28 bags of charcoal which is equivalent to 840'000 TShs per year. This defines an amortisation period of 10.5 years. In this case, Azania had a reduction of 2.3 bags of charcoal per month. However, according to the head master and the teacher functioning as patron for the students in January 2010, the school saved at least 5 bags of charcoal per months since the installation of the biogas plants. If this information was reliable, the amortisation period would only be max. 5 years. As plant 1 was capable of taking up the double amount of the recommended feeding amount (16 kg/d instead of 8 kg/d) without impairment of the digester activity, the amortisation period could therefore be reduced by half.

3.10 Inspection of other institutional plants

The interviews were conducted on 10th and 16th of December 2009 and on 12th of January 2010. A summary of the obtained information are shown in Table 19.

Table 19: Summary of the interviews conducted with the head master of the institutions, the cooks, and the operators of the biogas plants (to be continued).

Institution	Number of Students	CBS	Installed	Payment
WIPHAS	1460	1 x 5000L/4500L	April/Mail 2009	own expenses
Bethsiada	103, next year 133	1 x 4000L/3000L	October 2008	donation by NBC
Dogo Dogo Centre	max. 60	1 x 4000L/3000L	October 2009	donation by Canadian school
Azania	110, max. 180	3 x 4000L/3000L	August 2008	donation by Costech

Institution	Main energy source	Consumption of charcoal/firewood	Reduction in expenses for energy through biogas	Waste disposal and payment
WIPHAS	firewood	~7t firewood/month	no	garbage, no disposal costs
Bethsiada	firewood	~21t firewood/month	no	food waste for pigs, no disposal costes
Dogo Dogo Centre	charcoal	10-15 bags of charcoal/month	no	garbage, no disposal costs
Azania	charcoal	10-15 bags of charcoal/month with partial biogas substitution	yes	open dumping on the school compound, no disposal costs

Institution	Biogas use	Operation and maintanance costs	Feeding staff	Feeding amount (kg food waste + L fresh water per day)	Labor time
WIPHAS	2 times/week for tea, max. 2-3 h of gas	no	cook	20 kg 40 L	2 x 45 min
Bethsiada	7 times/week for tea, uji and vegetable, 2.5h of gas	no	cook	10-12 kg 40 L	2 x 2 h
Dogo Dogo Centre	3 times/week for tea, 1h of gas	operation costs 1500 TShs/d for fresh water, no maintenance cost	cook and students	14-20 kg 120 L	2 x 30 min
Azania	before research: 4 times/week for tea, uji and beans	no	students	8 kg 0 L (before monitoring)	2 x 1 h

Institution	Effluent use	Problems	What does the customer want	In use at the moment
WIPHAS	recycling in the biogas plant	gas amount less than promised, plant does not work stable	trainings of three days in a row, awareness rising	yes
Bethsiada	watering the flowers	difficulties in feeding, biogas stove too small, broken gas valve, not used since 4 months, biogas plant does not work stable	more trainings for how to operate the plants	no
Dogo Dogo Centre	recycling in the biogas plant	no stairs to feed the plant, not enough food waste, blockages of inlet pipe	graining machine for fruit peelings	no
Azania	recycling in the biogas plant, sometimes watering nearby plants	not enough food waste	graining machine for fruit peelings	yes

4 Discussion

4.1 On-site measurements

The gas volume used for cooking was measured with either the gas meter or by scale. Higher flow rates were (= L biogas per minute) were calculated by reading the scale than by the gas meter. The average flow rate by scale was 20 L/min whereas for by gas meter it was 15 L/min. Reasons weree either that the gas meter itself slowed down the flow rate or that the reading from scale and the scale itself were error-prone. This also applied to the gas production measurements as different students were involved in reading the scale in order to calculate the gas productions.

The measurements of the daily waste productions were difficult as a consequent waste separation could not be achieved and the students took their dinner to their dormitories.

4.2 Laboratory results

COD values were different from the TS and VS values due to the very delicate sampling of the prepared dilutions of the food waste (Table 4). This particular step was prone to systematic error. Therefore the gas production per kg COD is rather not representative.

4.3 Comparison with Lohri (2009)

The main specifics of waste composition, nutritional content of effluent, the biogas productions and the operational parameters were compared between the results Lohri obtained in 2009 and this current study (Table 20). While the solid contents of the feed material are identical, the ammonium and phosphate concentrations are slightly different. This can be explained by the different composition of the feed material. Nevertheless, the concentration range is the same and far below the toxic thresholds (> 2.7 g NH_4^+/L, Kaltschmitt et al., 2009). The gas yield reported by Lohri (2009) is 60% higher than obtained in this study even though OLR and HRT are in the same range. But the observed biogas yield in this study goes along with the values reported in the literature (Eder and Schulz, 2003; Deublein and Steinhauser, 2008).

Table 20: Comparison with Lohri (2009)

Components	Parameters	Unit	Lohri (2009)	This study (plant 2)
Waste	TS	%	24	26
	VS	% of TS	91	91
Effluent	NH_4^+-N	mg/L	74.1	285.7
	PO_4^{3-}-P	mg/L	55.7	33.4
Biogas	Gas production	L/kg VS	640	450
	CH_4 content	%	56.8	58.2
Operation	HRT	d	42.5	58.8
	SRT	d	300	143
	OLR	kg VS/m^{3}d	0.53	0.48
Performance	Reduction rate of TS, VS, and COD	%	84.9, 92.2, 83.1	88.8, 94, 96.3
Gas burner	Flow rate	L/min	4.5	15

4.4 Technical aspects

In respect to structural and biological stability as well as to the local availability of the construction materials, the institutional plants can keep up with the ARTI household plants. With more than one plant, there was the issue of having many single pipes from each gas holder going into the kitchen. Having these pipes on eye level made it inconvenient for the feeding procedure and susceptible for vandalism (Figure 23). In mid January 2010 these pipe arrangements were replaced by only one pipe going into the kitchen (see Appendix A for detailed description of the changes).

Figure 23: Hanging pipes for the gas transfer.

Due to the soft texture of the feeding material, blocking of the inlet pipe occurred seldom at Azania. Though, it has been reported in other institutions. If the fruit peelings and the vegetable waste from the preparations will be added to the feedstock, then one has to assure that these are cut or grained into small pieces (<1 cm^3).

The dilution factor of 1:7.5 (in case of 8 kg/d: 4kg food waste plus 30 L fresh water) is rather high. Considering water shortages and water scarcity in general, the dilution factor could be reduced to 1:1 or 1:2. As long as the effluent water is clear enough and not used as fertilizer, the food waste could be diluted with the effluent water instead of fresh water. Consequently, the number of back flushes of the overflowing water has to be increased.

Due to the loose fit of the gas holder tank and the digester tank gas loss occurs through the gap which accounts for about 17.5% of the total gas production. Having this identified, ARTI-TZ will promote one larger system consisting of 5000L digester tank and 4500L gas holder due to the better fit and therefore less methane emissions to the atmosphere.

The three biogas stoves were found to be too many as they can never be used at the same time. If one biogas burner was in operation and the second burner should be ignited, then the sudden opening of an additional gas outlet resulted in lack of incoming gas for the first burner (reduction in flow rate). The flame then got blown off unless both burners were ignited at the same time. The 6 h of continuous gas availability was only assured if all three gas holders were full and if only one burner was used at the time. It would be better to convert one biogas stove into a household stove as there was one smaller pot which was used during school vacations and occasionally by the students for their personal cooking. Further, as soon as the gas holders were emptied three quarters, the flames started to reduce in size. This happened after 4.5-5 hours of cooking. In this stage, it was likely that the flames went out without being noticed by the cooks. Therefore increased attention had to be paid to the stove with regular checks if the flames were still on. Adjusting the biogas supply by closing the valve increased the risk of extinction of the flame.

Increase in pressure on the gas holder would allow making use of the remaining biogas of about 500 L per gas holder. Though, this would mean that the burning duration would decrease (see gas pressure test done by Lohri, 2009).

Figure 24: Biogas stove, arrows showing space for heat loss and broken bricks

The efficiency of the heat transfer from biogas to the pot could be improved if the pot and the stove showed a tight fit (Figure 24). Further, the material out of which the stoves were

constructed showed short structural longevity. Constructed only one year ago, all three biogas stove showed damages at the end of the monitoring period.
The gas burners were susceptible to clogging; the holes were either clogged by dust and rust or by food particles. The cylinder around each hole made cleaning difficult (Figure). Thus the number of open holes got reduced which affected the gas supply. Further, the distance from the gas burner to the pot bottom was an essential factor for efficiency of cooking with biogas.
Considering Table 10, 1 m^3 of biogas will substitute 3.3 kg of charcoal at Azania. Experiences and estimates made by other biogas users report 1 m^3 of biogas substitutes 1.5-1.7 kg of charcoal (http://www.hedon.info/BP22:BiogasPropertiesStovesAndLamps, http://findarticles.com/p/articles/mi_7471/is_200912/ai_n49418672/). This big difference can be explained by several factors which all play a role to a certain extent: i) overuse of charcoal, ii) low efficiency of the charcoal stoves, iii) different calorific values of biogas and charcoal, and iii) better efficiency of the biogas stoves.

Figure 25: Gas burner (left: from top, diameter 36 cm, right: view at the cylinders surrounding each hole, height 2 cm

Biological performance

The biological performances of about 500 L biogas/kg VS (incl. losses) were in the same range as in the literature findings shown in Table 21.

Table 21: Comparison of the biogas production from literature with this study

Feedstock	VS [%]	CH_4 [%]	Biogas [L/kg VS]	Reference
Korean mixed food waste	87	73	600	Zhang et al. (2007)
Kitchen waste	80-98	45-61	200-500	Schulz & Eder (2006)
Canteen leftovers	75-98	n.a.	400-1000	Deublein & Steinhauser (2008)
Tanzanian canteen waste	91	56.8	640[1]	Lohri (2009)
Tanzanian canteen waste	91	57.4	450[2]	This study plant 2
Tanzanian canteen waste	91	54.7	403[2]	This study plant 1

[1] Value corresponds to 78% of the real biogas production, 22% escape to the atmosphere
[2] Value corresponds to 82.5% of the real biogas production, 17.5% escape to the atmosphere

Optimal values of A/TIC are around 0.3 (Mata-Alvarez, 2003). A/TIC ratios above this range mean that the plant is overfed, below the opposite. Having A/TIC ratios of less than 0.1 in all three plants, this indicates that the plants are “very hungry” and the amount of feeding can be increased. Another sign for the plants being capable to take up more is the rather low OLR compared to reported values in the literature. For mesophilic conditions (30-40°C), Mata-Alvarez (2003) proposes an OLR of 1-4 kg VS/m^3d for a HRT of 14-30 d and an OLR of 1.8-4.8 kg VS/m^3d for a HRT of 20-55 d is shown in Kaltschmitt et al. (2009). As the temperature in the digester is little below the optimal mesophilic temperature and the digester content not well mixed, an OLR of 2-2.5 VS/m^3d can be considered as possible. This would mean that a plant can be fed with up to 40 kg/d.

4.5 Economic aspects

Costech sponsored the ARTI biogas plants at Azania because they regard these plants as a good alternative among other types of biogas plants, in terms of both, financial and material aspects. As the first pilot project in Tanzania, Azania is open to everybody who is interested in this technology and likes to see it operating.
Feeding the plants with 8 kg/d, the cooks could either use daily biogas for tea and cabbage alternately or use it only every third day to cook beans or makande when all tanks were full. Either way, they saved up to 35 kg charcoal per week. Hence, with an initial cost of 8’850’000 TShs the amortisation time is 10.5 years. An increase of feeding to 16 kg/d for all plants would reduce the charcoal consumption by almost one third and so the amortisation time to 4 years. As institutions have to think in long-term perspective, 4 years is quite reasonable.
Azania was the only institution which stated that they profited from the biogas plants. They stated that the number of bags of charcoal reduced from over 20 per month to 10-15 per month which then revealed an amortisation rate of maximum 5 years with a feeding rate of 8 kg/plant*d.
There were no operation costs at Azania. The students volunteered to feed the plants. The maintenance costs were also negligible. Further, one has to consider the future development of the charcoal price (Table 22). This had risen fivefold in Dar es Salaam from 5’000 TShs in 2003 to 25’000 TShs in 2007 (Peter and Sander, 2009). Currently, the price is per bag is about 30’000-35’000 TShs.
The purchase of an institutional biogas plant is worthwhile if the availability of food waste and the operation of the plants are guaranteed throughout the year. As in case of Azania, an increase in the feed amount up to 16 kg/plant*d was not possible with own sources. Making arrangements regarding collection of food waste from nearby schools could solve this shortage. In general, the availability of food waste has to be well estimated before the installation of a biogas plant. If food waste was given away or sold to piggeries as it was done in many cases, biogas plants might not be a good option. Direct animal feeding is an equal or favoured solution to reduce the amount of organic waste.

Table 22: Amortization periods in years for 8 and 16 kg/plant*d and different charcoal prices.

Food waste [kg/plant*d]	Price per bag of charcoal [TShs]			
	25’000	30’000	35’000	40’000
8	12.5	10.5	9	8
16	5	4	3.5	3

4.6 Social aspects

Interviews with the cooks at Azania showed that they appreciated biogas and considered it as a clean energy source. But they claimed also that it takes too long to cook with biogas or that there is not enough biogas for cooking and consequently, they have to switch from biogas to charcoal. So they still preferred charcoal. Further, they argued that some meals need strong heat to be prepared which is (at the moment) not induced with biogas and that meals prepared with biogas do not taste the same as with charcoal. As different people are responsible for cooking and for feeding the plants, the cooks depend on the discipline of regular feeding by the students. Those students depend themselves on a consequent

waste separation by the cooks and the other boarding students. Hence, a satisfactory operation of the plants and thus significant savings in charcoal consumption can only be achieved if all make their contribution.
Unlike charcoal, the amount of biogas is limited per day. This fact demands from the cooks a more time efficient way of cooking as one cannot allow the water to be boiling for a long time before the food is added. Moreover, as the gas holders descent, more attention has to be paid in order that the flame does not go out. Emissions of methane have to be avoided.
The experience showed that cooking with biogas was appropriate for lunch whereas dinner should be prepared on charcoal. The residual heat of charcoal keeps the dinner warm which is not possible with biogas.
Finally, in the beginning neither the project initiator nor ARTI-TZ could understand the initial refusal of using biogas and its defamation later on by the cooks. Eventually they found out that this was caused by the fact that the cooks took charcoal for their private consumption (which is still true) and feared the reduction in charcoal purchase by the school.

5 Conclusions and Recommendations

5.1 Conclusions

Feeding: The recommended feeding of an ARTI biogas system of 4000L/3000L can be increased up to 16 kg/d without impairing the digester activity. Looking at the low A/TIC and the OLR values, these suggest an even higher increase up to 40 kg/d. But this has yet to be tested. In the case of Azania, a doubling of the recommended feeding is not possible with own sources of food waste. Therefore, Azania has to tap new sources in order to operate the biogas plants at their capacity. The neighbouring school for girls, Jangwani Secondary School, would be an optimal partner. There are two other schools nearby if Azania should plan to increase the number of plants. Further, the real amount of food waste which would be available is reduced due to inconsequent separation of food waste and occasional removal of food waste for animal food. There is organic waste (preparation waste from the kitchen and fruit peelings) which is currently not fed into the plants and accounts for about 8 kg/d.
The fresh water requirements for the dilution (i.e. 180 L/d for all three plants) could not be guaranteed during the monitoring period due to water shortage or rationing.
The effluent (slurry) is mostly used to increase the mixing of the digester content by back flushing it into the tank. Rarely, it is used as biofertilizer (to replace chemical fertilizer).

Operation: All institutions mandated internal personal - cooks and/or students - in order to operate the plants and save additional expenses. There are no financial incentives which could motivate the operators to take care of optimal feeding and maintenance. Azania argued that hiring an external person to operate the plants would impose additional costs, which is contrary to their objectives to reduce expenses.

Cooking: Cooking with biogas is not only a one point action of ignition of the gas. The perception of the daily emptying of water traps and regular checking of the presence of the flame (especially when the gas holders are nearly down) has to be considered as normal instead of extra work; similar to the cleanup of the charcoal stoves which is done daily. As the gas availability is daily limited compared to charcoal, the cooking with biogas has to be time efficient.

Customer Service: The current customers of the institutional plants are by majority unsatisfied by the performances of their biogas plant and therefore also with the cooking performance with biogas. Different reasons such as overfeeding, broken gas valves, oversized gas burners and lack of appropriate feeding platform hindered a smooth operation of the biogas plants and cooking with biogas. Further, the customers seemed to depend too much on ARTI-TZ rather than to exchange broken item by themselves through the local market. This could also be explained by their reluctance to deal with the biogas plant as they fear to harm the plant and also by the fact that the plants were donated.

All in all, it is a big challenge to fully change from charcoal to biogas. Rather, if the biogas capacity can be fully exploited, biogas plants are very good option for a partial substitution of charcoal leading to a successful organic waste management and reduction in unsustainable energy consumption.

5.2 Recommendation for Azania and other institutions

- *Better fit of the plants*: According to ARTI-TZ, they already advise their customer to purchase the larger model which consists of a 5000 L digester tank and a 4500 L gas holder tank. This larger plant fit better and hence the loss is less than 17.5% of biogas. However, higher costs will arise for bigger plants and the availability of food waste has to be ensured as well.
- *Design of the gas burner*: Due to the cylinders around the holes, an efficient cleaning of the gas burner is not possible. This leads to clogging of the holes and hence a reduction in the gas supply.
- *Design of the gas stove*: More care about the choice of the material used is advisable for the design of the stove which surrounds the gas burner. Purchasing better quality material imposes more costs in the first place, but then no repair costs are incurred. Adjusting the size of the biogas stove to the size of the pots used at the institutions (tight fit) will reduce heat loss to the surrounding and all the heat is transferred to the pot.
- *Reduction in fresh water consumption and increased feedback of effluent*: If the food waste is diluted 1:1 or 1:2 with water, this seems to be enough for a smooth flow of input into the digester. It also makes less susceptible to water shortages. If the volume of fresh water for dilution is reduced or overflow water fully replaces fresh water, the number of feedback effluent has to be increased. Due to the smaller input volume, the enhanced feedback counteracts the reduced input volume.
- *Elimination of many single hanging pipes*: If there are more than one biogas plants, pipes from each biogas plant going into the kitchen and hence having many single pipes on eye level disturb a smooth operation of the plants (Figure 22). Combination of single pipes and putting it out of reach for children reduces susceptibility of damage and disturbance during feeding.
- *Assessment of the amount of organic waste*: In case of Azania and Dogo Dogo Centre, there is not enough food waste available for a constant feeding at high level. Hence, new sources of food waste have to be made accessible or a biogas plant is not a good option for both organic waste management and renewable energy source.
- *Cutting machine*: Operators of several institutions asked for a cutting machine to chop organic waste rather quickly into small pieces. As the waste amount is much higher than on household level, this would ease the work of the operator and waste which was thrown away before can be used as feeding material.
- *Training of all involved groups*: Especially in institutions, many individuals (e.g. school: head master, teachers, students, and cooks) are involved in a stable operation of the biogas plants. Therefore, not only the operators of the plants and the cooks should be given instructions but also the head master, teachers, and students have to be informed of the purpose of the biogas plants and made responsible for a smooth running (consequent waste separation, quick replacement of broken materials, listening and responding to reasonable demands of operators and cooks, controlling of operation of the plants and cooking with biogas).
- *Secure feeding during the whole year*: If the responsible operators of the biogas plants are not present to continue feeding, then the duty has to be passed over to a deputy.
- *Careful with projections about daily biogas cooking duration*: The burning duration per day is dependent on several factors: i) gas production rate (which itself is dependent on the feeding rate), ii) pressure on the gas holder, iii) size of the gas burner (influences the flow rate) and iv) distance the gas has to travel (proximity of biogas plant to biogas stove). For an accurate projection of daily burning duration, all these

factors have to be taken into consideration and evaluated individually from institution to institution.

- *Customer's list*: In case the customer wants to take care of some services himself for which ARTI-TZ would charge him, ARTI-TZ should provide a list of what services are needed regularly. The customer has to be informed that without carrying out these services, an optimal operation and performance of the plant cannot be guaranteed. Further, possible markets can be included in order to find replacements for broken things.

References

Clesceri LS et al. (1998). Standard methods for the examination of water and waste water. 20th Edition. American Public Health Association, Washington, ISBN: 0-87553-235-7

Deublein D and Steinhauser A (2008). Biogas from waste and renewable resources: An introduction. Wiley-VCH-Verlag, Weinheim, ISBN: 978-3-527-31841-4

Kaltschmitt M et al. (2009). Energie aus Biomasse - Grundlagen, Techniken und Verfahren. Springer, Heidelberg, ISBN: ISBN 978-3-540-85094-6

Lohri C (2009). Research on anaerobic digestion of organic solid waste at household level in Dar es Salaam, Tanzania. Bachelor Thesis at ZHAW (Zurich University of Applied Science) in collaboration with EAWAG (Swiss Federal Institute of Aquatic Science and Technology)

Mata-Alvarez J (2003). Biomethanization of the organic fraction of municipal solid wastes. IWA Publishing, London, ISBN: 1-900222-14-0

Mbuligwe SE (2002). Institutional solid waste management practices in developing countries: a case study of three academic institutions in Tanzania. Resources Conservation and Recycling, 35, 131–46

Mbuligwe SE and Kassenga GR (2004). Feasibility and strategies for anaerobic digestion of solid waste for energy production in Dar es Salaam city, Tanzania. Resources, Conservation and Recycling, 42, 183–203

Peter C and Sander K (2009). Environmental crisis or sustainable development opportunity? Transforming the charcoal sector in Tanzania. Working Paper. The World Bank, Report Number: 50207.

Eder B and Schulz H (2006). Biogas Praxis: Grundlagen, Planung, Anlagenbau, Beispiele, Wirtschaftlichkeit. Ökobuch Magnum, Staufen bei Freiburg, ISBN: 3-936896-13-5

Zhang et al. (2007). Characterisation of food waste as feedstock for anaerobic digestion. Bioresource Technology, 98, 929-935

Appendix

A Azania Secondary School

A.1 Test of a different gas burner

The gas burner is an essential apparatus affecting the cooking time. Its suitability is dependent on several factors such as the orifice sizes and number, mixing chamber dimensions, grate heights.
A different gas burner was tested at Azania. This burner had been installed at Dogo Dogo Centre (A) and replaced the Azania burner (B). Though the flames were more concentrated in the centre and spread along the pot bottom, it could not be shown that this gas burner reduced the cooking time. It took even longer to boil water during the few trials made. For WIPHAS a larger model of the Azania stove was fabricated (C, D).

A Gas burner from Dogo Dogo Centre was tested at Azania.

B Current gas burner at Azania

C One firewood stove at WIPHAS transformed into a biogas stove

D Gas burner at WIPHAS

A.2 Implementation of new pipe system

In order to remove the several hanging pipes on eye level leading from the biogas holders into the kitchen, a new piping system has been implemented.

What we (ARTI-TZ and myself) did:

- Exchange of 0.5 inch pipes with 0.75 inch pipes (outside the kitchen) and 0.5 inch pipes (inside the kitchen) (G)
- Unite all the gas flow pipes near the gas holders, so that only one pipe goes into the kitchen (A,E)
- Pipe going into the kitchen protected in a hard tube with a slight angle downwards into the kitchen (F)
- Equalizing the different weight of the tires on top of the gas holders with sand bags (F)
- New water traps near gas holders (B, C)
- New water traps in front of the biogas stove including individual gas valves (I)
- Removal of the black water trap with the gas valves (H)
- Supply of gas to two biogas stoves instead of three (H)

Conclusion:

If the new installation has a significant effect on the cooking time is yet to be tested. However, one trial was made with 27 kg of beans. The beans were ready after 5 hours by 2 pm, but the flames were so small at 2 pm that the pot had to be shifted to a charcoal stove as the gas was not enough to keep the beans warm enough until the coming of the students for lunch around 2.30 pm. The new installation increases for certain the professionalism aspect of biogas delivery to stoves in the kitchen (no hanging pipes anymore on eye level).

A Original pipes (0.5 inch) were replaced by 0.75 inch pipes. All gas streams were united through a T-cross.

B Water trap needed to be installed near the gas holders.

C Pipe with water traps. State of the pipes when the gas holders are full. The pipes bend so that condense water can be taken away through the water traps.

D Condition of the pipes when the gas holders are empty. The idea was that the condense water would flow back into the tanks, so that no water trap would have been needed. Accumulation of water occurred in front of the gas valve causing blockage of the outlet gas pipe.

E Gas holders at their full capacity (seen tilted at the top of digester tanks), condensed water trapped where plastic pipes bent mostly, hard tube on a slight angle leading into the kitchen.

F Gas holders after using biogas, pipes near gas holders straight. VERY IMPORTANT: Even out of the different weight of the tires by help of sand bags.

G Change of 0.75 inch pipe from outside to 0.5 inch inside the kitchen in order to increase the pressure. Two outlets to each gas stove.

H 0.5 inch pipes leading to each biogas stove. Slight slope of the pipes to prevent accumulation of condensed water.

I Inlet of gas into the gas stove. Additional water trap and the gas valve placed in front of the inlet.

B ARTI-TZ

Pictures of the ARTI-TZ office in Dar es Salaam:

Demonstration plant (household size) at the ARTI office in Dar es Salaam

ARTI office with display of the products sold by Jet (Joint environmental techniques, commercial partner of ARTI)

Information posters about ARTI Compact Biogas Plants (left), ARTI Charcoal briquetting system, and ARTI Sarai Cooker

B.1 Current activities concerning biogas plant promotions

Living Lab

Finnfund is a Finnish development finance company that provides long-term risk capital for private projects in developing countries (http://www.finnfund.fi/en_GB/ Frontpage/). As the suitability of renewable energy has yet to be tested on a large scale in cities of developing countries, ARTI-TZ proposed its ARTI Compact Biogas Systems in order to promote the biogas technology. The idea behind this project is to identify the economic thinking of the participants. Will the society ever apply renewable energy in their real life? As the investment costs as well as the operation and maintenance are the main obstacles in promoting ARTI biogas plants, the Living Lab is implemented along with the “gas for cash” service. ARTI-TZ provides the customer with a full set-up of biogas plant and is responsible for the operation and maintenance (waste collection, feeding, effluent collection). In exchange, the customer pays for the amount of gas used. It has yet to be discussed if this happens according to the amount of gas consumed or based on fixed monthly fee which of course would have to be cheaper than the equivalent spent monthly for charcoal. The daily feeding and maintenance, done by external people, removes the burden of the customer of collecting enough food waste every day. Living Lab consists of several neighbourhoods with domestic and institutional units. The income out of selling the gas and the effluent as fertilizers serves as payback for the initial cost and later will be reinvested in new biogas units.

Living Lab is still in the proposal stage and the concept has to be developed further. Funding is not yet guaranteed. The project duration will be three years. If the outcome of Living Lab is successful, the idea of “gas for cash” will be adapted to other African cities where energy and organic waste problems are present.

Nairobi plants

ARTI-TZ expands to the Kenyan market. The project funded by the Dutch government involves an installation of one institutional biogas unit of 5000L/4500L at a temple and three domestic units of 1500L/1000L in Nairobi. ARTI-TZ cooperates hereby with the company Carbon Africa (http://www.carbonafrica.co.ke/home.html). ARTI-TZ met Carbon Africa through the East Africa Energy Conference. The set-up was planned in February 2010, and after 11 month of monitoring, the project will be evaluated in December 2010. Further cooperation between ARTI-TZ and Carbon Africa will then be discussed.

Business in Development Challenge

Business in Development (BiD) Network engages thousands of entrepreneurs, experts and investors from all over the world to stimulate entrepreneurship and economic growth in emerging markets. Bid Network runs the BiD Challenge which is a business plan competition for entrepreneurs that deliver access to clean energy in developing countries (http://www.bidnetwork.org/page/71938). ARTI-TZ submitted its formal application involving ten institutions with biogas plants according to the idea of “gas for cash”. The winner will be announced in April 2010.

Radio

Radio 1 is the most popular radio station in Tanzania. ARTI-TZ participated for the first time in 2008 in their environmental program on Fridays. Since then, ARTI-TZ is “on air” once per month promoting renewable energy technologies.

30 governmental institutions
One project in prospect is the collaboration with the Tanzania government to provide 30 governmental institutions (schools, governmental offices, military barracks etc.) with four biogas units of 5000L/4500L each. The institutions would be responsible themselves for the feeding and maintenance of the biogas plants. ARTI-TZ carries out the trainings of specific regional technicians and the kitchen staffs. The technician will be the contact person for ARTI-TZ. The objective is to replace one bag of charcoal (about 65 kg) per day. The concrete concept will be submitted in April 2010. The project duration will be one year.

B.2 Follow up on recommendations made by Chris Lohri in 2008

(Written by Dennis Tessier, ARTI-TZ director, 26.1.2010)

Digester/gas holder size

ARTI collected all the available information on tank sizes from all the tank producers in Tanzania and adopted a domestic model and an institutional model to promote.

For the domestic the standard size is SIMTANKs 1500 litre digester and a 1000 litre gas holder. The diameters are 115cm and 110cm respectively, resulting in a mere 5 cm space. The height difference between 173cm and 129cm also allows the gas holder to fully sink into the digester. Therefore, the 1000 litre gas holder holds significantly more gas when it is full, namely 756 litres.
For the institutional biogas plant, the standard size is AFRITANKS 5000 litre digester and a 4500 litre gas holder. The difference in diameters is 185cm to 172cm (13cm), which makes for an excellent fit. The heights are 205cm and 210cm which allows for only a small space at the top of the gas holder.
Other models in between the domestic and institutional exist with reasonable dimensions in case customers request a specific size, but we find the above mentioned models to be most popular.

Gluing of fittings

We still glue the fittings. We have taken the recommendation into consideration. The reason why we have not adopted the recommendation is that, while the threads do not need to be glued, the PVC fittings have to be glued where it is connected to the PVC pipes. Furthermore, if the pipes were not glued the slight movements resulting from feeding and use would loosen the fittings.
The fittings on top of the gas holder are partly glued, but the cost of replacing the parts that are glued versus service visits for small leakages justifies the gluing.

Swift elbow

We continue to use the swift elbow with our CBS 3” (domestic) and 4” (institutional). This has proved to be very beneficial to the customer and the service provider. We will also start using a much stronger 4” PVC pipe for the institutional feed pipes to allow for more durability.

2” Ball Valve

We reviewed the recommendation but have not implemented it for three reasons. The first is that it adds 37,000 Tsh to the total cost of the CBS and second, having the ball valve increases maintenance as they tend to break after some time and third, children like to play with them thus inviting misuse.

Moisture Trap

A great deal of thought was put forward on the subject of moisture traps. Chris made several nice recommendations. The three way valve with a clear hose was the best option, but we could not find such valves in Tanzania. The bottle was nice but looked too cheap.
We have since found a perfect solution based on the bottle trap concept but using garden sprinkler parts. The first moisture traps were procured in Canada but we have since found a local supplier.

Daily Operation

We have adjusted the feeding of the system to 4kg food waste per 1000 litres of digester size. Therefore, the 1500 digester is feed 6kg per day. The 5000 litre digester is fed 20kg food waste. We will continue to test the full capacity of the systems.
We also include a funnel for feeding with each system and this seems to reduce the risk of snails entering the system. We also recommend covering the feed pipe if there is only one funnel for multiple systems. How this instruction is followed amongst customers varies.
We have adapted the recommendation of recycling overflow and customers have responded positively as it does enhance gas production and reduce the water requirement.
A detailed instruction manual has been developed and translated into Swahili.

Service follow up

Each biogas system installed now comes with three months free service in which a technician visits the biogas plant and once a month for the initial three months to inspect

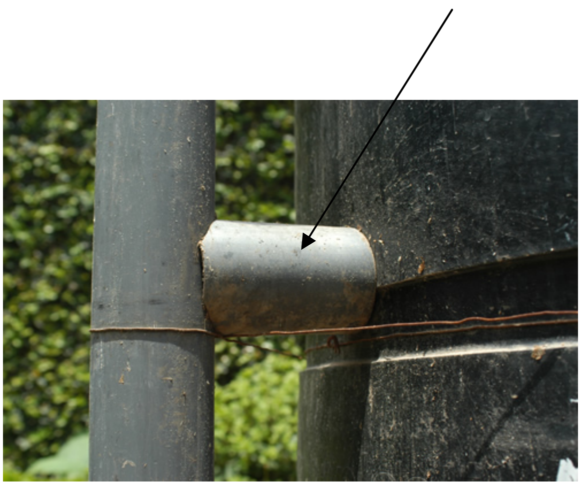
the CBS and to re-educate the users. The technician has a service checklist that is signed by the owner and the technician.
While the technicians can still improve, it has definitely helped improved performance and customer satisfaction.
We also provide the phone numbers of the Tanzanian technicians directly rather than just Dennis or Potnis because people feel nervous to call the boss if they have made a mistake or if there is a problem.

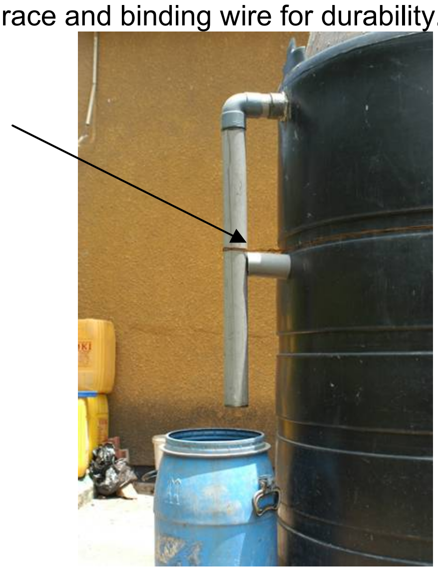
Cost

We have increased the size of the CBS and now offer two buckets, a feed pipe and a modern single burner stove. We have also improved service delivery with a user's manual and 3 free service visits.
The cost is now 895,000 Tsh for the domestic unit, an increase of 50,000.
This allows for approximately a 250,000 Tsh profit on a domestic biogas plant barring any other unexpected costs. Usually there are unexpected costs.
We are currently petitioning the government to lift all taxes on biogas specific tanks and parts.
No rebate system is currently being considered.

Other improvements

We have reinforced the feed pipe and overflow with a brace and binding wire for durability.





B.3 CBS manual for the institutional plant (4000L/3000L)
(provided by ARTI-TZ, in Kiswahili)

Joint Environmental Techniques

P.O Box 60055
Goba Road, Mbezi Beach, Dar es Salaam
0786 427 949/0715 235 126
jetenvironmental@gmail.com

Kuujali mtambo wako
ARTI COMPAT BIOGAS SYSTEM (CBS)

Asante kwa kutumia mtambo wa gesi itokanayo na mabaki ya vyakula (CBS). Pindi mafundi watakapofunga mtambo wa gesi na kufundisha jinsi ya kutumia (mtambo) nakukukabidhi. Itakuwa jukumu lako kulitunza.

Mwangozo huu utakusaidia kufurahia nishati hii mbadala inayoshaidia kutunza mazinigira

Kulisha

Njia rahisi ya kuelewa jinsi ya kulisha mtambo wa gesi, unahitaji chakula na maji kwa ajili ya kuvuna gesi ya vyakula. Gesi hii inatumia vyakula vya aina mbali mbali kama ifuatavyo: maganda ya viazi, nidizi, karoti, mabaki ya vyakula kwa ujumla. Isipokuwa mifupa, plastiki, vitu vigumu, visivyooza. N.K. ili kutumia maganda ya ndizi na viazi inabidi kusaga kwa kutumia mashine ya kusugia nyama au blender. Ukimaliza kusaga chakula chako changanya na maji kwa kiwango kinacho takiwa kwa kila mtambo. Kama usipochanganganya na maji mtambo wako uatiziba.

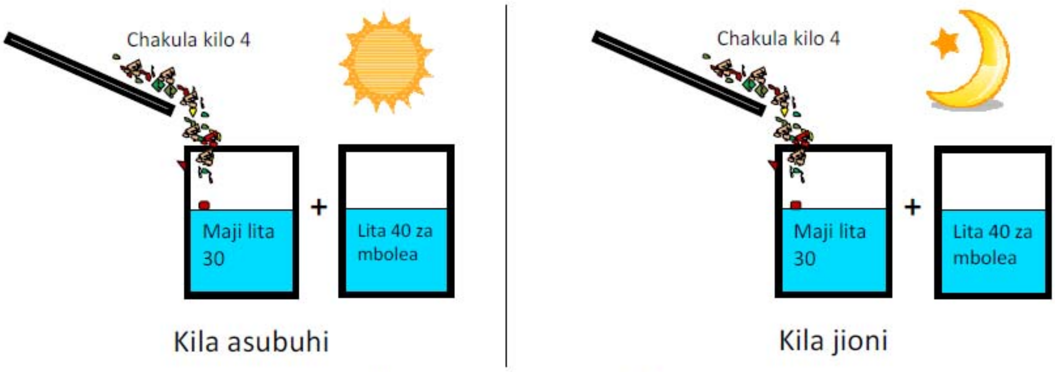
Mabaki ya vyakula 4kg

Matayaresho ya mabaki ya chakula

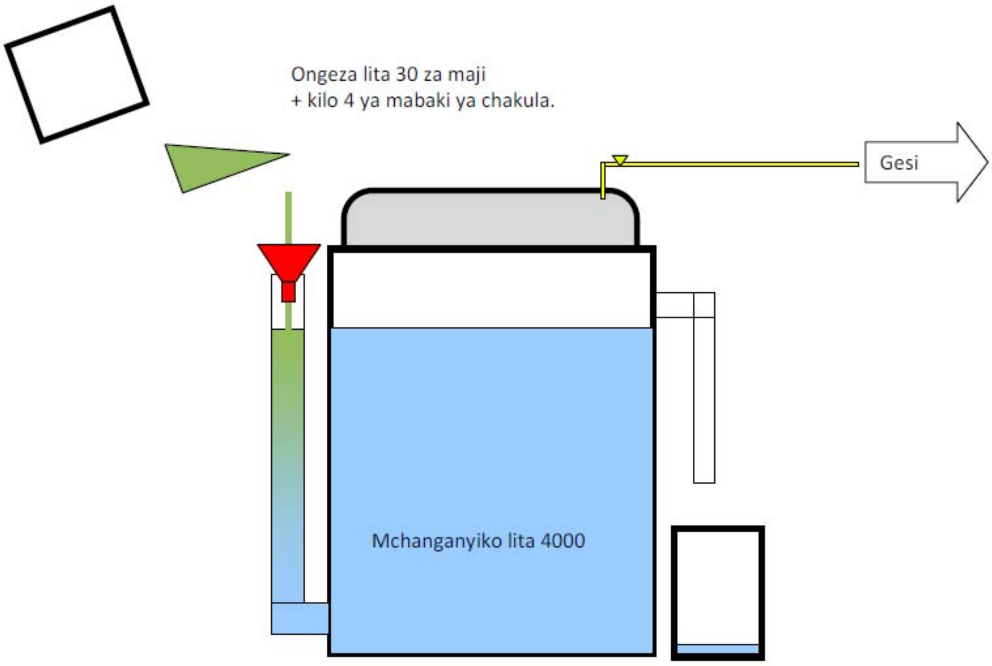
Hitimisho

Kama ukulisha mtambo wako wa gesi kwa makini na kuujali kwa tumia maelezo hapo chini mtambo wako wa gesi utadumu kwa muda mrefu sana. Tafadhali, usiweka sabuni, na dawa za kutoa madoa, na vifaa vingine vyaweza kuuwa bacteria wanazalisha gesi. Kwa kila mchanganyiko wa lita elfu (1000) moja lazima ujaze kilo mbili (2kg) za mabaki ya chakula tafadhali. Fwata muongozo huu ili upate gesi iliyobora. Kili siku unatakiwa kulisha chakula mara mbili kwa siku. Asabuhui kilo moja pamoja na maji lita 30. Jioni kilo moja (1kg) na lita kumi (10 lita) ya maji. (baada ya kulisha chakula hongeza maji lita 40 ili ukuwezeshe kusukuma chakala kwenye mtambo wako).

Mfano wa utendaji kazi wa ujazo wa lita 4000

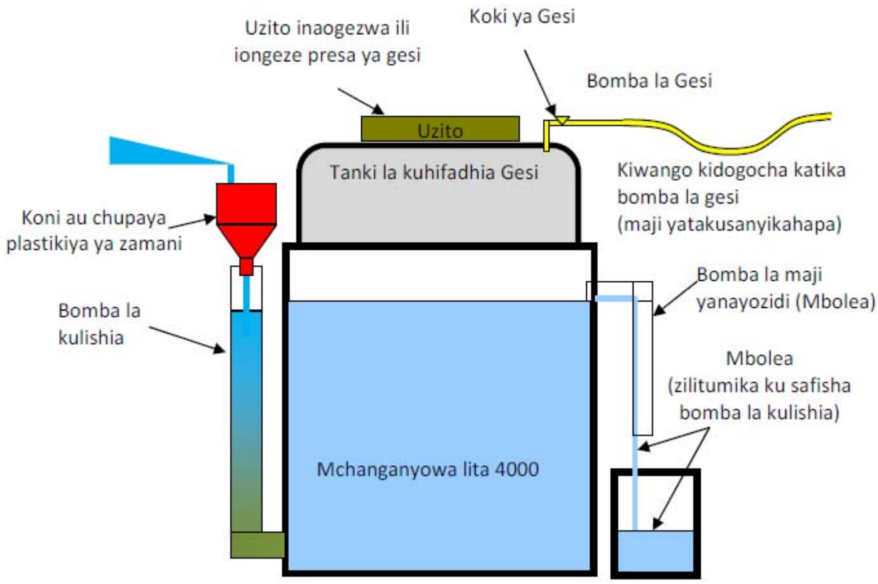


* Kiwango cha Mbolea kinacho hitajika kinaonekana hapo chini ,katika jedwali,katika ukurasa unaofuata.



Dondoo za kupata gesi bora katika kitua chako.

- Jaribu kulisha mtambo wako mara 1 asubuhi na mara 1 jioni hii itaruhusu gesi zaid kutengenezwa.
- Kuongeza chakula zaidi ya ilivoshauriwa hakuta ongeza utengenezaji wa gesi zaidi kwakuwa itaharibu bakteria na hasa kupunguza uzalishwaji wa gesi.
- Badala ya maji masafi, unaweza kutumia pia majimaji yatokayo katika mtambo wa gesi. Hii itakusaidia kutunza maji na kuendeleza kazi ya kuchanganya sababu majimaji yanayo mwagikatoka katika bomba yana bakteria ndani yake. .



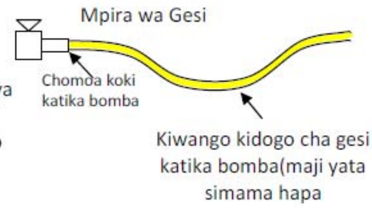
Ratiba za ulishaji wa kila siku			
Ukubwa wa dumu	Asubuhi	Jioni	Mwagilia baada ya kulisha.
Lita 1000	Kilo 1 za chakula + Lita 10 za maji	Kilo 1 ujazo + Lita 10l za maji	Lita 20 vimiminika toka katika mtambo (au maji)
Lita 1500	Kilo 1.5 za chakula. + Lita 10 za maji.	Kilo 1.5 za chakula + Lita 10 za maji.	Lita 20 vimiminika toka katika mtambo (au maji)
Lita 2000	Kilo 2 za chakula +Lita 15 za maji	Kilo 2 za chakula + Lita 15 za maji	Lita 20 vimiminika toka katika mtambo (au maji)
Lita3000	Kilo 3 za chakula + Lita 20 za maji	Kilo 3 za chakula + Lita 20 za maji	Lita 30 vimiminika toka katika mtambo (au maji)
Lita 4000	**Kilo 4 za chakula + Lita 30 za maji**	**Kilo 4 za chakula + Lita 30 za maji**	**Lita 40 vimiminika toka katika mtambo (au maji)**
Lita 5000	Kilo 5 za chakula + Lita 40 za maji	Kilo 5 za chakula + Lita 40 za maji	Lita 60 vimiminika toka katika mtambo (au maji)

Kukabiliana na Tatizo

Kama mtambo wako wa gesi unatatizo,tafadhali endeleakuulisha kwa ufasaha pindi unautengeneza kama umefuata hatua.zote hapo chini na bado ukashindwa kuutengeneza mwenyewe, tafadhali wasiliana nasi ili tukutumie mafundi kukusaidia.

Gesi Kushindwa kutoka katika jiko.

Gesi ya mimea ina kiasi kidogo cha mvuke (maji) na wakati mwingine mvuke huu unakusanyika ndani ya bomba kutoka katika mtungi wa gesi kuelekea katika jiko na kuzuia gesi kutoka. Ili kurekebisha ,funga koki juu ya mtungi wa kuhifadhia gesi,tenganisha mpira katika koki, kungu'ta maji na unganisha mpira katika koki. Kawaida maji hujikusanya pale mpira unapo ningi'chini hivyo hakikisha unakagua urefu wa mpira.



Chunguza mianya ya gesi.

Kama utagundua gesi yako inaisha kwa haraka sana, au mtungi wako hauongezeki inaweza kuwa na mwanya. Kama gasi yako inafuja ni mara nyingi sana kutokea katika koki juu ya mtungi wa gesi. Cha kwanza kabisa, jaribu kunusa kuizunguka koki na weka alama gesi inapotokea. Kama hii imeshindikana, taratibu mimina mchanganyiko wa maji na sabuni ya kuoshea vyombo kuzunguka vishikizo pindi ukiangalia vifundo vya hewa toka katika mtungi. Kama utaona vifundo vya hewa, una mwanya. Kurekebisha hii, rahisi nunua "M" Seal au contact cement na weka sehemu yenye mwanya. Pindi gundi itakapo kauka, angalia kama kunamwanya mwingine.

Weka maji yenye sabuni palipo na tundu katika bomba

Kuzibua bomba la kulishia.

Kama huku kata chakula katika vipande vidogo vya kutosha au kama hutumii maji ya kutosha bomba lako la kulishia litaziba. Wakati mwingine hii hutokea na kutatuatatizo, lakini nirahisi kutatua. Rahisi chukua mpira wa kunyeshea bustani na sukuma chini katika bomba la kulishia, sukuma na vuta na mara ya nne mpaka chakula kilichoziba kitoke. Pindi hii imekamilika, toa mpira na mwaga lita 10 za maji katikabomba la kulishia ili kuhakikisha kuzuizi chote kimetoka. Kama maji yanashindwa kwenda chini na bomba bado limeziba, rudia mchakato huo mpaka maji yawezekuingia ndani ya tanki.

Mawasiliano kwa huduma

Ni muhimu kwetu kwa mtambo wako wa gesi ya mimea kufanya kazi kwa ufanisi. Kama unaswali au hitaji la huduma tafadhali wasiliana na mafundi wetu waliohitimu, au kutumia namba za mawasiliano juu ya ukurasa wa kwanza.Asante.

JET Compact Biogas Technician: Kennedy: 0712 404 291 au Dennis: 0715 235 126

B.4 Price list of the biogas plants and equipments
(provided by JET, commercial partner of ARTI-TZ)

This price list was valid until the study ended. Now after the study, ARTI-TZ has thought over their pricing as the upfront costs probably have limited dissemination of the ARTI biogas plants. For further information, see www.arti-africa.org.

Joint Environmental Techniques

P.O Box 60055
Goba Road, Mbezi Beach, Dar es Salaam
0786 427 949/0715 235 126

Price Listing - 2008		
Item	**Cost (Tsh)**	**Details**
ARTI Compact Biogas Systems (CBS)		
1500/1000	895,000	**Prices for DSM only.** Includes CBS unit, single burner stove, installation, commissioning and 3 service visits. Prices do not include base and feeding platform.
2000/1500	1,200,000	
2500/2000	1,350,000	
4000/3000	1,800,000	
5000/4000	2,200,000	
CBS Accessories		
Stove - Single	60,000	Stainless steal biogas stove with flame regulator
Stove - Double	110,000	Stainless steal biogas stove with flame regulator
Stove - Institution	220,000	Solid steel biogas stove with flame regulator
Parts Kit (excluding tanks and 3" pipe)	140,000	All connectors, joints, valves and adhesives.
CBS Fabrication (labour)	400,000	Add Tsh 75,000 for every increase in digester size
Starter Pack (250 litres)	240,000/1000litres	Activated bacteria super charge
Maintenance Visit (DSM)	45,000	Transport and labour
Complete CBS Recharge (DSM)	125,000	Transport and Labour, exclusive of starter pack.
Sarai Cookers, Charcal Kilns and Charcoal Briquettes		
Sarai Cooker (LRG)	75,000	complete set, stainless steel
Kiln (LRG)	350,000	exclusive of delivery and extruder
Charcoal (Retail)	2,000	3 Kilo bag
Charcoal (Wholesale)	12,500	25 Kilo bag
D.Light		
Solata S380	22,500	2 setting solar light with panel
Nova S100	50,000	4 setting solar light with panel
Nova S200	65,000	4 setting solar light with phone charger and panel

C Questionnaire regarding ARTI Compact Biogas Plant

Date: ....
Interviewee: ....
Location: ....
Phone: ....

General information
Volume digester: .... Volume gasholder: ....
Date of installation: .... Cost: ....
Size of institution: ....

Questions for the head of institution

- What was the motivation to install ARTI plants at your school?
- How did you get to know ARTI?
- Expectations: How much substitution do you want to achieve with biogas?
- Former energy source wood/charcoal/LPG?
- What did you do with your food waste before installing the biogas plants?
- Did you have to pay for disposal? If yes, how much?
- How did you decide on how many plants to install?
- How much did a plant cost and who paid for it?
- In the beginning you had somebody who was responsible of the feeding. How much did you pay him? Why did he leave? Why don't you hire somebody else? Who does the operation of plants now? How many?
- What are the maintenance costs? Do you provide any protective gear or any other tools (buckets, gloves, weighing balance)?
- How many bags of charcoal do you buy per month now? How much does one bag cost? How much does it weight? How many bags of charcoal did you use to buy? Any reduction?
- Any problems with the plants? What if the operator is not available?
- For what do you use the effluent at the moment?
- How was the feedback of the cooks?
- Would you recommend the biogas plants to other schools, orphanages, restaurants, hospitals?
- Anything else you would like to say?

Questions for the operator

- Do you know the purpose of the biogas plant? What do you know about the biogas production?
- Where is the feedstock collected?
- How many times do you feed the plant per day?

- Explain please the procedure of feeding the plant!
- How much feedstock is put in each plant at once? Per day?
- Do you recycle the effluent? How many times, how many liters respectively?
- How much feedstock do you have available per day? More or less than recommended?
- Is the feedstock pre-treated/blended: no □ yes □
  if yes, with what/how?
- What do you need for dilution: water □ effluent □
- With how much water/effluent do you dilute feedstock for influent?
- Do you wear any protective gear? Who provides these and other tools (e.g. buckets, weighing balance)?
- For what do you use the effluent?
- Any problems operating the plant (work of convenience)?
- Suggestion of improvements of the design of plant?
- Working hours per day?
- Salary per day?

Questions for the cooks

- How often do you use biogas for cooking?
- How long do you use biogas for cooking per day?
- For what type of food do you use biogas?
- Is there enough biogas for daily cooking?
- How many cooking stoves? Do you use all cooking stoves?
- How much charcoal did you use before biogas? And how much charcoal do you use now per day? (How much do you replace former energy source by using biogas at the moment?)
- What is your opinion about biogas? Good or bad experience? What did change actually? (E.g. cooking time, hotness of flame, smoke, cleaning etc.)
- Are you aware of the consequences of using charcoal and firewood?
- Advantage and disadvantage of using biogas and charcoal, respectively.
- Any operating difficulties (opening valves, condense water accumulation, what when flame goes out suddenly etc)?
- Which type of energy do you prefer? Why?

D Laboratory data

Laboratory results

					food waste							
				Parameter	dry weight	moisture content	waste 1:1	waste 1:1	TS	VS	CODtot	CODdis
				Unit	[%]	[%]	TS %	VS %	[g/L]	[g/L]	[g/L]	[g/L]
				Pretreat.								
	Date	Day	ph digester	kg/d for plant 1								
	27.10.2009	2	7.07	8	24.98	75.02			292.06	289.34	746.3	45.9
	29.10.2009	4	6.85	8	28.61	71.39			309.6	291.36	141.6	156.0
	02.11.2009	8	6.84	8	24.36	75.64			256.56	250.08	62.4	
	04.11.2009	10	6.86	8	23.30	76.70			216	208.56	250.8	130.5
	09.11.2009	15	6.84	12	25.72	74.28	13.04	97.54	185.28	179.04		
	12.11.2009	18	6.85	12	30.09	69.91	11.90	96.04	293.52	281.76	414.6	26.9
	16.11.2009	22	6.9	12	32.01	67.99	16.11	97.24	289.2	285.36		213.6
	23.11.2009	29	7.1	16			11.88	96.53	254.98	247	374.3	106.4
	26.11.2009	32	6.97	16	25.86	74.14	12.92	95.37	276.83	264.48	543.4	29.9
	01.12.2009	37	7.14	16	27.97	72.03	14.37	94.89	238.26	231.61	1007.0	170.1
	03.12.2009	39	7.11	16	26.97	73.03	13.38	97.39	232.94	224.96	579.5	1.9
	07.12.2009	43	7.23	16	25.00	75.00	13.10	95.16	267.71	230.09	315.4	52.3
	11.12.2009	47	7.12*	16					257.26	250.99	630.8	49.4
	14.12.2009	50	7.25*	20	22.08	77.92	11.69	96.91	203.36	197.92	110.4	208.8
	17.12.2009	53	7.22	20				85.03	268.96	202.72	472.0	19.2
	21.12.2009	57	7.38	20	30.04	69.96	16.52	96.69	282.88	280.16	384.0	56.4
	28.12.2009	64	7.47	20	24.86	75.14	13.55	95.18	240.48	228.8	454.4	86.4
	31.12.2009	67	7.4	20								
	04.01.2010	71	7.52*	20	22.92	77.08	11.90	62.91	286.08	172		
	07.01.2010	74	7.45	20	26.20	73.80	13.97	91.10	278.88	221.6	273.6	
	11.01.2010	78	7.43	20					343.68	312	212.8	

*rain and no fresh water

	feedstock diluted according to plant 1															
	CODtot	CODtot	CODdis	CODdis	TS	TS	VS	VS	NH_3-N	NH_4^+-N	TKN	PO_4^{3-}	Ptot	Cond.	TDS	Salinity
	[g/L]	[g/d]	[g/L]	[g/d]	[g/L]	[g/d]	[g/L]	[g/d]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mS/cm]	[g/L]	[ppt]
Day									dis	dis	tot	fil	fil	tot	tot	tot
2	87.8	5970.4	5.4	367.2	34.36	2336.48	34.04	2314.7	15	15.05						
4	11.80	566.4	13.00	624	51.6	2476.8	48.56	2330.9	38	38.13		23		1.56	0.78	0.8
8	10.40	499.2			42.76	2052.48	41.68	2000.6	43	43.14		37		1.72	0.86	0.9
10	41.80	2006.4	21.75	1044	36	1728	34.76	1668.5	25	25.08	224	40		1.34	0.67	0.7
15					30.88	2223.36	29.84	2148.48	28	28.09		37		1.35	0.68	0.7
18	69.10	4975.20	4.48	322.20	48.92	3522.24	46.96	3381.12	27	27.09		54		2.10	1.05	1.1
22			35.60	2563.20	48.20	3470.40	47.56	3424.32	25	25.08	70	58		2.08	1.04	1.1
29	78.80	5988.80	22.40	1702.40	53.68	4079.68	52.00	3952.00	25	25.08		56		2.20	1.10	1.1
32	114.40	8694.40	6.30	478.80	58.28	4429.28	55.68	4231.68	20	20.07		69	17	2.07	1.04	1.1
37	212.00	16112.00	35.80	2720.80	50.16	3812.16	48.76	3705.76	20	20.07	1002.4			1.71	0.86	0.9
39	122.00	9272.00	0.40	30.40	49.04	3727.04	47.36	3599.36	22	22.07	1680	60	15	2.25	1.13	1.2
43	66.40	5046.40	11.00	836.00	56.36	4283.36	48.44	3681.44	24	24.08				2.25	1.12	1.1
47	132.80	10092.80	10.40	790.40	54.16	4116.16	52.84	4015.84	27	27.09		52		1.86	0.93	0.9
50	27.60	2208.00	52.20	4176.00	50.84	4067.20	49.48	3958.40	17	17.06		43.5		2.12	1.06	1.1
53	118.00	9440.00	4.80	384.00	67.24	5379.20	50.68	4054.40	64	64.21	1932	64		2.57	1.29	1.3
57	96.00	7680.00	14.10	1128.00	70.72	5657.60	70.04	5603.20	72	72.24				3.27	1.63	1.7
64	113.60	9088.00	21.60	1728.00	60.12	4809.60	57.20	4576.00	111	111.37	588	73		3.41	1.70	1.8
67																
71					71.52	5721.60	43.00	3440.00						1.974***	0.99	1
74	68.40	5472.00			69.72	5577.60	55.40	4432.00						2.38	1.19	1.2
78	53.20	4256.00			85.92	6873.60	78.00	6240.00	52	52.17				3.06	1.53	1.6

grey font color: 40L fresh water instead of 60L, these values not included in average values instead values of the controls were taken

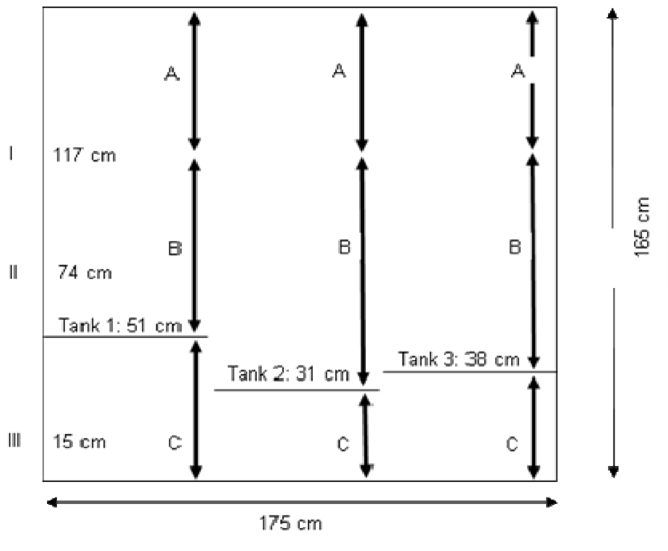
	effluent 1																	
Day	**CODtot**	**CODtot**	**CODdis**	**TS**	**TS**	**VS**	**VS**	**VS**	**NH_3-N**	**NH_4^+-N**	**PO_4^{3-}**	**PO_4^{3-}-P**	**Ptot**	**A/TIC**	**TKN**	**Cond.**	**TDS**	**Salinity**
	[g/L]	[g/d]	[g/L]	[g/L]	[g/d]	[g/L]	[g/d]	% TS	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]		[mg/L]	[mS/cm]	[g/L]	[ppt]
									dis	dis	fil	fil	fil	dis		tot	tot	tot
2	26.50	1272.00	1.30	2.76	187.68	0.92	62.56	33.3	298.5	299.5	108.5	35.4		0.029				
4	3.15	151.20	2.85	2.52	120.96	1.12	53.76	44.4	295.5	296.5	102.5	33.4		0.005		4.35	2.18	2.30
8	3.63	174.05		2.72	130.56	1.52	72.96	55.9	241.5	242.3	105.5	34.4		0.016		4.44	2.22	2.4
10	2.16	103.49	0.39	2.72	130.56	1.08	51.84	39.7	178.5	179.1	97.0	31.6		0.003	280	4.34	2.17	2.3
15	3.75	270.00		3.16	227.52	1.44	103.68	45.6	244.5	245.3	109.0	35.5	142.5	0.068		5.04	2.52	2.7
18	1.30	93.60	0.34	3.08	221.76	1.40	100.80	45.5	210.0	210.7	92.0	30.0		0.036		4.39	2.19	2.3
22	3.96	285.12	0.90	2.56	184.32	1.68	120.96	65.6	220.5	221.2	102.5	33.4		0.020	263.2	4.4	2.2	2.3
29	1.62	123.12	0.34	2.24	170.24	0.68	51.68	30.4	253.5	254.3	104.5	34.1		0.010		4.52	2.26	2.4
32	1.27	96.52	0.06	3.24	246.24	1.36	103.36	42.0	294.0	295.0	105.0	34.2	110	0.006		4.45	2.222	2.4
37	2.76	209.76	0.69	6.16	468.16	3.92	297.92	63.6	295.5	296.5				0.010		4.71	2.35	2.5
39	1.26	95.76	0.14	3.72	282.72	2.92	221.92	78.5	295.5	296.5	107.0	34.9	113	0.024	604.8	4.54	2.27	2.4
43	1.21	91.96	0.83	3.84	291.84	2.24	170.24	58.3	291.0	292.0	112.5	36.7		0.017		4.78	2.39	2.6
47	1.00	76.00	0.06	3.44	261.44	2.08	158.08	60.5	303.0	304.0	100.5	32.8		0.019		4.67	2.33	2.5
50	3.75	300.00	1.00	3.40	272.00	1.84	147.20	54.1	286.5	287.5	109.5	35.7		0.036		4.73	2.37	2.5
53	1.88	150.00	0.35	12.52	1001.60	7.36	588.80	58.8	282.0	282.9	102.5	33.4		0.015		4.75	2.38	2.5
57	1.30	104.00	0.50	2.84	227.20	1.12	89.60	39.4	291.0	292.0	103.0	33.6		0.021		4.69	2.35	2.5
64	1.98	158.00	1.23	3.08	246.40	1.52	121.60	49.4	301.5	302.5	126.0	41.1		0.032		4.93	2.46	2.6
67	1.65	132.00	0.53	3.08	246.40	0.56	44.80	18.2	282.0	282.9	117.0	38.1	160	0.034		4.82	2.41	2.6
71	1.10	88.00	0.35	3.04	243.20				321.0	322.1	121.0	39.4		0.039		4.88	2.44	2.6
74	7.90	632.00	6.23	2.68	214.40				336.0	337.1	124.0	40.4	146	0.007		4.89	2.45	2.6
78	2.03	162.00	2.65	2.92	233.60	1.76	140.80	60.3	334.5	335.6	128.0	41.7	155	0.070		4.83	2.42	2.6

	effluent 2																		
	CODtot	**CODtot**	**CODdis**	**CODdis**	**TS**	**TS**	**VS**	**VS**	**VS**	**NH_3-N**	**NH_4^+-N**	**PO_4^{3-}**	**PO_4^{3-}-P**	**Ptot**	**A/TIC**	**TKN**	**Cond.**	**TDS**	**Salinity**
	[g/L]	**[g/d]**	**[g/L]**	**[g/d]**	**[g/L]**	**[g/d]**	**[g/L]**	**[g/d]**	**% TS**	**[mg/L]**	**[mg/L]**	**[mg/L]**	**[mg/L]**	**[mg/L]**		**[mg/L]**	**[mS/cm]**	**[g/L]**	**[ppt]**
Day										**dis**	**dis**	**fil**	**fil**	**fil**	**dis**		**tot**	**tot**	**tot**
2	6.80	326.40	**42.35**	2032.80	2.76	132.48	1.04	49.92	37.7	315.0	316.1	100.5	32.8		0.009		4.59	2.29	2.4
4	2.60	124.56			2.64	179.52			0.0	262.5	263.4	91.5	29.8		0.000		4.85	2.44	2.6
8	0.81	38.78	0.71	33.96	2.68	182.24	1.16	55.68	30.6	246.0	246.8	75.0	24.5		0.000	364	4.84	2.42	2.6
10	1.97	141.84			2.80	190.40	1.04	70.72	37.1	220.5	221.2	95.5	31.1		0.017		5.46	2.73	2.9
15	3.78	272.16	0.32	23.04	4.36	296.48	2.44	165.92	56.0	241.5	242.3	77.0	25.1		0.023		4.87	2.43	2.6
18	2.96	213.12	1.95	140.40	2.48	168.64	1.00	68.00	40.3	298.5	299.5	109.0	35.5		0.027	280	4.84	2.42	2.6
22	2.60	197.60	1.06	80.56	2.84	193.12	0.80	54.40	28.2	316.5	317.6	107.0	34.9		0.077		4.82	2.41	2.6
29	6.00	456.00	0.83	63.08	3.16	214.88	1.36	92.48	43.0	303.0	304.0	109.0	35.5	90	0.069		4.72	2.36	2.5
32	3.29	250.04	0.26	19.76	4.16	282.88	2.64	179.52	63.5	291.0	292.0				0.021		4.78	2.39	2.6
37		0.00	0.03	2.28	4.24	288.32	2.96	201.28	69.8	310.5	311.5	87.0	28.4	89	0.019		4.62	2.31	2.5
39	0.46	34.96	0.29	22.04	3.56	242.08	2.24	152.32	62.9	252.0	252.8	114.5	37.3		0.028		4.76	2.38	2.5
43	1.07	81.32			3.36	228.48	2.12	144.16	63.1	297.0	298.0	100.5	32.8		0.018		4.70	2.35	2.5
47	1.58	126.40	0.52	41.60	3.68	250.24	2.48	168.64	67.4	234.0	234.8	101.0	32.9		0.007		4.54	2.27	2.4
50	7.33	586.40	0.44	35.20	10.60	720.80	5.80	394.40	54.7	312.0	313.0	102.0	33.3		0.043		4.58	2.29	2.4
53	0.85	68.00	0.16	12.80	2.20	149.60	0.80	54.40	36.4	295.5	296.5	97.5	31.8		0.022		4.43	2.21	2.4
57	0.69	55.20	0.16	12.80	2.24	152.32	0.64	43.52	28.6	295.5	296.5	162.0	52.8		0.014		4.50	2.25	2.4
64	2.07	165.60	0.15	12.00	2.28	155.04	1.00	68.00	43.9	288.0	289.0	103.0	33.6	103	0.028		4.46	2.23	2.4
67	1.16	92.80	0.09	7.20	2.64	190.08			0.0	295.5	296.5	105.5	34.4		0.016		4.40	2.20	2.6
71	3.72	297.60	1.11	88.80	2.04	146.88			0.0	292.5	293.5	103.0	33.6	117	0.018		4.40	2.20	2.3
74	0.17	13.60	2.16	172.80	1.16	83.52	2.40	172.80	206.9	328.5	329.6	105.0	34.2	115	0.005		4.32	2.16	2.3
78																			

	effluent 3																
	CODtot	CODtot	CODdis	CODdis	TS	TS	VS	VS	VS	NH_3-N	NH_4^+-N	PO_4^{3-}	PO_4^{3-}-P	A/TIC	Cond.	TDS	Salinity
	[g/L]	[g/d]	[g/L]	[g/d]	[g/L]	[g/d]	[g/L]	[g/d]	% TS	[mg/L]	[mg/L]	[mg/L]	[mg/L]		[uS/cm]	[g/L]	[ppt]
Day										dis	dis	fil	fil	dis	tot	tot	tot
2																	
4					2.48	168.64	1.16	55.68	33.0	250.5	251.3	91.5	29.8	0.016	4.29	2.15	2.3
8	1.57	106.83	0.54	36.38	1.96	133.28	0.24	11.52	8.6	258.0	258.9	92.0	30.0	0.007	4.27	2.13	2.3
10	1.61	115.56			2.36	160.48	0.88	59.84	37.3	223.5	224.2	84.0	27.4	0.056	4.72	2.36	2.5
15	0.18	12.96	0.54	38.88	2.32	157.76	1.08	73.44	46.6	229.5	230.3	81.0	26.4	0.002	4.32	2.16	2.3
18			0.83	59.76	1.92	130.56	0.84	57.12	43.8	253.5	254.3	91.0	29.7	0.032	4.33	2.17	2.3
22	1.29	98.04	0.31	23.56	1.84	125.12	0.36	24.48	19.6						4.58	2.29	2.4
29	1.34	101.84	0.21	15.96	2.56	174.08	0.96	65.28	37.5	279.0	279.9	93.0	30.3	0.000	4.49	2.24	2.4
32															4.64	2.32	2.5
37																	
39																	
43																	
47																	
50																	
53																	
57	0.58	46.40	0.77	61.60	1.80	122.40	0.52	35.36	28.9	277.5	278.4	106.0	34.6	0.009	4.3	2.15	2.3
64																	
67	0.39	31.20			2.28	164.16				277.5	278.4	94.0	30.6	0.000	4.28	2.14	2.3
71	2.53	202.40	0.44	34.80	2.12	152.64				292.5	293.5	96.0	31.3	0.012	4.21	2.1	2.2
74	0.55	44.00	0.68	54.40	2.32	167.04	2.56	184.32	110.3	298.5	299.5	94.0	30.6	0.034	4.26	2.13	2.3
78																	

Layering

Sampling point	weight of dish [mg]	weight of dish + dried residue [mg]	weight of dish + dried residue after ignition [mg]	sample weight [mg]	**dry weight [%]**	**moisture content [%]**	sample volume [mL]	**TS [g/L]**	**VS [g/L]**	**pH**	**Redox**	**VS [% TS]**
	digester contents at different heights											
1.I	41710	41774	41740				25	**2.56**	**1.36**	7.77	-90.30	53.13
1.II	29221	29326	29290				25	**4.20**	**1.44**	7.81	-92.50	34.29
1.III	30578	31154	30677	24586	**2.34**	**97.66**	25	**23.04**	**19.08**	7.77	-90.40	82.81
2.I	29607	29673	29661				25	**2.64**	**0.48**	7.70	-86.00	18.18
2.II	28439	28511	28493				25	**2.88**	**0.72**	7.71	-86.70	25.00
2.III	29888	30434	29981	25182	**2.17**	**97.83**	25	**21.84**	**18.12**	7.64	-83.00	82.97
3.I	43617	43687	43671				25	**2.80**	**0.64**	7.65	-83.50	22.86
3.II	29551	29636	29605				25	**3.40**	**1.24**	7.72	-87.70	36.47
3.III	46315	46941	46410	24938	**2.51**	**97.49**	25	**25.04**	**21.24**	7.66	-84.00	84.82



Onsite Measurements Azania Plants

Azania Plant 1

Date	Day	Feed [kg/d]	pH	Temp below water table [°C]	Redox [mV]	Average air temp [°C]	CH4 [vol%]	CO2 [vol%]	O2 [vol%]	NH3 [ppm]	H2S [ppm]	Gas production [L]	Air pressure [Pa]	Time
26.10.2009	1		7.2	29.9	-57.9	28.6	68	41	0.2	2240	1090			9.30
27.10.2009	2	8	7.07	30.0	-50.1	27.9								9.30
28.10.2009	3	8				28.1								
29.10.2009	4	8	6.85	30.1	-37.7	27.4	68	39	-0.1	2640	1550			9.30
30.10.2009	5	8	6.87	32.2	-38.3	27.1	68	40	0	1440	1640			13.45
31.10.2009	6	8				27.7								
01.11.2009	7					27.0								
02.11.2009	8	8	6.84	30.0	-36.7	27.2	66	46	0.1		1460			6.15
03.11.2009	9	8	6.92	32.2	-41.6	27.2	63	43	0.1		1480			10.15
04.11.2009	10	8	6.86	30.2	-38	27.4	63	46	0.1	690	1460			6.45
05.11.2009	11	8				27.6								
06.11.2009	12	8				28.2								
07.11.2009	13	8	6.94	32.6	-42.7	29.1								13.00
08.11.2009	14					29.7								
09.11.2009	15	12	6.84	30.9	-36.9	28.7								6.30
10.11.2009	16	12	6.9	31.7	-40.6	28.8	59	48	0.2	2200	1170			11.00
11.11.2009	17	12	6.93	32.4	-42.2	28.2								12.00
12.11.2009	18	12	6.85	30.4	-37.7	28.2	58	50	-0.1	1250	1050			6.00
13.11.2009	19	12	6.84	31.9	-36.8	28.3								10.00
14.11.2009	20	8	6.89	33.8	-39.8	28.3	58	50	0	1240	935			16.00
15.11.2009	21					28.0								
16.11.2009	22	12	6.9	31.0	-40.1	28.1	60	45	-0.1	1030	960			6.30
17.11.2009	23	12	6.99	31.1	-45.3	27.3	60	48	0	680	1000			7.00
18.11.2009	24	12	6.99	33.2	-45.6	28.2	55	58	-0.1	785	970			14.00
19.11.2009	25	12				27.3								

20.11.2009	26	12	6.99	32.3	-45.6	28.3	60	48	-0.1	1170	920			14.00
21.11.2009	27	8	7.03	32.5	-47.7	29.1	60	48	-0.1	780	935			14.30
22.11.2009	28		7.03	31.2	-48.1	28.4	61	48	0.1	555	945			9.45
23.11.2009	29	10	7.1	30.5	-51.6	28.3	61	46	0.1	635	975	850	101295	6.00
24.11.2009	30	16	7.12	32.1	-52.9	27.4	62	46	0	715	1060	700	101327	14.00
25.11.2009	31	16	7.07	31.7	-49.9	28.1	61	46	0	734	1090			11.15
26.11.2009	32	16	6.97	31.0	-44.3	28.1	59	47	-0.2	635	1080			6.30
27.11.2009	33	16				28.7	58	48	-0.1	735	1080	1579	101188	13.00
28.11.2009	34	8				28.7								
29.11.2009	35													
30.11.2009	36	16				29.9	59	48	0.1	1340	1010			9.30
01.12.2009	37	16	7.14	31.8	-54.8	28.9	60	48	0.1	800	1040			6.00
02.12.2009	38	16				29.3						1371	101112	
03.12.2009	39	16	7.11	31.8	-58.7	29.5	58	49	-0.2	1050	1060			6.00
04.12.2009	40	16	7.18	34.3	-56.8	29.9	58	50	-0.2	830	1010	1569	101200	12.00
05.12.2009	41	8	7.19	33.0	-57.3	29.0								9.30
06.12.2009	42		7.22	33.0	-53	29.0	58	49	0.1	965	1030			10.00
07.12.2009	43	16	7.23	31.7	-59.3	29.0	60	47	0.1	685	1010	900	101100	6.30
08.12.2009	44	16				28.0								
09.12.2009	45	16	7.25	32.6	-59.7	28.7								14.30
10.12.2009	46	16				27.8						1708	101238	
11.12.2009	47	16	7.12	30.3	-53.2	27.8	58	48	-0.3	880	1080			6.15
12.12.2009	48	8				27.9								
13.12.2009	49		7.24	31.6	-60.2	28.6								10.00
14.12.2009	50	20	7.25	30.7	-60.4	29.1	58	49	-0.1	1260	1050	1320	101037	7.00
15.12.2009	51	20	7.27	31.5	-61.5	29.8	58	49	0	780	1040			8.30
16.12.2009	52	20				28.1						1200	101186	
17.12.2009	53	20	7.22	30.9	-59	29.6	57	50	-0.6	950	1040			6.00
18.12.2009	54	20	7.25	32.6	-60.9	30.2	55	52	-0.4	710	895			14.30
19.12.2009	55	8	7.37	32.6	-67.6	29.7						1771	101157	9.00
20.12.2009	56					30.0						1733	101250	
21.12.2009	57	20	7.38	31.2	-67.8	29.2	58	49	-0.1	1040	910			10.15
22.12.2009	58	20	7.33	31.9	-65.5	29.2	58	49	-0.2	760	925			8.30

23.12.2009	59	20				28.5						1705	101083	
24.12.2009	60	20				29.5								
25.12.2009	61					27.3								
26.12.2009	62					28.7						1043	101137	
27.12.2009	63	20	7.45	32.8	-72.1	29.4	61	46	0.1	1620	1090			11.30
28.12.2009	64	20	7.47	31.3	-73.2	28.9	61	46	0		1100	1096	101050	9.00
29.12.2009	65	20	7.4	30.4	-69.3	29.5	60	47	0	680	1130			7.30
30.12.2009	66	20				28.8						1074	101075	
31.12.2009	67	20	7.4	31.2	-69.4		58	50	-0.1	930	1040			8.45
01.01.2010	68					29.2								
02.01.2010	69	20	7.46	32.0	-73	30.1	57	48	0	496	1010			8.30
03.01.2010	70	20										1500	101300	
04.01.2010	71	20	7.52	29.4	-75.7		60	47	0	870	1030			7.30
05.01.2010	72	20	7.46	30.4	-72.9	30.2								9.15
06.01.2010	73	20	7.44	29.1	-71.3	26.6	59	50	-0.2	855	980	1422	100912	8.00
07.01.2010	74	20	7.45	29.3	-72	29.3	62	45	0	600	955			6.15
08.01.2010	75	18	7.44	30.1	-71.4	28.4	58	50	-0.2	605	930			9.00
09.01.2010	76	20	7.43	29.0	-70.8	28.1	59	50	0	515	895	925	101000	8.15
10.01.2010	77	20	7.47	28.9	-73.2	28.1								
11.01.2010	78	20	7.43	28.9	-70.8	28.6	58	50	0	560	935	1059	101086	6.00
12.01.2010	79	20	7.5	29.7	-74.8	28.5	58	50	-0.3	750	925			14.00
13.01.2010	80	20				29.2						1200	101188	
14.01.2010	81	18	7.55	29.8	-77.9	28.3	57	50	-0.2	595	875			10.30
15.01.2010	82	20				29.1						1114	101437	
16.01.2010	83	16	7.51	29.4	-75.4	29.5	59	52	-0.3	665	835			9.30
17.01.2010	84	20				29.6						1029	101467	
18.01.2010	85					29.0								
19.01.2010	86		7.53	30.6	-76.7	28.8	59	50	0.1	910	825			8.00
20.01.2010	87		7.67	30.8	-84.9	28.1								8.30
21.01.2010	88		7.67	31.2	-84.9	29.7								8.30
22.01.2010	89					29.9								
23.01.2010	90		7.65	31.4	-83.9	29.8								9.00
24.01.2010	91		7.71	33.0	-87.4	29.7								11.00

25.01.2010	92					30.0								
26.01.2010	93					28.1								
27.01.2010	94		7.7	32.2	-87	29.5								9.00
28.01.2010	95					29.8								
29.01.2010	96					29.3								

afternoon measurements

Azania Plant 2

Date	Day	Feed [kg/d]	pH	Temp below water table [°C]	Redox [mV]	Average air temp [°C]	CH4 [vol%]	CO2 [vol%]	O2 [vol%]	Gas production [L]	Air pressure [Pa]	Time
26.10.2009	1		7.25	30.9	-60.4	28.55	70	39	0.1			9.30
27.10.2009	2		7.18	31.1	-56.6	27.85						9.30
28.10.2009	3					28.1						
29.10.2009	4	8	6.99	30.5	-45.8	27.35	70	36	-0.1			9.30
30.10.2009	5	8	6.99	31.5	-45.7	27.05	70	37	0			13.45
31.10.2009	6	8				27.7						
01.11.2009	7					27						
02.11.2009	8	8	6.9	29.9	-40.1	27.15	66	42	0			6.15
03.11.2009	9	8	6.93	32.2	-42.2	27.15	65	43	0.1			10.15
04.11.2009	10	8	6.9	30.2	-40.2	27.4	64	43	0.1			6.45
05.11.2009	11	8				27.55						
06.11.2009	12	8				28.15						
07.11.2009	13	8	6.98	31.5	-45.2	29.1						13.00
08.11.2009	14					29.65						
09.11.2009	15	8	6.96	30.5	-44	28.65						6.30
10.11.2009	16	8	6.99	31	-45.5	28.8	61	46	0.2			11.00
11.11.2009	17	8	7	31.5	-46	28.2						12.00
12.11.2009	18	8	6.93	30	-41.9	28.15	61	46	0			6.00
13.11.2009	19	8	6.96	31.3	-43.9	28.25						10.00
14.11.2009	20	8	7.05	32.2	-48.8	28.25	60	47	0.1			16.00

15.11.2009	21					27.95						
16.11.2009	22	8	6.97	30.2	-44.4	28.1	62	47	0			6.30
17.11.2009	23	8	7.06	30.7	-49.8	27.25	62	46	0.1			7.00
18.11.2009	24	8	7.04	31.8	-48.4	28.15						14.00
19.11.2009	25	8				27.3						
20.11.2009	26	8	7.05	31.1	-49.1	28.3	62	45	-0.2			14.00
21.11.2009	27	8	7.06	31.7	-49.6	29.05	62	46	-0.1			14.30
22.11.2009	28		7.09	30.9	-51.2	28.4	62	46	0			9.45
23.11.2009	29	8	7.09	31.5	-51.3	28.25	62	45	0	529	101295	6.00
24.11.2009	30	8	7.18	31.4	-56.4	27.4	63	44	0	627	101327	14.00
25.11.2009	31	8	7.16	31.7	-55.6	28.05	63	44	-0.1	750	101300	11.15
26.11.2009	32	8	7.07	30.2	-50	28.1	63	42	-0.4	880	101150	6.30
27.11.2009	33	8				28.7	62	46	-0.1	758	101188	13.00
28.11.2009	34	8				28.7						
29.11.2009	35					0						
30.11.2009	36	8				29.9	62	45	0.1			9.30
01.12.2009	37	8	7.17	31.4	-55.7	28.85	62	45	0.1	771	101114	6.00
02.12.2009	38	8				29.25				886	101112	
03.12.2009	39	8	7.16	30.9	-55.6	29.45	62	45	-0.1			6.00
04.12.2009	40	8	7.26	32.3	-61	29.85	61	45	0	646	101200	12.00
05.12.2009	41	8	7.24	32	-60.2	28.95				873	101175	9.30
06.12.2009	42		7.26	32.1	-61.4	29	61	46	0.1	629	101114	10.00
07.12.2009	43	8	7.24	31.2	-60.2	28.95	62	45	0.1	400	101100	6.30
08.12.2009	44	8				27.95				768	101075	
09.12.2009	45	8	7.28	31	-62.3	28.7						14.30
10.12.2009	46	8				27.75				969	101238	
11.12.2009	47	8	7.24	29.3	-53.8	27.8	63.45	45	0			6.15
12.12.2009	48	8				27.9						
13.12.2009	49		7.3	31	-63.4	28.6				758	101012	10.00
14.12.2009	50	8	7.27	29.8	-61.6	29.1	62	45	0	675	101037	7.00
15.12.2009	51	8	7.32	32.1	-64.9	29.75	62	45	0.1			8.30
16.12.2009	52	8				28.1				900	101186	
17.12.2009	53	8	7.26	30.7	-61.2	29.6	61	45	0			6.00

18.12.2009	54	8	7.31	33.4	-64.4	30.2	60	46	0			14.30
19.12.2009	55	8	7.35	32.8	-66.3	29.65				1029	101157	9.00
20.12.2009	56					30				867	101250	
21.12.2009	57	8	7.35	31.3	-66.3	29.2	60	46	0.1	893	101300	10.15
22.12.2009	58	8	7.35	31.6	-66.5	29.2	60	47	0.1	814	101175	8.30
23.12.2009	59	8				28.5				821	101083	
24.12.2009	60	8				29.45						
25.12.2009	61					27.25						
26.12.2009	62					28.65				417	101137	
27.12.2009	63	8	7.47	31.4	-73.3	29.35	64	43	0.1			11.30
28.12.2009	64	8	7.41	31	-69.5	28.85	65	43	0	470	101050	9.00
29.12.2009	65	8	7.37	30	-67.6	29.45	64	42	0			7.30
30.12.2009	66	8				28.8				758	101075	
31.12.2009	67	8	7.45	30.9	-72	0	63	45	0	726	101025	8.45
01.01.2010	68					29.15						
02.01.2010	69	8	7.53	31.9	-76.7	30.05	61	46	0.1			8.30
03.01.2010	70	8				0				600	101300	
04.01.2010	71	12	7.51	29	-75.5	0	63	45	0.1	611	101120	7.30
05.01.2010	72	12	7.5	30	-75.1	30.15						9.15
06.01.2010	73	12	7.47	28.6	-73.1	26.6	63	46	0.1	622	100912	8.00
07.01.2010	74	12	7.46	29.3	-72.7	29.3	62	45	0	682	100850	6.15
08.01.2010	75	8	7.46	29.2	-72.3	28.4	62	45	0			9.00
09.01.2010	76	12	7.51	28.8	-75.3	28.1	62	47	0.2	450	101000	8.15
10.01.2010	77	12	7.44	28.7	-71.1	28.1				600	100900	
11.01.2010	78	12	7.44	28.8	-71.5	28.6	62	45	0.2	1024	101086	6.00
12.01.2010	79	12	7.5	29.4	-75	28.5	60	47	-0.1			14.00
13.01.2010	80	12				29.15				1032	101188	
14.01.2010	81	10	7.53	29.3	-76.8	28.25	58	48	0			10.30
15.01.2010	82	12				29.1				986	101437	
16.01.2010	83	8	7.52	29.5	-76.2	29.5	60	50	0			9.30
17.01.2010	84	12				29.6				943	101467	
18.01.2010	85					29						
19.01.2010	86		7.51	30.1	-75.5	28.75	60	49	0.1			8.00

20.01.2010	87		7.64	30.6	-83.3	28.05						8.30
21.01.2010	88		7.66	31.4	-84.1	29.7						8.30
22.01.2010	89					29.85						
23.01.2010	90		7.62	31.1	-81.1	29.75						9.00
24.01.2010	91		7.64	32	-83.4	29.65						11.00
25.01.2010	92					29.95						
26.01.2010	93					28.1						
27.01.2010	94		7.67	31.5	-84.8	29.5						9.00
28.01.2010	95					29.75						
29.01.2010	96					29.3						

afternoon measurements

Azania Plant 3

Date	Day	Feed [kg/d]	pH	Temp below water table [°C]	Redox [mV]	Average air temp [°C]	CH4 [vol%]	CO2 [vol%]	O2 [vol%]	Gas production [L]	Air pressure [Pa]	Time
26.10.2009	1		7.18	31.3	-56.5	28.55	68	40	0.1		9.3	9.30
27.10.2009	2		7.13	31.3	-53.6	27.85					9.3	9.30
28.10.2009	3					28.1						
29.10.2009	4		7.08	30.7	-50.8	27.35	68	38	0		9.3	9.30
30.10.2009	5		7.06	32.4	-49.3	27.05	68	37	0.1		13.45	13.45
31.10.2009	6					27.7						
01.11.2009	7					27						
02.11.2009	8	8	6.96	29.8	-43.8	27.15	70	35	-0.2		6.15	6.15
03.11.2009	9	8	6.99	32.7	-45.7	27.15	70	37	-0.1		10.15	10.15
04.11.2009	10	8	6.92	31.2	-41.7	27.4	68	38	0		6.45	6.45
05.11.2009	11	8				27.55						
06.11.2009	12	8				28.15						
07.11.2009	13	8	6.91	32.9	-40.9	29.1					13	13.00
08.11.2009	14					29.65						
09.11.2009	15	8	6.84	30.9	-36.9	28.65					6.3	6.30

10.11.2009	16	8	6.99	31.3	-45.7	28.8	63	44	0.1		11	11.00
11.11.2009	17	8	6.98	32	-45	28.2					12	12.00
12.11.2009	18	8	6.85	30.6	-37.3	28.15	62	46	-0.1		6	6.00
13.11.2009	19	8	6.94	32.1	-42.6	28.25					10	10.00
14.11.2009	20	8	7.03	34.1	-48.1	28.25	61	46	-0.1		16	16.00
15.11.2009	21					27.95						
16.11.2009	22	8	6.9	31.3	-40.6	28.1	61	47	-0.2		6.3	6.30
17.11.2009	23	8	7.04	31.9	-48.6	27.25	62	47	0		7	7.00
18.11.2009	24	8	7.09	33.7	-51.3	28.15					14	14.00
19.11.2009	25	8				27.3						
20.11.2009	26	8	7.06	32.5	-49.4	28.3	63	44	-0.2		14	14.00
21.11.2009	27	8	7.05	33.3	-49	29.05	62	44	-0.3		14.3	14.30
22.11.2009	28		7.08	31.7	-50.6	28.4	63	46	-0.2		9.45	9.45
23.11.2009	29	8	7.09	31.8	-51.2	28.25	62	45	-0.2		6	6.00
24.11.2009	30	8	7.16	33.2	-55.4	27.4	63	44	-0.1		14	14.00
25.11.2009	31	8	7.13	32.8	-53.5	28.05	62	45	-0.2		11.15	11.15
26.11.2009	32	8	7.04	31.7	-48.7	28.1	63	44	0.1		6.3	6.30
27.11.2009	33	8				28.7	60	46	-0.3		13	13.00
28.11.2009	34	8				28.7						
29.11.2009	35					0						
30.11.2009	36	8				29.9	61	46	0		9.3	9.30
01.12.2009	37	8	7.17	32.9	-55.7	28.85	61	46	-0.1	1200	6	6.00
02.12.2009	38	8				29.25				857		
03.12.2009	39	8	7.17	32.3	-55.7	29.45	61	45	-0.3		6	6.00
04.12.2009	40	8	7.26	34.2	-61.4	29.85	60	46	-0.1		12	12.00
05.12.2009	41	8	7.25	33.3	-60.7	28.95					9.3	9.30
06.12.2009	42		7.29	33.2	-62.7	29	60	45	0		10	10.00
07.12.2009	43	8	7.26	32.9	-61	28.95	61	45	0		6.3	6.30
08.12.2009	44	8				27.95						
09.12.2009	45	8	7.28	32.6	-62.5	28.7					14.3	14.30
10.12.2009	46	8				27.75						
11.12.2009	47	8	7.24	30.9	-60.2	27.8	62	46	0		6.15	6.15
12.12.2009	48	8				27.9						

13.12.2009	49		7.29	32.3	-63	28.6					10	10.00
14.12.2009	50	8	7.27	31.4	-62	29.1	60	46	0		7	7.00
15.12.2009	51	8	7.31	30.9	-63.9	29.75	61	46	-0.1		8.3	8.30
16.12.2009	52	8				28.1				857		
17.12.2009	53	8	7.27	32.5	-61.8	29.6	61	46	-0.1		6	6.00
18.12.2009	54	8	7.34	31.5	-65.5	30.2	59	45	0.1		14.3	14.30
19.12.2009	55	8	7.35	31.6	-66.1	29.65				1143	9	9.00
20.12.2009	56					30				800		
21.12.2009	57	8	7.37	32.5	-67.7	29.2	60	47	0	753	10.15	10.15
22.12.2009	58	8	7.37	32.7	-67.7	29.2	57	45	0.8	600	8.3	8.30
23.12.2009	59	8				28.5				695		
24.12.2009	60	8				29.45						
25.12.2009	61					27.25						
26.12.2009	62					28.65				1237		
27.12.2009	63	8	7.49	32.8	-74.8	29.35	62	45	0.1		11.3	11.30
28.12.2009	64	8	7.46	31.7	-72.6	28.85	63	44	0	470	9	9.00
29.12.2009	65	8	7.4	31	-69.5	29.45	63	44	-0.1		7.3	7.30
30.12.2009	66	8				28.8				632		
31.12.2009	67	8	7.45	31.7	-72.4	0	62	45	0	698	8.45	8.45
01.01.2010	68					29.15						
02.01.2010	69	8	7.55	32.9	-77.8	30.05	61	45	0		8.3	8.30
03.01.2010	70	8				0				540		
04.01.2010	71	12	7.53	29.7	-76.3	0	62	45	0.1	568	7.3	7.30
05.01.2010	72	12	7.5	30.6	-74.8	30.15					9.15	9.15
06.01.2010	73	12	7.46	30	-72.7	26.6	62	46	0	578	8	8.00
07.01.2010	74	12	7.46	30.1	-72.6	29.3	62	45	0	694	6.15	6.15
08.01.2010	75	8	7.48	30	-73.9	28.4	61	46	0		9	9.00
09.01.2010	76	12	7.51	29.3	-75.2	28.1	62	45	0.1	350	8.15	8.15
10.01.2010	77	12	7.44	29.1	-71.3	28.1				483		
11.01.2010	78	12	7.47	29.1	-73.4	28.6	62	45	0	282	6	6.00
12.01.2010	79	12	7.52	30	-76.1	28.5	61	46	-0.1		14	14.00
13.01.2010	80	12				29.15				1056		
14.01.2010	81	10	7.52	29.7	-76.2	28.25	59	49	-0.2		10.3	10.30

15.01.2010	82	12				29.1				729		
16.01.2010	83	0	7.5	30.2	-75.1	29.5	59	50	-0.2		9.3	9.30
17.01.2010	84	12				29.6				286		
18.01.2010	85					29						
19.01.2010	86		7.5	31.3	-75.2	28.75	60	49	0		8	8.00
20.01.2010	87		7.63	31.7	-82.5	28.05					8.3	8.30
21.01.2010	88		7.64	32.2	-83	29.7					8.3	8.30
22.01.2010	89					29.85						
23.01.2010	90		7.62	31.9	-82.3	29.75					9	9.00
24.01.2010	91		7.64	33.4	-83.6	29.65					11	11.00
25.01.2010	92					29.95						
26.01.2010	93					28.1						
27.01.2010	94		7.68	31.6	-85.5	29.5					9	9.00
28.01.2010	95					29.75						
29.01.2010	96					29.3						

afternoon
measurements

Kitchen Measurements

Mean biogas consumption for 110 students			
mean biogas consumption [L]	**meal**	**biogas [L]**	**# students**
3193.00	rice	3193	110
		1348	40
		1850	55
1985.00	meat	1985	110
824.00	cabbage	1034	110
		738	110
		700	110
		565	110
2506.00	ugali	1825	110
		2785	110
		2716	110
		2698	110
1468.00	uji	1150	110
		1786	110
		1100	70
4375.00	beans	3900	110
		4850	110
		3530	70
		3780	70
	tea	1350	70
5641.00	makande	5641	110

Mean charcoal consumption for 110 students			
mean charcoal amount [kg]	**meal**	**charcoal [kg]**	**# students**
15.25	tea, ugali	17.5	110
		13	90
	tea, ugali, cabbage	13	70
18.63	tea, beans	15.5	110
		18	110
		21	110
		20	110
13.00	ugali, cabbage	13	110
12.50	beans	10	90
		15	110
9.20	ugali	6	70
		9	110
		9	110
		8.5	110
		8	110
		11.5	110
9.25	rice	10	110
		8.5	110
14.25	makande	13	110
		15.5	110
		9.5	70
		13	70
9	meat	9	110

Average cooking time (110 students)		
	Biogas [min]	**Charcoal [min]**
Tea		65
Uji	83	75
Ugali	137	100
Beans (lunch)	245	219
Beans (lunch & dinner)	295	271
Cabbage	55	40
Makande	345	340
Rice	94	104
Meat	155	120

Mass balance calculation for the period 9.11.2009 – 13.12.2009
Feeding amount were tried to adjust to the real input in the field.

	Plant 1					**Plant 2**				
Date	**Food waste L/d real**	**Feed C [g/d]**	**Gas prod. NL/d**	**Gas C [g/d]**	**Effluent C [g/d]**	**Food waste L/d real**	**Feed C [g/d]**	**Gas prod. NL/d**	**Gas C [g/d]**	**Effluent C [g/d]**
9.11.09	12	1486.4	1123	601	52.7	8	991.0	716	382.9	39.0
10.11.09	12	1486.4	1123	601	52.7	8	991.0	716	382.9	39.0
11.11.09	12	1486.4	1123	601	52.7	8	991.0	716	382.9	39.0
12.11.09	12	1486.4	1123	601	52.7	8	991.0	716	382.9	39.0
13.11.09	12	1486.4	1123	601	52.7	8	991.0	716	382.9	39.0
14.11.09	8	991.0	716	383	52.7	8	991.0	716	382.9	39.0
15.11.09		0.0	484	259	52.7		0.0	484	258.9	39.0
16.11.09	12	1486.4	1123	601	52.7	8	991.0	716	382.9	39.0
17.11.09	12	1486.4	1123	601	52.7	8	991.0	716	382.9	39.0
18.11.09	12	1486.4	1123	601	52.7	8	991.0	716	382.9	39.0
19.11.09	12	1486.4	1123	601	52.7	8	991.0	716	382.9	39.0
20.11.09	12	1486.4	1123	601	52.7	8	991.0	716	382.9	39.0
21.11.09	8	991.0	716	383	52.7	8	991.0	716	382.9	39.0
22.11.09		0.0	484	259	52.7		0.0	484	258.9	39.0
23.11.09	10	1238.7	1410	754	52.7	8	991.0	716	382.9	39.0
24.11.09	16	1981.9	1410	754	52.7	8	991.0	716	382.9	39.0
25.11.09	16	1981.9	1410	754	52.7	8	991.0	716	382.9	39.0
26.11.09	16	1981.9	1410	754	52.7	8	991.0	716	382.9	39.0
27.11.09	16	1981.9	1410	754	52.7	8	991.0	716	382.9	39.0
28.11.09	8	991.0	716	383	52.7	8	991.0	716	382.9	39.0
29.11.09		0.0	484	259	52.7		0.0	484	258.9	39.0
30.11.09	16	1981.9	1410	754	52.7	8	991.0	716	382.9	39.0
1.12.09	16	1981.9	1410	754	52.7	8	991.0	716	382.9	39.0
2.12.09	16	1981.9	1410	754	52.7	8	991.0	716	382.9	39.0
3.12.09	16	1981.9	1410	754	52.7	8	991.0	716	382.9	39.0
4.12.09	16	1981.9	1410	754	52.7	8	991.0	716	382.9	39.0
5.12.09	8	991.0	716	383	52.7	8	991.0	716	382.9	39.0
6.12.09		0.0	484	259	52.7		0.0	484	258.9	39.0
7.12.09	12	1486.4	1410	754	52.7	8	991.0	716	382.9	39.0
8.12.09	16	1981.9	1410	754	52.7	8	991.0	716	382.9	39.0
9.12.09	16	1981.9	1410	754	52.7	8	991.0	716	382.9	39.0
10.12.09	16	1981.9	1410	754	52.7	8	991.0	716	382.9	39.0
11.12.09	16	1981.9	1410	754	52.7	8	991.0	716	382.9	39.0
12.12.09	8	991.0	716	383	52.7	8	991.0	716	382.9	39.0
13.12.09		0.0	484	259	52.7		0.0	484	258.9	39.0
Total [kg/35d]	**390.0**	**48.3**	**38.4**	**20.5**	**1.8**	**240.0**	**29.7**	**23.9**	**12.8**	**1.4**
		Cin		**Cgas**	**Cout**		**Cin**		**Cgas**	**Cout**

Csed = Cin – Cgas – Cout = **25.9 kg C**

Csed = 15.6 kg C

Waste characteristics	
Dry weight [%]	26.3
Moisture content [%]	73.7
Density	~1
TS [g/L]	263.7
VS [g/L]	242.5
VS [% TS]	91.9
CODtot [g/L]	427.9
CODdis [g/L]	149.1
%C	51.1
C [g/L]	123.9
C/N ratio	26
NL/kg VS	386