Sandec
Water and Sanitation in
Developing Countries

Evaluation of small-scale biogas systems for the treatment of faeces and kitchen waste

Case study Kochi, South India

Nicolas Estoppey, May 2010

Nicolas Estoppey
Nicolas_estoppey@bluewin.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:

Estoppey, N. (2010): *Evaluation of small-scale biogas systems for the treatment of faeces and kitchen waste,* Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf, Switzerland.

Cover picture: A BIOTECH toilet linked biogas plant in Kumbalanghi, South India.

Abstract

In order to reduce the environmental problems and hazards to inhabitants caused by the increasing generation of municipal solid waste and a lack of sanitation infrastructure in Indian cities, the organisation BIOTECH has installed about 650 plants for food waste and 150 toilet linked biogas plants in Kumbalanghi, South India. Those plants, installed and subsidized as part of the Kumbalanghi Model Tourism Project (KMTP), enable to co-digest the food and toilet waste and to avoid discharges to the backwaters, the large and touristic wetland ecosystem surrounding the village. In addition, the plants produce biogas and organic fertilizer for the families. As research data about biogas plants in developing countries is still very scarce, the aim of this study was to evaluate the technical performance of two biogas systems; one fed with kitchen waste only and one with toilet waste in addition. Further, the economic feasibility and social acceptance of the systems were assessed.

The Toilet Linked Biogas Plant (TLBP) was daily fed by the family with an average of 3.6kg solid waste (mainly rice leftovers and faeces) and 36.5L of liquid waste (mainly flushing water and organic waste water). The Food Waste Biogas Plant (FWBP) was fed with an average of 2.9kg solid waste (mainly rice leftovers and slaughtered chicken waste) and 11.7L of liquid waste (mainly organic waste water) per day.
The technical performances of both plants are similar. The pH (TLBP: 6.91, FWBP: 7.38) and the temperature (TLBP: 29.1°C, FWBP 27.5°C) were stable and appropriate to anaerobic digestion. Because of the flushing water, the substrate flow rate of the TLBP (40L) is almost three times higher than for the FWBP (14.6L). This leads to different concentrations of volatile fatty acids (TLBP: 82mg/L, FWBP: 657mg/L) and unequal hydraulic retention times (TLBP: 37d, FWBP: 100d). However, it doesn't affect by an important way the treatment efficiency as the values for the reduction of total solids volatile solids and chemical oxygen demand are comparable. In addition, the daily gas production is in the same range (TLBP: 690L/d, FWBP: 684L/day).
The very watery effluent is rich in nitrogen and potassium compared to phosphorus. The high percentage of nitrogen in its ammonium form obtained through the anaerobic process increases the usefulness of the effluent as a fertilizer. However, regarding inactivation of E.Coli and Total Coliforms, the effluent should only be used for crops that are not eaten raw. Further, it should not be discharged into the backwaters as its organic load and nitrogen content exceed the Indian environmental standards for discharge of environmental pollutants.

The increase of the plant price due to a change of material and the decrease of subsidies lead to investment costs of 593USD for a toilet linked plant of 2m^3 digester volume. This is five times higher than during the starting phase of the tourism project and represents up to 5 monthly wages of an average family. On the contrary, the operation and maintenance costs are low as the system is very robust. Savings are done first of all through the substitution of LPG and firewood (38.5USD/year). The amortization period amounts up to 16 years whereas only 3.2 years were needed with the previous model and the subsidies. The survey showed that most families were completely satisfied by the system and would recommend it to other families, giving improved waste management and gas production as main advantages. On the other hand, some families with toilet linked plants considered the bad smell of the effluent and its handling as problematic. Only one family has self-restraint regarding the use of gas from faeces. On average, the produced biogas enables to cook for more than 3 hours. The families still use an additional cooking fuel when they need to cook quicker and with more than one stove. In general, it can be said that the monitored systems are suitable for the treatment of kitchen and toilet waste, with the main hindrance of high investment costs and a need for further treatment of the effluent.

Content

Abbreviations

A/TIC	Ratio of acids to total inorganic carbon
BPL	Below poverty line
CDPK	City development plan Kochi
COD	Chemical oxygen demand
E	Effluent
FRP	Fibreglass reinforced plastic
FW	Food waste
GPR	Gas production rate
HRT	Hydraulic retention time
K_{tot}	Total potassium
KMTP	Kumbalanghi model tourism project
KSUPD	Kerala sustainable urban development project
LPG	Liquefied petroleum gas
MSW	Municipal solid waste
MSWM	Municipal solid waste management
NH4 -N	Ammonium
NH_3	Ammonia
N_{tot}	Total nitrogen
OFMSW	Organic fraction of municipal solid waste
OLR	Organic loading rate
P_{tot}	Total phosphorous
RCC	Reinforced cement concrete
SGP	Specific gas production
TS	Total solids
TW	Toilet waste
VFA	Volatile fatty acids
VS	Volatile solids

1. Introduction

1.1. Rationale

Indian cities are confronted with increasing flows of people due to rapid industrialization and population explosion.[1] Thus thousand of tons of municipal solid waste (MSW) are daily generated and their inappropriate management (open dumps and landfills) leads to environmental problems and hazards to inhabitants. The situation is made worse by the use of inadequate latrines which don't enable to treat toilet waste. In coastal and wetland areas, "hanging latrines" and other similar toilet facilities which discharge directly to the water body are commonly used. They are very smelly and unpleasant, but very common in Kerala's backwaters, a very large wetland ecosystem in the South of India.

As toilet waste and the most important fraction of MSW are of organic nature, their anaerobic co-digestion in biogas plants is a promising technology providing in addition gas and fertilizer. To improve the sanitary and environmental conditions in the very sensitive ecosystem of Kerala's backwaters, the organisation BIOTECH from Thiruvananthapuram has developed small scale toilet linked biogas plants enabling to co-digest human and kitchen waste on household level. To date, BIOTECH has installed about 150 toilet linked plants and 650 plants for kitchen waste on the island of Kumbalanghi near Kochi. The goal is to develop Kumbalanghi as an "Integrated Tourism Village" in which waste and environmental pollution would be bothersome. Most of the costs were paid by the Kumbalanghi Panchayat, the Kerala government (Tourism department) and the central government (Non conventional energy department).

1.2. Objectives

Information and research data about biogas plants in developing countries is still very scarce, although this is not a new technology. The overall goal of this study is to gain reliable data on the performance of small scale biogas systems treating kitchen waste and faeces on household level. For this purpose, two BIOTECH biogas plants were monitored and evaluated on Kumbalanghi; one plant fed with kitchen waste only and one plant connected to a toilet.

Specific objectives:

- Evaluation of the technical performance of the system (gas production, treatment efficiency),
- Analysis of the effluent quality,
- Evaluation of the economic feasibility and the social acceptance by the users.

[1] The percentage of urban population in India, which was 20% in 1971, has grown to 28% in 2001 and is expected to reach 40% by 2021 (SINCLAIR KNIGHT MERZ, 2005).

.

2. Background information

2.1. State of Kerala, Kochi city and Kumbalanghi village

2.1.1. General facts

The state of Kerala is located at the Southwest tip of India and constitutes 1.18% of the country's total area (CDPK, 2006).
According to the latest census of India, dating back to 2001, Kerala houses 31.8 millions of inhabitants which represent 3.1% of the Indian population. Its population density is 819 persons per square kilometres, what makes it one of the most densely populated states in the country. About one quarter of the population lives in urban areas.

Figure 1: Localization of Kochi (A), state of Kerala, India (Google Earth).

Kochi city (Figure 1), the largest urban agglomeration in Kerala, counted 1,250,900 inhabitants in 2006. It consists of the Kochi Corporation, two municipalities and thirteen adjoining Panchayats (including Kumbalanghi Panchayat) (CDPK, 2006). According to the census 2001, during the years 1981 to 2001, the average decadal growth was 7.83% in Kochi Corporation, 18.65% in the municipalities and 12.13% in the Panchayats.

Figure 2: Bridge over the backwaters linking Kumbalanghi and another island.

Kochi city has a flat topography characterized by small and large islands which form the backwaters (Figure 2). It has a tropical climate with annual variation of temperature between 26°C and 33°C (SINCLAIR KNIGHT MERZ, 2005).

Kumbalanghi Panchayat has a population of 31,193 inhabitants in 2006 of which 56% lived below the poverty line (BPL).[2] The area is 15.77 km^2, with a population density of 1978 persons/km^2 (CDPK, 2006).

[2] Kerala has formulated its own criteria to define a BPL family. There are 9 parameters and if the family does not have access to 4 or more parameters than it is classified as BPL. For urban areas the parameters are the followings : No land/Less than 5 cents of land, No house/dilapidated house, No sanitation latrine, Family without colour TV, No regular employed person in the family, No access to safe drinking water, Women headed house hold/Presence of widow divorcee, Socially disadvantaged groups SC/ST & Mentally retarded/disabled member in the family.

2.1.2. Solid waste generation and composition

In Kochi Corporation[3], the average waste generation per person is 707 g/d. With almost 280t of waste per day, which represents more than 66% of the MSW in Kochi Corporation, the households generate by far the highest share of solid waste (Table 1).

Table 1: Sources and amount of waste in Kochi Corporation in the year 2001 (SINCLAIR KNIGHT MERZ, 2005).

Sources of Waste Generation	Waste generation [t/day]	Percentage to the total [%]
Domestic waste	*279.12*	*66.22*
Commercial	89.15	21.15
Institutional	10.66	2.53
Road sweeping	18.63	4.42
Drain cleaning	7.97	1.89
Clinic waste	9.31	2.21
Construction/Demolition	6.66	1.58
Total	**421.50**	**100**

As shown in Table 2, more than half of the MSW in Kochi Corporation consists of vegetables.

Table 2: Composition of MSW in Kochi Corporation in the year 2001 (SINCLAIR KNIGHT MERZ, 2005).

Physical composition	Percentage by weight [%]
Vegetables	*58.0*
Paper	4.9
Metals	0.7
Glass	0.3
Plastics, rubbers	1.1
Wooden matter	6.0
Stones, earth	14.0
Textiles	2.0
Miscellaneous	13.0
Total	**100.0**

As the highest share of MSW comes from the households and is of organic nature, its treatment by anaerobic digestion at household level is a promising method to treat the waste at the source.

[3] Data regarding the solid waste generation and composition is available only for Kochi Corporation but should be relatively similar in Panchayats.

2.1.3. Current solid waste management and sanitation systems

According to the Kerala Municipalities Act 1994, Municipal Corporations have the obligatory responsibility to ensure the roads and streets sweeping as well as the drain cleaning. They shall also arrange to collect and dispose of solid waste generated in the city. Thus, sanitary workers daily clean the main streets and the centre of Kochi Corporation whereas the frequencies for the other parts vary (Sinclair Knight Merz, 2005). However, the adjoining Panchayats, like Kumbanlanghi, have no official solid waste management[4]. The families dispose of their organic waste in the surroundings, burn the plastic and paper in their garden (Figure 3A) or threw them directly into the backwaters (Figure 3B and Figure 3C).

Figure 3: On the left (A): Plastic and paper burnt in the families' garden in Kumbalanghi . In the middle (B) and on the right (C): Pollution of the backwaters by solid waste in Kumbalanghi.

Table 3 and the Table 4 give information on the types of latrines used in Kerala's households and the kind of drainage connectivity for the waste water outlet.

Table 3: Type of latrines within the houses in Kerala in the year 2001 (Census of India, 2001).

	Percentage of households [%]		
Type of latrine within the house	**Rural area**	**Urban area**	**Total**
Pit latrines	12.8	11.1	12.4
Water closet	62.0	74.8	65.2
Other latrines	6.6	6.2	6.5
No latrine	18.7	8.0	16.0

Table 4: Types of drainage connectivity for waste water outlet in Kerala in the year 2001 (Census of India, 2001).

	Percentage of households [%]		
Type of drainage connectivity for waste water outlet	**Rural area**	**Urban area**	**Total**
Closet drainage	5.8	14.9	8.0
Open drainage	10.2	16.0	11.7
No drainage	84.0	69.1	80.3

[4] Personal communication with the ex-President of Kumbalanghi Panchayat (2002-2005).

In Kochi city, the low lying terrain and the relatively high groundwater level lead to an ineffective disposal of sewage effluent through individual soakage pits. For that reason, a number of households have connected their latrines to existing drains and canals, what can lead to environmental problems and hazards for public health (SINCLAIR KNIGHT MERZ, 2005).

According to the CITY DEVELOPMENT PLAN OF KOCHI (2006), 20% of the population in the adjoining Panchayats of Kochi city that lived under the poverty line (BPL) in 2001 had no toilet, 3% used community toilets and 8% had toilets without septic tank. At that year, 56% of the population of Kumbalanghi was considered as BPL. In 2010, it is still common to see hanging latrines (Figure 4A) or other latrines where human excreta goes right into the water body (Figure 4B).

Figure 4: On the left (A): Hanging latrines (B) Latrines with an outlet discharging the human excreta into the backwaters.

2.2. BIOTECH

In the followings, a general description of the organization BIOTECH as well as a more detailed description of its domestic biogas plants and the situation in Kumbalanghi are exposed. Most of the data come from personal communication with the director of BIOTECH and from their website (www.biotech-india.org). When this is not the case, the references are mentioned in the text.

2.2.1. General description

BIOTECH has been established as a NGO in 1994 by its actual director Mr. Saji Das. Based in Kerala's capital Thiruvananthapuram, with regional offices in Kochi and Calicut, BIOTECH aims to implement, promote, popularize and do research in Waste Management, Non-conventional Energy and Energy Conservation Programmes. BIOTECH received the Ashden Award for food security in 2007[5].

BIOTECH is specialized in the development of biogas digesters for the treatment of the organic fraction of MSW (OFMSW) and toilet waste in urban areas. Different sizes of plants have been developed for domestic, institutional and municipal level (Figure 5).

Up to date, BIOTECH has installed 16,300 domestic plants. Most of them have a volume of $1m^3$ (Figure 5A), but models with a volume up to $6m^3$ are also available, with the possibility to connect toilets. More details about those domestic plants are given in the next chapter.

[5] The Ashden Awards has the aim to "bring to light inspiring sustainable energy solutions in the UK and developing world and help ensure that they are spread more widely"(www.ashdenawards.org).

To date, about 230 institutional plants (Figure 5B) have been installed in hostels, schools, hospitals and other similar places, where the gas is used for cooking in the canteen. The digesters have a volume of 4 to $10m^3$ and are made of ferro-cement. The gasholder is made of fibreglass reinforced plastic (FRP) coated steel for bigger plants or a drum made of FRP for smaller plants (HEEB, 2009).
At municipal level, BIOTECH already inaugurated 46 plants which enable to treat the market waste (Figure 5C). Generally those plants have one or two $25m^3$ floating drum digesters. The electricity production from the biogas through generators enables to light the market and the surroundings (HEEB, 2009).

Figure 5: On the left (A): $1m^3$ domestic plant. In the middle (B): $4m^3$ institutional plant (HEEB, 2009). On the right (C): $4m^3$ market plant equipped with generator (HEEB, 2009).

The personnel structure of BIOTECH has been discussed in detail in the report of HEEB (2009). Table 5 shows how the personnel developed between January 2009 and March 2010.

Table 5: Employment structure of Biotech in 2009 and 2010.

Field of occupation		2009	2010
Production	Engineers	5	6
	Workers	50	70
	Associated masons	60	60
Service	Supervisors	15	20
	Associated supervisors	200	30
Operation of market plants		20	42
Administration		30	30
Advertisement		20	27
Media		-	3
Information		2	1

The increase of workers in the production and the advertisement as well as the creation of jobs in the media sector shows the director's intention to continue propagating the use of biogas plants and to make people aware. The numbers of operators for the markets plants has doubled because of the 18 new plants installed during that year. Finally, let's notice that the supervision of the household level plants[6] is now organised in a more centralised way compared to the year 2009, where supervisors living in the neighbourhood were providing the service on their own account (HEEB, 2009).

[6] After sell visits are done every six months during the first three years.

2.2.2. Domestics plants

The domestic biogas plants installed at 16,300 households constitute the biggest part of BIOTECH's activities. In the past, the basement of the digesters were made of Ferro-Cement (until 2005) or of Reinforced Cement Concrete (RCC, until 2008). Now, BIOTECH has stopped the construction of such plants and delivers prefabricated portable plants entirely made of fibreglass reinforced plastic (FRP) (Figure 6).

Figure 6: $1m^3$ fibreglass reinforced plastic plant for the treatment of kitchen waste.

Domestic plants with a volume of $1m^3$ to $6m^3$ are available. The smaller ones ($1m^3$ and $2m^3$) exist with or without water jacket, whereas the bigger ones are all designed with water jacket. This technology, where the gasholder does not float directly on the effluent but in a filled water compartment, enables to minimise the gas loss and improves the cleanliness of the plant[7]. For the models having a volume of $2m^3$ or more, BIOTECH offers the possibility to connect toilets in addition to the food waste input. Table 6 gives the number of the different kinds of domestic plants which have been installed until March 2010.

Table 6: Number of different domestic plants installed by BIOTECH until March 2010.

	Ferro-cement plant	FRP plant
$1m^3$ non-water jacket	14,400	1,000
$1m^3$ water jacket	40	300
$2m^3$ non water jacket	120	-
$2m^3$ water jacket + toilet linked	180	15
More than $2m^3$	60	185
Total	**14,800**	**1,500**

Let's notice that 8,500 of the 16,300 domestic plants have been installed in rural area and the other 7'800 ones in urban area.

Compared to the RCC plants, the full-FRP ones offer many advantages which made BIOTECH choose to produce only those ones at a domestic level.

- Less time is spent for transportation as the whole plant can easily be carried (Figure 7).
- Less time is spent to install the plant. If 2 days were required for a RCC plant, now 2 hours are enough for a FRP one.
- No special manual skills are needed to install the plant. Whereas the RCC plant required four workers (2 masons and 2 helpers), only one is needed to install a FRP one.

Figure 7: Transport of a $4m^3$ plant.

[7] A sketch of a plant equipped with such a technology is given in the chapter "2.3.3 Domestic plants in Kumbalanghi".

- The excavation of a pit is not absolutely necessary. The labour charge is reduced and it is more convenient for urban areas as the families have the possibility to install the plant on the roof (Figure 10).
- The FRP plants resists better the salty water and the installation is easier in places close to sea level (Figure 9).
- The attractiveness is better and the customers can even chose their preferred colour. In addition, as it is movable, they can take it with them if they move.
- The advertisement is easier and a road show can be used to promote them (Figure 8).

Figure 10: A $1m^3$ domestic plant on the roof of a house in Kochi.

Figure 9: $2m^3$ toilet linked plant in Kumbalanghi.

Figure 8: Road show.

However, despite all these advantages, the price is a big drawback. Indeed, a $1m^3$ RCC plant costs about Rs10,000 (220USD) whereas a $1m^3$ FRP is about Rs15,000 (330USD). For a $2m^3$ toilet linked plant the price increased from about Rs23,000 (506USD) to Rs33,000 (725USD). The BIOTECH director intends to start additional implementation projects[8] with the short-term goal to minimize the price by producing the plants at large scale.[9] To reduce the prices of those domestic plants, BIOTECH can count on the help of the Ministry of New and Renewable Energy of the Central Government. In 2010, this one subsidizes the plant by giving Rs4000 for a $1m^3$ plant and Rs8000 for a $2m^3$ (or bigger) plant. Let's mention that a few Panchayats also give subsidies of about Rs3500 to the families acquiring a domestic plant.

2.2.3. Domestics plants in Kumbalanghi

In December 2003, the Kumbalanghi Model Tourism Project was started in order to promote the village as an international tourism destination (Figure 11). As part of that project, the initial goal was to install biogas plants in every household of the village in order to solve the problems of waste dumping and water pollution at source (HARIDAS, 2007, EXPRESS NEWS SERVICE, 2007). Besides the central government (Ministry of New and Renewable Energy), the Kumbalanghi Panchayat and, especially, the Kerala Government (Tourism Department) subsidized the plants. Thanks to that, more than 600 $1m^3$ plants for kitchen waste and 150 toilet linked plants were installed. Unfortunately, in 2005, when the LDF government came to the power[10], funds ceased and only few additional $1m^3$ plants for kitchen waste were installed.

Figure 11: Sign announcing Kumbalanghi Model Tourism Village.

[8] The director wants to start new implementation projects through advertisement in media and awareness programs in meetings.

[9] At the moment, 20 to 50 domestic plants are produced per day. The BIOTECH director's goal is to reach a production of 200 plants per day.

[10] K.V. Thomas, the Minister for Tourism and Fisheries between 2001 and 2004 in Government of Kerala came from Kerala and belonged to the Congress party. He was very involved in the Kumbalanghi Model Tourism Project. When the LDF Government came to the power, K.V. Thomas was no more supported in its project.

The cross section and the top view sketches of a biogas plant as installed in Kumbalanghi are given below (Figure 12). The general sketch of the BIOTECH prefabricated eco friendly toilet is given in Appendix A.

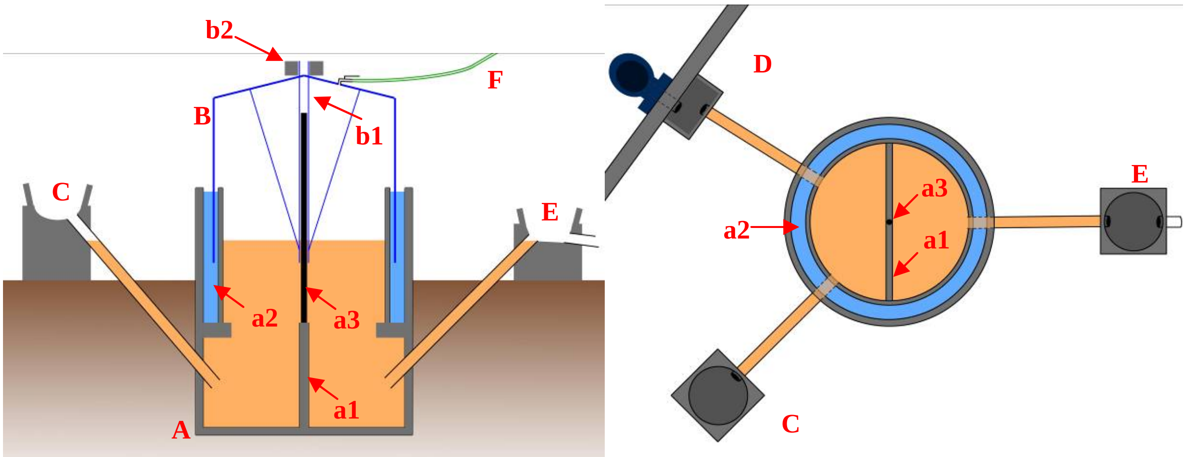


Figure 12: Cross section and top view of a 2m^3 toilet linked plant installed in Kumbalanghi.

The plants have a floating drum design and consist of a digester tank (A), a gasholder drum (B), a food waste inlet (C), a toilet waste inlet (D) (not drawn on the cross section), an effluent outlet (E) and a biogas outlet (F).

The digester tank (A) is made of prefabricated Reinforced Cement Concrete (RCC) elements fitted together in an excavated pit. As Kumbalanghi is very close to sea level, in most of the cases, the initially wanted excavation of a 180cm pit and pile-up of 7 RRC rings of 30cm were not possible. So, the digester depth varies according to the plant and the measurements given in the followings are the ones of the monitored plants in this study. The digester has an external diameter of 142cm and is 160cm deep. The anaerobic digestion of food and toilet waste occurs in it. An orthogonal barrier to the flow direction (a1), having a height of 70cm, separates the lower part of the digester into two “rooms”. Thus, the unsuspended solids are blocked in the first room and their retention time is longer than the one of liquids which can flow over the barrier. Thanks to a filled water compartment, called water jacket (a2), the biogas can be collected almost in its integrity by the gasholder. A metallic central axe (a3) anchored in the orthogonal barrier serves as a guide frame for the gasholder. At the orthogonal barrier level, the internal diameter of the digester is 134cm whereas at the water jacket level it is 108cm. The usable digester volume of a 2m^3 plant is 1.465m^3.

The gasholder (B) is made of FRP and has a diameter of 120cm and a height of 110cm. It moves up when biogas is produced and goes down when the gas is used for cooking. Because the central tube (b1) is guided by a metallic axe, it moves straight and can not tilt to the side. A stone (b2) of 20kg is kept on the gasholder to make it heavy and thus increase the gas pressure.

The food waste inlet (C) and the effluent outlet (E) both consist of a square base (about 45x45cm) made of bricks and are linked to the digester by a pipe at an angle of about 45°. The toilet waste inlet (D) consists of an observation room (in cement or brick) which is linked by a pipe, at one side, to the latrines (with or without a flush) and, at the other side, to the plant. The food and toilet waste arrive in the first room of the digester and the effluent goes out from its second room.

A valve on the gasholder enables to connect a pipe which carries the biogas to the kitchen where the families can cook on a biogas stove.

For the construction of such a toilet linked biogas plant in Kumbalanghi, the families had to pay the cement (100kg), the bricks (25 usual and 8 cement ones), the cow dung (100kg) and the excavation of a pit of 180cm. Then, BIOTECH employees (two masons and two helpers) came and usually constructed the plant in 6 hours. One additional week was necessary to make the cement harder. Afterwards, cow dung was put into the digester and after about three days, families could start putting in food waste and get biogas. The families got in advance subsidies from the central government, the Kerala government and the Kumbalanghi Panchayat and after completing the installation, the plant was checked by a central government employee.

2.3. Anaerobic co-digestion

The anaerobic co-digestion is the simultaneous treatment of more than one substrate in the same digester. According to Mata-Alvarez (2003), the mixing of several wastes types has positive effects on the anaerobic digestion process because it improves the methane yield, improves the process stability and achieves a better handling of the waste. In addition, such a system is economically more favourable as it combines different waste streams in one common treatment facility.

In the case of the co-digestion of food waste and toilet waste, the low C:N ratio and biodegradability content of the toilet waste are compensated by the high values characterizing those two parameters for the food waste. Thus, the major problem of ammonia toxicity due to low C:N ratio is avoid and the low biogas yield due to the small content of biodegradable matter is increased. At the opposite, the high content of macro and micronutrients of toilet waste compensate the relatively low content of those ones in the food waste. The so obtained effluent is a rich source of inorganic plants nutrients.

Nevertheless, as soon as faeces are used as fertilizer, the health risk has to be considered. Indeed, as shown in Table 7, the number of most pathogens in faeces is higher than the median infective dose (Feachem & al, 1983). If pathogens are not sufficiently inactivated during the AD process, an improper use of the fertilizer can lead to infection of the families.

Table 7: Number of pathogens per gram of faeces and the median infective dose (Feachem & al, 1983).

Pathogen		Average number of organisms per gram of faeces	Median infective dose (ID_{50})
Bacteria	Pathogenic E. Coli	10^8	$>10^6$
	Salmonella spp.	10^6	$>10^6$
	Vibrio cholerae	10^6	$>10^6$
Viruses	Enterovirus	10^6	$<10^2$
Protozoa	Entamoeba histloytica	$1.5*10^5$	$<10^2$
Helminths	Ascaris lumbricoides	10^4	$<10^2$
	Hoockworms	800	$<10^2$
	Schistosomia mansoni	40	$<10^2$
	Taenia saginata	10^4	$<10^2$
	Trichuris trichiura	$2*10^3$	$<10^2$

3. Methods

The study is divided into two main sections:

3.1. Monitoring part which focuses on:
- Technical performance (treatment efficiency, gas production and composition)
- Quality of effluent and its suitability as organic fertilizer

3.2. Survey part which gives qualitative data on:
- Economic feasibility of the system
- Social acceptance by the user

3.1. Monitoring part

In order to assess the performance of the BIOTECH biogas systems, two plants were selected (Figure 13). Both of them are designed to be linked to latrines and have the characteristics as described in chapter 2.2.3. However, one plant is currently not connected to the toilet. This enables to compare the performance of a plant for food waste only (plant 1) with the one of a toilet linked biogas plant (plant 2).

Figure 13: On the left: (A) Plant 1. On the right: (B) plant 2. The two 2m^3 water jacket plants selected for the monitoring. Both have inlets for the food waste (FW) and the toilet waste (TW) and an outlet for the effluent (E). However, no toilets are connected to plant 1and thus only food waste is fed.

During the first two weeks, discussions with the two families were done in order to have a first idea of how they operate the plants and to explain them the goals of the study. Then, these two plants were monitored and evaluated during 8 weeks (03.01.2010 – 27.02.2010) regarding the following aspects:

- Analysis of feedstock
- Analysis of effluent
- Measurement of gas production
- Measurement of gas composition

3.1.1. Amount and composition of feedstock - Sampling of feedstock and effluent

Food waste


Figure 14: Sorting out of the waste done by the families.

The two families were asked to daily collect their kitchen waste in buckets by separating the solid food waste from the organic waste water (waste water that originates in the kitchen). The different kinds of organic waste water were collected in separate buckets (Figure 14).
Five days per week the solid food items were sorted out and weighted with a kitchen scale (TEFAL, max. 5kg, acc. 1g), whereas the volumes of the different organic waste waters were measured with a graduated container. On sampling days, 10% of every item was collected and packaged in one box.
On the two remaining days, the families were asked to write down the estimated quantities of what they put into the plant. Those estimations have not been taken into account in the calculations but enabled to estimate if the families fed a non usual item or a non usual quantity of waste.
The days after sampling, at the BIOTECH office, the feedstock samples were mixed with a kitchen blender (Vijay®) for about 30 minutes and homogenised. Portions of it were brought to the “Cochin University of Science and Technology” to carry out the analysis of Total Solids and Volatile Solids.

Toilet waste


Figure 16: Collection of the black water.


Figure 15: Toilet connected to plant 2 with a 4L toilet flush.

The family owning the toilet linked biogas plant was asked to note down the number of times they used the latrines. After each use, the person ticked on a table if he/she urinated, defecated or urinate and defecate as well as if he/she used the 4L toilet flush or not (Figure 15). Once a week, over a period of 24 hours, the family collected the black water (urine, faeces and flushing water) by connecting a pipe to the toilet outlet and using a 10L bucket (Figure 16). The whole daily black water was kept in an 80L bucket and mixed energetically with a stick before taking a sample of 500ml. In addition, two samples were taken using sterile tubes of 15ml in order to carry out the pathogen measurements.

Effluent

Five days per week, the effluent was collected while the feedstock was poured into the plant. In order to check if pH and temperature (measured on site) are identical at different heights within the plant, three effluent samples were taken one after the other. On sampling days, 300ml of the three parts of effluent was collected and packaged in one box.
In addition, for the plant 2, two to three effluent samples were taken using sterile tubes of 15ml in order to carry out the pathogen measurements.

3.1.2. Measurement of chemical and bacteriological parameters

The explanation, the relevance (aim), the measuring method and the measuring frequency of each studied parameter on the food waste (FW), the toilet waste (TW) and the effluent (E) are given in the Table 8 (DEUBLEIN & STEINHAUSER 2008, LOHRI 2009, WHO 2006). Detailed methods for the parameters marked with asterisk (*) are given in Appendix B.

Table 8: Explanation, relevance, measuring method and frequencies of each studied parameter on the food waste (FW), the toilet waste (TW) and the effluent (E).

Parameter	Explanation & *Relevance (aims)*	Frequency		Method/Apparatus	
On site					
pH	Intensity of acidic or basic character at a given temperature. -> *to determine the feedstock influence on the acidity/basicity. The optimal pH-range for a good bacterial activity is 6.5 - 7.5.*	E	5x / week	Eco10pH (*Hach-Lange*)	
Temperature	Kinetic energy of atoms or molecules -> *to determine the feedstock influence on the temperature. The optimal range for a good bacterial activity is 32- 42°C.*	E	5x / week	Eco10pH (*Hach-Lange*)	
Cochin University					
Total Solids (TS)*	Estimation of all the organic and inorganic solid matter -> *to characterize the FW and the E and describe the waste reduction.*	FW	2x / week	Oven (*Kemi*) Scales	
		E	2x / week		
Volatile Solids (VS)*	Approximation of the organic fraction of the dry matter -> *to characterize the FW and the E and describe the reduction of organic load.*	FW	2x / week	Muffle-Furnace (*Wheel engineering Works*) Scales	
		E	2x / week		
Biotech office					
After dilution to the measurement ranges					
COD_{total}	Amount of oxygen required to oxidise all the organic and inorganic matter -> *to characterize the FW and the E and describe the reduction of organic load.*	FW	2x / week	LCK 014&114 *(Lange)*	Thermoblock Nanocolor Vario Compact *(Macherey -Nagel)* LASA20 (*Hach-Lange*)
		TW	1x / week		
		E	2x / week		
N_{total}	Amount of nitrogen -> *to evaluate its availability in the FS (needed by the anaerobic bacteria) and the E (essential nutrient for organism growth).*	FW	2x / week	LCK 338 *(Lange)*	
		TW	1x / week		
		E	2x / week		
P_{total}	Amount of phosphorus > *to evaluate its availability in the FS (needed by the anaerobic bacteria) and the E (essential nutrient for organism growth).*	FW	2x / week	LCK 350 *(Lange)*	
		TW	1x / week		
		E	2x / week		
K_{tot}	Amount of phosphate -> *to evaluate its availability in the E (essential nutrient for organism growth).*	E	1x / week	LCK 328 *(Lange)* LASA20 *(Hach-L)*	
E. Coli / Coliforms	Concentration of the pathogens -> *to determine if the pathogens removal is sufficient to use the effluent for irrigation (<10^5 CFU of E. Coli in 100ml of effluent)*	TW	1x / week	Petrifilm *(3M)*	
		E2	2x / week		
After filtration (paper filter) and dilution to the measurement ranges					
$COD_{dissolved}$	Amount of oxygen required to oxidise the dissolved organic and inorganic matter -> *to describe the amount of quickly digestible feedstock and its influence on the plant activity and the effluent.*	FW	1x / week	LCK114 *(Lange)* Thermoblock *(Macherey-Nagel)* LASA20 *(Hach-L)*	
		TW	1x / week		
		E	1x / week		
After filtration (textile) and dilution to the measurement ranges					
NH_4-H	Amount of ammonium - nitrogen -> *to describe the increase of NH_4^+ released by the anaerobic digestion of N-compounds.*	FW	1x / week	LCK 302 *(Lange)* LASA20 *(Hach-L)*	
		TW	1x / week		
		E	2x / week		
After filtration (textile)					
VFA*	Amount of volatile fatty acids (carbon chain of 6 carbons or fewer) produced in the first stage of the process -> *to determine the feedstock influence on the VFA production by knowing that the inhibiting concentration is 3000 mg/l.*	E	2x / week	Kapp titration	
A/TIC ratio*	Amount of acids (A) compared to Total Inorganic Carbon (TIC) -> *to get process stability information for the digester.*	E	2x / week	Kapp titration	

Because of the high content of suspended particles in the samples, the micro filtration could not be carried out before the NH_4-H, VFA and A/TIC ratio measurements. Only a rough filtration was done. Thus, we must be aware that the NH_4-H values can slightly differ from the real ones because of the turbidity whereas the VFA measurement will be a bit higher than the real one. Nevertheless, the values obtained for the NH_4-H enabled to get a good approximation of the ions proportion in comparison with the total nitrogen. The A/TIC ratio gives good information about the stability of an anaerobic digester even in using only a rough filtration (LOHRI 2009).

3.1.3. Measurement of gas production

The daily gas production of the two plants was measured by using two gas meters (Erdgas Zürich AG, Q_{min} = 0.04m^3/h, Q_{max} = 6m^3/h, P_{max} = 0.5 bar). In both cases, the meter was installed as close as possible to the plant (Figure 17). The tube connecting the gasholder to the meter inlet was fixed to a tree (A) to enable a free movement of the gasholder. The tube connecting the meter outlet to the stove was fitted with a "three ways" to carry out the gas composition measurements (B). Thus, all the gas used (cooking and measurements) was counted by the meter.

In the evening, when the families had finished cooking (about 10pm), the gas holder was completely emptied. The value given by the meter was written down in order to obtain the daily production by subtracting this value by the one of the day before. For plant 1, the author of the report could be on site five days per week. So, twice a week the average of the daily gas production was done using the production of two days. For the plant 2, a member of the family was asked to do this task every day.

Figure 17: Connected gas meter. The fixation (A) enables the gasholder to move freely. The "three ways" installed at the point B enables to carry out CO_2 measurements.

3.1.4. Measurement of gas composition

Five times per week the CO_2 content was measured using a BRIGON CO_2-Indicator. The probe could be completely inserted into the tube through the "three ways" (Figure 18). Its proximity with the plant enabled to avoid the presence of external air as much as possible. All connections were made tight by using PTFE tape.

Figure 18: "Three ways installed to carry out the CO2 measurements.

3.2. Survey part

To gain information on the economic feasibility and the social acceptance of the toilet linked biogas plants, face to face interviews were completed with 17 plant owners (Figure 19A and Figure 19B). In order to have a point of comparison, interviews were also carried out with 10 households owning an "ordinary" (kitchen waste) plant (Figure 19C). The questionnaire is given in Appendix C.

The economic feasibility is assed according to the following aspects:

- Investment costs (purchasing price of plants, subsidies, amount paid by the customer)
- Operation and maintenance costs (broken pieces)
- Savings (substitution of cooking energy, reduction of waste management fees, substitution of former fertilizer)

For the price of the plants and the subsidies offered to the families, data obtained from personal communications with the director is used in addition.

The social acceptance is evaluated according to:

- General opinion of the users
- Self-restraints to use biogas produced from toilet waste
- Convenience of cooking with biogas compared to the former cooking fuel
- Effective use of the plant and application of the given instruction for its proper functioning

Figure 19: On the left (a): Face to face interviews. In the middle (b): 2m^{3}toilet linked biogas plant. On the right(c): 1m^{3}ordinary biogas plant.

4. Results

4.1. Technical performance and quality of effluent

The results obtained during the monitoring period are presented below. Despite the period preceding the monitoring, during which the feeding habits of the families were tried to be understood as well as possible, a few "unexpected" feedings were done during the first two monitoring weeks. These observations will be mentioned in the following, however, only the data of the last 6 weeks (17.01.2010 – 27.02.2010) were used for the analysis.

4.1.1. Characterization of the feedstock

Firstly, the feeding habits as well as the amount and composition of the feedstock are described for both plants. Secondly, their chemical characteristics are presented.

Feedstock amount and composition of plant 1

The feedstock of plant 1 comes from the family owning the plant (4 adults & 2 children) and the neighbour family (2 adults and 2 children). They collect their kitchen wastes (food waste and organic waste water) during a 24h period. Everyday, at about 17 p.m., the lady of the owning family fetches the buckets, feeds the plant and uses a stick to push all the content into the digester.
In addition, the man of the owning family sells chicken on Sundays. Thus, important quantities of slaughter chicken waste (legs, heads, stomachs and blood) are fed on those days.[11] As shown in Figure 22, the solid part of the feedstock is very different on "usual" days when it consists of about 2kg of kitchen waste (Figure 20) and on "chicken" days when about 6.7kg of chicken waste is added (Figure 21).

Figure 20: Typical feedstock of plant 1 on «usual» days.

Figure 21: Important quantities of chicken waste (legs, heads, stomachs and blood) fed on Sundays and celebration days.

[11] Chicken waste was also fed on Saturdays during the first two weeks (03.01.10 – 16.01.10) and no sampling could be done on those days.

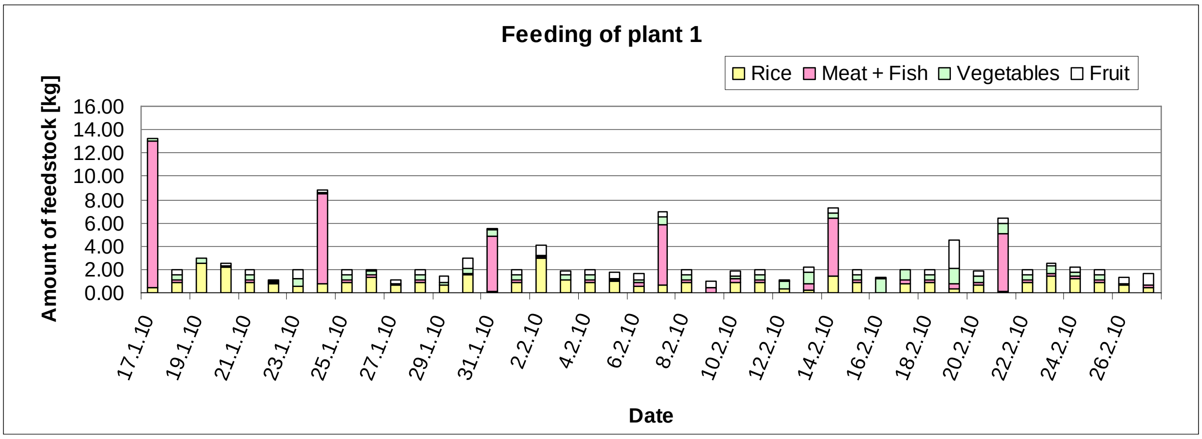


Figure 22: Amount and composition of feedstock per day (the 17.1.10 being a Sunday). For the two days per week during which the waste could not be weighed, an average of the sampling days (without chicken) was taken to construct the histogram.

Keeping in mind that the feedstock is very different once a week, the daily average amount of feedstock and its composition are given in Figure 23:

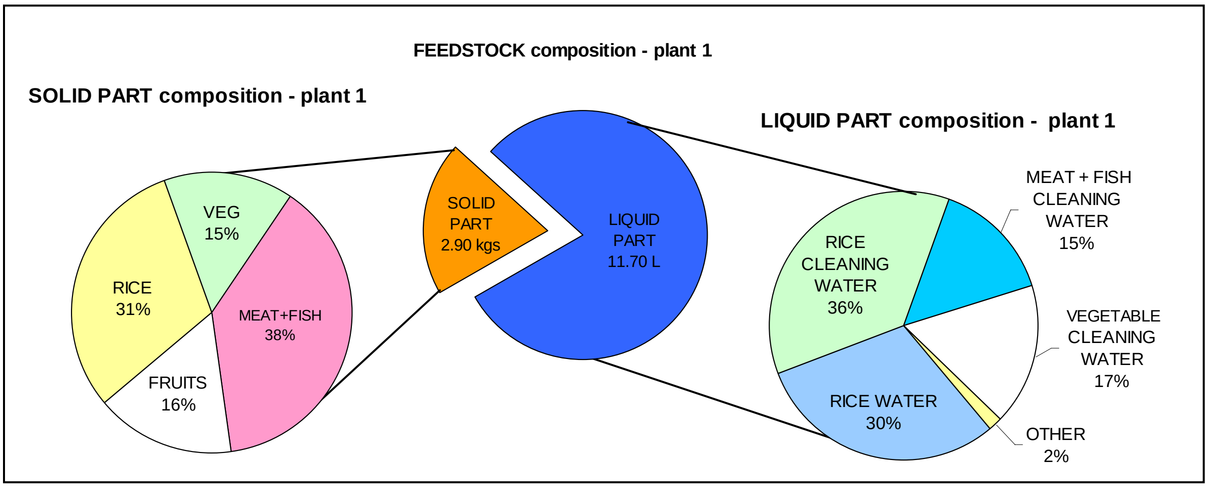


Figure 23: Feedstock composition of plant 1. The central pie chart gives the daily average amount of solid and liquid food waste of plant 1. The external pie charts give their composition.

Thus, the feedstock consists of an important part of organic waste waters (about 82% of the volume). The order from the richest to the poorest water in organic matter is probably the following one (the pragmatic reason is given in brackets):

1) Meat and fish cleaning water (presence of blood)
2) Rice cooking water (a thick layer of solid matter forms after decantation)
3) Rice cleaning water (a thin layer of solid matter floats)
4) Vegetable cleaning water (a few pieces of vegetable)

Regarding the solid parts, let's notice that the "rice" fraction is food leftovers whereas the main parts of the vegetable and fruit waste are the peels and other non edible parts (roots and tough parts).

Feedstock amount and composition of plant 2

Besides feeding the toilet linked plant with excreta, the owning family (2 adults & 2 young adults) adds its kitchen wastes (food waste and organic waste water) as well as rice leftovers and rice water from three other families.
The owning family collects their kitchen wastes during a 24h period. During the afternoon, three other families bring their kitchen waste, most of the time rice and rice water, which are considered by the family as good substrates to produce gas. Every day, at about 18:30 p.m., the kitchen waste is poured into the plant and a stick is used to push all the content in the digester. As shown in Figure 24, even if the amount of food waste varies, there are no special feedings as observed in plant 1.[12]

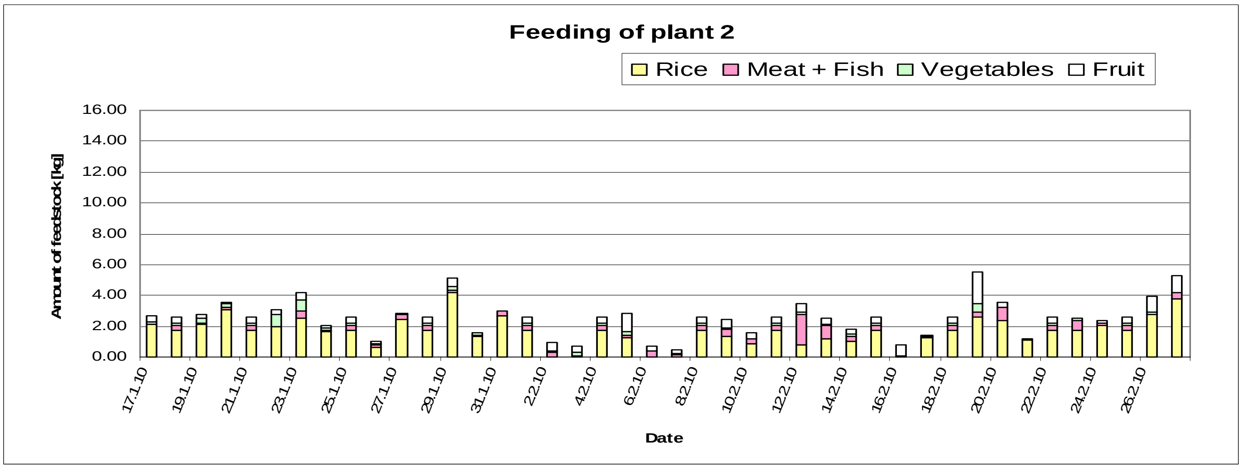


Figure 24: Amount and composition of feedstock per day. For the two days during which the waste could not be weighed, an average of the sampling days was taken to construct that histogram.

Regarding the toilet waste, the latrines are used on average 3.9 times per day to defecate and 5.7 times per day to urinate. These relatively low values for urination can be explained by three main reasons. Firstly, on working days, the latrines are only used in the morning and in the evening by the father and the children who are at work and at school during the day. Secondly, the family also has a second sanitation unit which is not connected to the biogas plant, but pours out directly into the backwaters. It was made to only take shower but when they are in a hurry and the toilet is occupied, they also use them as a latrine. Finally, the men don't always use the latrines to urinate.

In order to calculate the daily average amount of feedstock, estimation of the amount of faeces and urine has been done using the data from literature (FEACHEM, 1983, NIWAGABA 2009, SCHOUW, 2001). In view of the 3.9 defecations reported by the family of four (see above), it was assumed that each person defecates once a day and that they use almost always their latrine at home So, the daily average amount of faeces produced per adult in the rural area of a developing country (350g) can be multiplied by the number of family members (4) to obtain an average value of 1.4 kg faeces per day.
For the urine, estimation is more difficult as the number of urination varies a lot among the people and as it wasn't possible to know how many times the family members urinate outside. Knowing that most adults produce between 1.0 and 1.3 kg of urine per day and urinate about 4 times a day, a value of 300g per urination has been chosen and multiplied by the 5.7 times the latrines are used to urinate. So, the average value of 1.71 kg urine per day is obtained.

[12] During the first week of monitoring (03.01.10 – 10.01.10), the family fed two times 5-10kg of cow dung but no sampling could be done.

The daily average amount of feedstock and its composition are given in Figure 25:

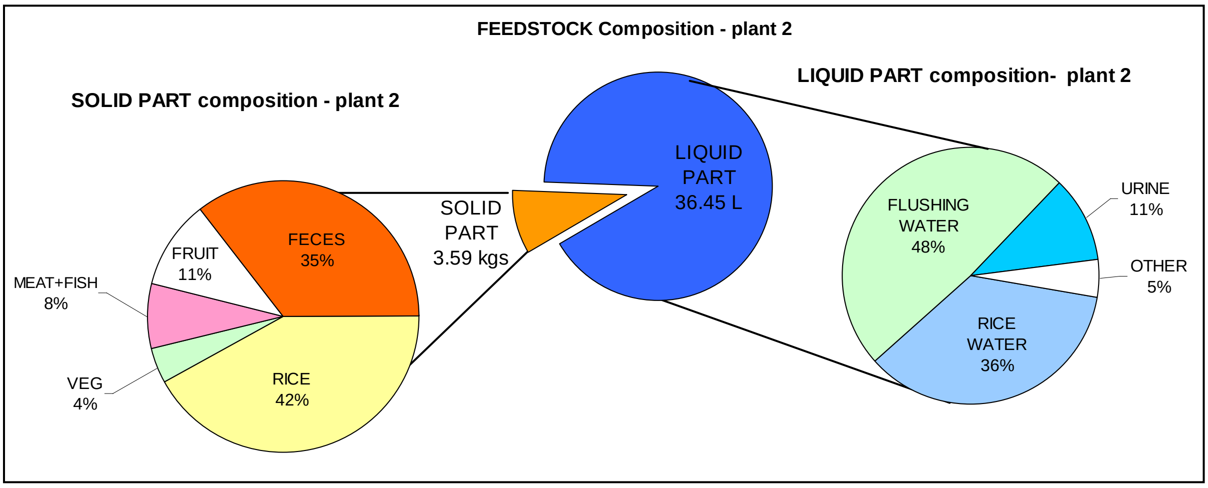


Figure 25: Feedstock composition of plant 2. The central pie chart gives the daily average amount of solid and liquid food waste of plant 2. The external pie charts give their composition.

Thus, because of the flushing water, the feedstock of plant 2 is composed of an important part of waste water (about 91% of the total volume). The flushing water constituted more than the half of that water. Because of that high quantity of flushing water, the family adds almost only rice water as organic waste water in order to not reduce the retention time too much.
Besides the faeces, the rice leftovers constituted the main part of the solid waste. Similar to plant 1, the fruit and vegetable wastes mainly consists of the peels and the non edible parts. In addition, this family has almost daily fish waste, mainly consisting of heads.

Chemical characteristics

As the chemical characteristics for kitchen waste, chicken waste and toilet waste can differ considerably, the different feedstocks were analysed separately. The detailed feedstock composition for both plants is given above (Figure 23 and Figure 25).

In Table 9 and Table **10**, the chemical characteristics of the feedstock are given for plant 1 and plant 2. The calculations were done based on the daily loads (that is, by multiplying the concentration obtained on a sampling day by the flow rate of the same day). Finally, the average of all sampling days was taken. The results are shown separately for the different feedstocks and were combined to get the characteristics of the effective feedstock.

Plant 1

Parameters characterizing the feedstock of plant 1 are given in Table 9.

Table 9: Characteristics of the feedstock. The days with chicken and the usual days have been combined by using the load of the different parameters X and doing: $kgX_{feedstock}/day = (1*kgX_{chicken}/day + 6*kgX_{usual}/day)/7$

	Food waste + chicken waste		Food waste only		Combined Feedstock
Parameter	n	Average value	n	Average value	Average value
1) TS [kg/day]	6	1.77	6	0.48	**0.67**
2) VS [%TS]	6	91.2	6	88.5	**88.9**
3) CODtot (gO_2/gTS)	6	1.81	6	1.42	**1.57**
4) Ntot (%TS)	6	5.7	6	2.8	**3.9**
5) Ptot (%TS)	6	0.5	6	0.4	**0.5**
6) NH4-H (%Ntot)	4	1.6	2	4.0	**2.6**
7) CODdiss (%CODtot)	2	17.0	3	30.6	**24.7**

Discussion of the parameters:

1) As the feedstock contains a lot of organic water which also contains solid matter, it wouldn't be correct to give the *TS* values in gram per kilogram of wet weight (as it is given in the literature). If, nevertheless, an approximation wants to be done by dividing the TS value of 0.67kg/days by the daily wet weight of 2.9kg, the value of 23% is obtained. The range given by MATA-ALVAREZ (2003) for TS of the organic fraction of MSW spreads from 10% (fruit and vegetable wastes) to 20-25% (kitchen waste mixed with garden waste). So, the measured value is relatively high and that is probably due to two reasons. Firstly, the organic water contains a significant part of solid matter (which is not taken into account in the wet weight). Secondly, the percentage of TS contained in the chicken waste is important. Indeed, SALMINEN & RINTALA (2002) found a value of 39% for the chicken offal, feet, and head.

2) The *VS* percentage is in accordance with the range of 85-90% given for organic fraction of municipal solid waste (MATA-ALVAREZ 2003).

3) The *COD* value of 1.57gO_2/gTS indicates that the feedstock has higher energy content than the OFMSW (1–1.3 gO_2/gTS) given by MATA-ALVAREZ (2003).

4) The *nitrogen content* of 3.9% is slightly higher than the literature values of about 2-3 %TS for the organic fraction of municipal solid waste (MATA-ALVAREZ 2003). However, SALMINEN & RINTALA (2002) have shown that the nitrogen content of blood chicken is 7.6%TS and the one of offal, feet, and head is 5.3%TS.

5) The *phosphorus content* of 0.5% is in the upper range of the values given in literature (0.2 to 0.5 %TS).
The COD:N:P ratio of 345:9:1 reflects a high content of nitrogen and phosphorus compared to the ratio recommended for MSW suitable for anaerobic digestion (600:7:1) (MATA-ALVAREZ 2003).

6) The percentage of nitrogen present in the form of ammonium is very low in the feedstock.

7) Compared to the samples without chicken, the dissolved COD of the samples with chicken is relatively low and means that the amount of quickly digestible matter is small.

Plant 2

The TS and VS values for toilet waste had to be taken from literature as no laboratory in Kochi was willing to analyse samples containing faeces. The literature values are given as 60-74 gTS/cap/day and 51 - 63gVS/cap/day (which corresponded to 85% of TS) (LOHRI, 2009, FEACHEM, 1983, SCHOUW & AL, 2001).
Parameters characterizing the food waste, the toilet waste and the combined feedstock (food waste + toilet waste) of the plant 2 are given in Table 10.

Table 10: Characteristics of the feedstock. The food waste and the toilet waste have been combined by using the load of the different parameters X and doing: $kgX_{feedstock}$/day = $kgX_{food\ waste}$/day + $kgX_{toilet\ waste}$/day. (*) For the toilet waste, the value ranges of TS and VS have been taken from the literature. (**) The CODtot value of the combined feedstock has been calculated in taking a literature value for the food waste (see the reason in the text).

	Food waste		Toilet waste (4 people)		Combined feedstock (FW + TW)
Parameter	**n**	**Average value**	**n**	**Average value**	**Average**
1) TS [kg/day]	12	0.732	-	*0.240 - 0.296**	**0.972 - 1.028**
2) VS [%TS]	12	90.1	-	*85** *(0.204-0.252 kgVS/day)**	**88.4 - 88.6**
3) CODtot (gCOD/gTS)	12	1.13	7	0.34 - 0.42 (0.100kgO_2/day)	***1.1*****
4) Ntot (%TS)	12	2.0	7	3.3 - 4.11 (0.010kgN/day)	**2.27 - 2.40**
5) Ptot (%TS)	12	0.3	7	0.3 - 0.4 (0.030kgP/day)	**0.31 - 0.32**
6) NH4-H (%Ntot)	5	4.7	6	30.9	**15.8**
7) CODdiss (%CODtot)	6	39.2	5	23.2	**35.8**

Initial comment on the toilet waste results:

According to WHO (2006), an Indian excretes each day about 7.4g of nitrogen and 1.1g of phosphorus. Compared to this literature values, the measured values of 10gN/day and 3gP/day in the toilet waste of 4 people are low. However, it can be explained by the fact that the family doesn't often use the toilet to urinate (1-2times/cap/day). Indeed, urine contains approximately 80-90% of the excreta nitrogen (about 6.3g/cap/day in India) and 20-50% of the excreta phosphorus (about 0.3g/cap/day in India) whereas faeces contain the rest (Niwagaba, 2009, WHO, 2006).
If we assume that a person defecates once a day and urinates four times a day, the calculated N and P contents of that toilet waste are 13gN/day and 3gP/day respectively. So, the measured values are approximately in accordance with the literature values.
The CODtot value is more than two times smaller than the TS value. Very few studies give COD values of faeces and urine. LOHRI (2009) obtained values of about 1.1mgO_2/mgTS. As the organic part of the toilet waste is about 85% of the total solid, CODtot values close to 1mgO_2/mgTS are, indeed, expected. The low measured value is most probably due to a problem of analysis. The toilet waste sample was difficult to homogenize perfectly and solid particles of faeces were probably not taken into account in the measurement. As the main part of the organic matter is contained in the faeces whereas the main part of nitrogen and phosphorus is contained in the urine, that problem of analysis is reflected mainly in the CODtot value (STRAUSS 2000). So, an estimated value of 0.240 – 0.296gO_2/day was taken to calculate the CODtot value of the combined feedstock. For the other parameters, the

contribution of the faeces being very small, the measured parameters were used to calculate the combined feedstock in keeping in mind that they could slightly differ from the real ones.

Discussion of the parameters:

1) It is interesting to notice that, in this particular co-digestion plant, a bit less than 3/4 of the dried matter comes from the food waste and a bit more than ¼ from the toilet waste. The optimal mixture between these two feedstocks couldn't be found in the literature. However, according to MATA-ALVAREZ (2003), the optimal ratio of OFMSW to sewage sludge in terms of specific gas production and VS reduction is 80:20 on a TS basis.

2) The rather low percentage of organic matter in the toilet waste is compensated by a high proportion in the food waste. Thus, the feedstock has a VS value which is comparable to the one of plant 1 and to the value given in literature (85-90%) for OFMSW (MATA-ALVAREZ, 2003).

3) The *COD* value of 1.13gO_2/gTS for food waste is in the range of 1–1.3 gO_2/gTS found in literature for OFMSW. As the toilet waste contains less organic matter, the COD value of the combined feedstock is a bit lower (1.1 gO_2/gTS), but still in the range.

4) The *nitrogen content* of 2% in the food waste is in accordance with the literature values of 2-3 %TS for the OFMSW (Mata-Alvarez 2003). The nitrogen content of the combined feedstock (2.27 – 2.40%TS) is slightly higher as urine is rich in nitrogen.

5) The *phosphorus content* of 0.3% in the food waste is in the range of 0.2 to 0.5 %TS given in literature for OFMSW (Mata-Alvarez 2003). It increases slightly in combination with toilet waste to 0.31-0.32%TS.
The values for COD_{tot}, N_{tot} and P_{tot} in the feedstock of plant 2 are lower than in plant 1 due to the chicken waste input in the latter. However, similar to plant 2, the ratio of COD:N:P of 287:7:1 in plant 2 reflects a high content of nitrogen and phosphorus compared to the ratio recommended for MSW suitable for anaerobic digestion (600:7:1).

6) The percentage of ammonium is higher in the feedstock of plant 2 compared to the one of plant 1 because urine contains high percentage of ammoniacal nitrogen.

7) The percentage of COD_{diss} shows that an important part of direct digestible matter is present in the feedstock.

4.1.2. Operational parameters

On site, three effluent samples were taken consecutively on each sampling day. The average values for pH and temperature are given in Table 11.

Table 11: pH and temperature of the effluent of plant 1 and 2, in both cases collected in three times.

	Effluent sample	Plant 1		Plant 2	
		Average value	Standard deviation	Average value	Standard deviation
pH	1st	7.50	0.05	6.98	1.0
	2nd	7.43	0.06	6.95	1.1
	3rd	**7.38**	**0.04**	**6.91**	**1.0**
Temperature [°C]	1st	29.8	0.14	29.7	1.3
	2nd	28.1	0.09	29.4	1.3
	3rd	**27.5**	**0.09**	**29.1**	**1.0**

For both plants, the first samples show higher temperature and pH values than the second one, which, again, was higher than the third one. This is explained by the fact that the effluent from the first sample was stored in the external part of the outlet pipe, which was heated through the outside air temperature. Furthermore, when the effluent is in contact with the air, the carbon dioxide can escape what leads to an increase of the pH. Therefore, the third effluent sample has the closest characteristics to the slurry inside the plant. These values are used for the comparison with literature data. Whereas both plants have pH values which are in the optimal range of 6.5 – 7.5, the temperature values are slightly lower than the optimal range of 32 – 42°C (DEUBLEIN & STEINHAUSER 2008). Let's notice that those values were very constant during the whole monitoring period.

Due to the flushing water, the flow rate of plant 2 (0.0400m^3) is much higher than the one of plant 1 (0.0146 m^3) (Table 12). Consequently, its hydraulic retention time is lower, namely 37 days for plant 2 compared to 100 days for plant 1. Still, the flow rate of plant 2 is lower than the maximal load for which the plant was designed (25-40 L of waste water and 4-5 kg of wet weight). The retention time is bigger than the 14 – 30 days given by Mata-Alvarez (2003) for plants treating OFMSW.
In comparison with the recommend OLR values of 1-4kgVS/m^3 given by that same author for OFMSW, the OLR for plant 1 and 2 of 0.41 and 0.58 respectively are very low. The main reason is probably the high quantity of water fed into those plants. The consequences of these OLR and HRT values regarding the treatment efficiency and the gas production will be discussed in the following chapters.

Table 12: Substrate flow rate, Hydraulic Retention Time and Organic Load Rate of plant 1 and 2.

	Plant 1	Plant 2
	Average value	Average value
Substrate flow rate [m^3/day]	0.0146	0.0400
HRT [days]	100	37
OLR [kgVS/m^{3}digester day]	0.41	0.58

Table 13 gives the concentration of volatile fatty acids in the effluent as well as the A/TIC ratio.

Table 13: Volatile fatty acids and A/TIC ratio of plant 1 and 2.

	Plant 1		Plant 2	
	Average value	Standard deviation	Average value	Standard deviation
VFA [mg/L]	657	234	82	50
A/TIC ratio	0.094	0.033	0.031	0.018

The concentration of volatile fatty acids of plant 1 is in the range given in literature of 200-2000mgVFA/L for anaerobic digesters (Mata-Alvarez, 2003). Despite the inconstant feeding the A/TIC ratio was constant and indicates high process stability.
Because of the high dilution due to the flush water, the VFA concentration of plant 2 is very low. As three measurements had even to be considered as "nil" (under 20mg/L), it would not be correct to say that the process stability is high but in any case there are not important variations.

4.1.3. Quality of the effluent

The two plants have a very watery effluent. The one of plant 1 has a dark brown colour whereas the one of plant 2 is light brown (Figure 26).

The values of the different parameters which characterize the effluent are given in Table 14. The reduction of TS, VS and CODtot compared to the feedstock are discussed in the following chapter. The fact that more solid matter goes out of plant 2 while its effluent is lighter is explained by the high flow rate of plant 2.

Figure 26: Effluent of plant 1 (on the left) and plant 2 (on the right).

Table 14: Characteristics of the effluent.

Parameter	Plant 1		Plant 2	
	n	Average value	n	Average value
1) TS [kg/day]	12	0.10	12	0.19
2) VS [%TS]	12	64.7	12	63.4
3) CODtot [mgO_2/l]	12	6211	12	3785
4) Ntot [mgN/l]	12	2222	12	871
5) Ptot [mgP/l]	12	78	12	61
6) Ktot [mgK/l]	7	2535	7	766
7) NH4-N [mg/L]	11	1406	10	420
NH4-N [%Ntot]	11	63.0	10	48.1
8) CODdiss [%CODtot]	6	21.5	6	11.7

Nutrients contents

As mentioned by LOHRI (2009), the quality of the effluent as a fertilizer can be evaluated only to a certain point as its suitability depends on the kind of plants it is applied. In order to have a rough idea of what represent the N, P, K quantities present in the slurry, a comparison can be done, as proposed by DRANGERT (1998), with the nutrients needed for 250kg of cereals which according to him can be the amount of cereals eaten by one person in one year (Table 15).

Table 15: Yearly amount of nitrogen, phosphorus and potassium going out of the plants and the nutrients needed for 250kg of cereals.

Parameter	Plant 1	Plant 2	nutrients needed for 250kg of cereals
Ntot [kg/year]	12.7	11.8	5.6
Ptot [kg/year]	0.4	0.8	0.7
Ktot [kg/year]	11.0	10.3	1.2

Even if that comparison is of limited validity, we can see that the amount of nitrogen and potassium would be more than sufficient to produce 250kg of cereals. On the other hand, the quantity of phosphorus in the effluent of plant 1 would not be high enough, and the one of plant 2 just sufficient for the 250kg of cereals.

Comparison with quality standards for compost, manure and nutrient solutions can also be done only up to a certain point. A complete nutrient solution for vegetables has a N:P:K ratio of 2:1:4 whereas the effluents have ratios of 28:1:33 (plant 1) and 14:1:13 (plant 2). So, it can only be said that both effluents seem to have very low phosphorus and relatively low potassium contents compared to the nitrogen content. In addition, the trace elements Fe, Ca, Mg and Zn must also be known as they are essential for plants grow.

Figure 27 shows the nitrogen and phosphorous content in the feedstock and effluent for the two plants. Although a small fraction of the nitrogen is lost in form of NH_3 and N_2 in the biogas, most of it leaves the plant through the effluent. In the case of phosphorus, all of it is found in the effluent. In equilibrium state where no accumulation of organic matter occurs inside the plant, the input and output fluxes of these two nutrients should be the same. For the monitored plants, the error bars (standard deviation) overlap and the two plants seem to be close to that equilibrium.

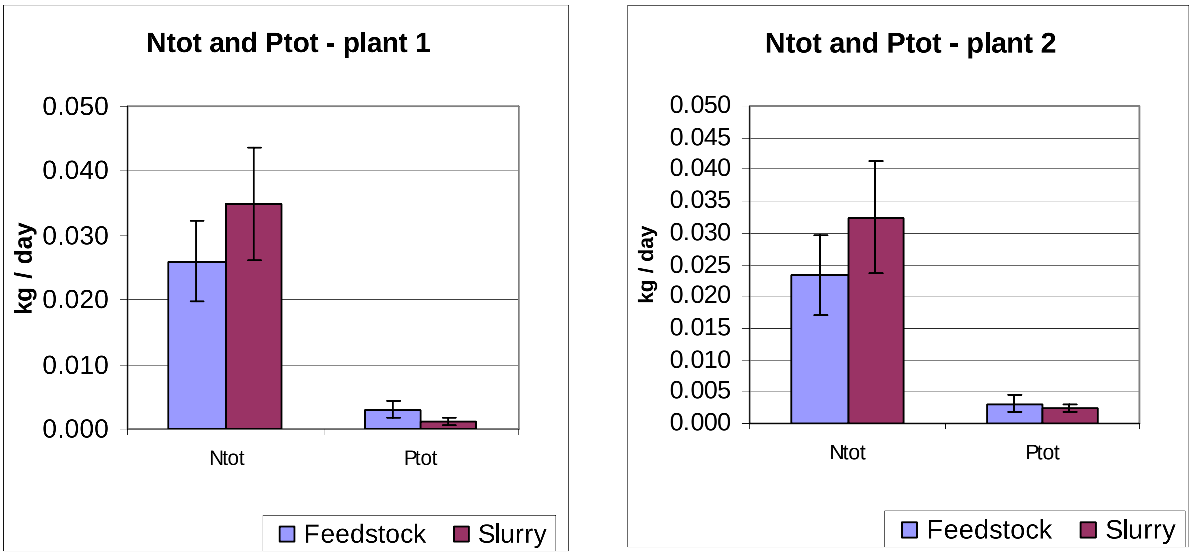


Figure 27: Nitrogen and phosphorus content in feedstock and effluent, on the left (A), for the plant 1 and, on the right (B), for the plant 2.

The nitrogen in the effluent is to a high extent found in form of ammonium (NH_4), namely 63% and 48.1%. In comparison, the NH_4 content in the feedstock was only 2.6% and 15.8%. That means that the anaerobic conditions lead to an increase of ammonium and therefore to a better quality of the effluent as a fertilizer.
According to CHEN & AL (2007), a certain Total Ammonia Nitrogen concentration (=TAN, that is, mostly ammonium ion and free ammonia) causes a 50% reduction in methane production. However, the values vary widely from 1700 to 14000mg/L. As the pH of the two plants is close to 7, it can be assumed that the biggest part of TAN is in its ammonium form. Thus, the measured ammonium values of 1406 and 420mgN/L are below literature values and the inhibition can be considered as low.

Let's underline that the CODtot and Ntot values in the effluent exceed by far the Indian environmental standards of 250mg/L and 100mg/L respectively for discharge of environmental pollutants (MINISTRY OF ENVIRONMENT & FORESTS). Consequently, the effluent should not be discharged into the backwaters without a further treatment as it is done by several families (see chapter 4.3.2.).

Pathogen content

Table 16 gives the concentrations of E.Coli and total Coliforms counted in the feedstock and the effluent of the plant 2. For the feedstock, the counting was done on the toilet waste and the dilution by the food waste was taken into account.

Table 16: Pathogen contents and inactivation in the effluent of plant 2.

	Average value in feedstock	Average value in effluent	Pathogen inactivation
Total Coliforms [CFU/100ml]	1.7*10^8	3*10^6	2.6
E Coli [CFU/100ml]	1.5*10^8	4*10^5	1.75

The E. Coli and total Coliforms inactivation during the anaerobic process are higher compared to literature values of 0.35 for total Coliforms and 1.51 ± 0.6 for E. Coli (SIDHU & TOZE, 2008).
The WHO-guidelines for "safe use of wastewater, excreta and greywater" recommend the use of waste water for restricted irrigation (i.e. for crops that are not eaten raw) if the effluent contains less that 10^5 Colony Forming Units (CFU) of E.Coli in 100ml. It could be relaxed to 10^6 when the exposure is limited. Thus, in the case our toilet linked plant, it is very important that the effluent is applied only on plant roots and never spread directly on the vegetables.
In order to check if the effluent of other toilet linked biogas plants on Kumbalanghi have similar concentration of pathogens, E.Coli were also counted in effluent samples of six other toilet linked plants. Five of them also had an E. Coli concentration in the range of 10^5 - 10^6 CFU/100ml.
Let's mention that the WHO-guidelines also stipulate that less than 1 helminth egg has to be found in one litre of effluent to use it safely. Unfortunately, analysis of helminth eggs couldn't be carried out in this study.

4.1.4. Evaluation of the treatment efficiency

The waste reduction can be expressed as the difference between the total solids content of feedstock and effluent. The reduction of organic load can be expresses as the reduction in VS or COD_{tot} between feedstock and effluent. Figure 28 and Figure 29 show those reductions calculated based on the average daily load.

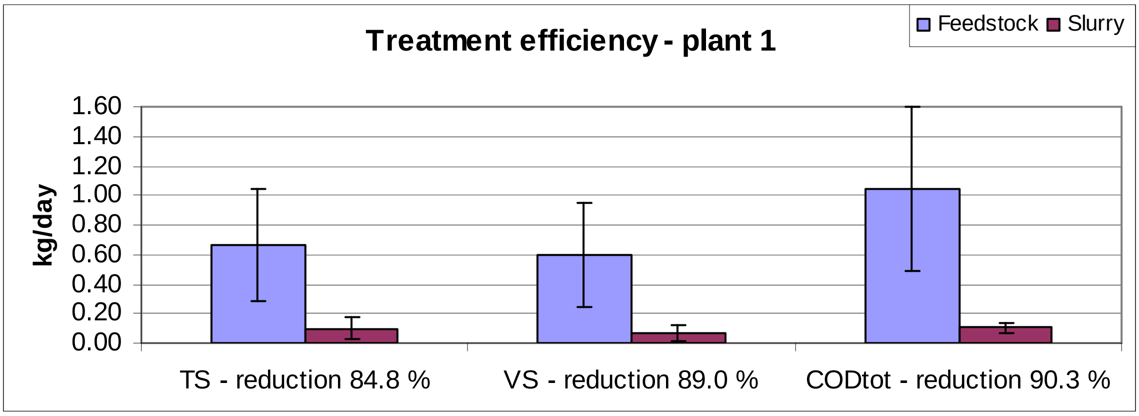


Figure 28: Treatment efficiency of plant 1.

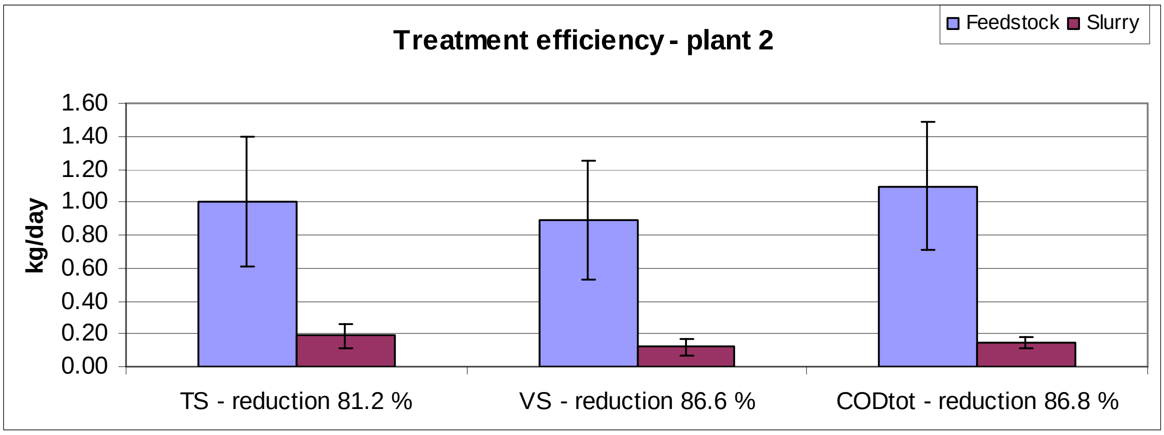


Figure 29: Treatment efficiency of plant 2.

The waste and organic load reductions of both plants are similar and show a high treatment efficiency. Thus, the fact that plant 2 has a hydraulic retention time almost three times lower than plant 1 doesn't seem to influence the treatment efficiency.

4.1.5. Gas production, composition and use

Gas production

Table 17 shows the gas yields for the two plants. As the gas pressure couldn't be measured, the results are not transformed into norm conditions. Thus, we must be aware that the values are slightly higher than the reality.

Table 17: Gas yield of plant 1 and 2.

	Plant 1	Plant 2
	Average value	Average value
Daily gas production [m^3/day]	0.684	0.690
GPR [m^3/m^3digester day]	0.47	0.47
SGP [m^3/kgVS day]	1.15	0.81

In both plants, the specific gas production (SGP) is very high. Regarding the slaughter chicken waste fed to plant 1, SALMINEN & RINTALA (2002) showed that offal, feet and heads of chicken have very high SGP in a range of 0.7–0.9g m3/kg VS. In addition, according to DEUBLEIN & STEINHAUSER (2008), the SGP of cereals and food leftovers can also be very high, namely 0.4-0.9 m3/kg VS and 0.4 – 1.0 m3/kg VS respectively.

Regarding plant 2, no literature values could be found for the SGP of raw faeces and urine, but DEUBLEIN & STEINHAUSER (2008) give a range of 0.20 – 0.75 m^3/kg VS for sewage sludge from households. The high SGP in plant 2 can be explained by the added food waste and organic waste water and the relatively high amount of added fish waste.

Gas composition

As biogas consists mainly of CO_2 and CH_4, the methane content was measured indirectly by measuring the CO_2 content (Table 18). It was very constant during the whole monitoring period and the results are in the range of 35-40% given in literature (MATA-ALVAREZ, 2003).

However, small quantities of water, hydrogen sulphide, nitrogen, ammonium, oxygen and hydrogen can also be present in the biogas. That's why the CH_4 content is probably 3-5% lower than the maximum given in Table 18. Such values are comparable to CH_4 contents of 50.6 to 62.5 for OFMSW given by MATA-ALVAREZ (2003).

Table 18: Gas composition of the plant 1 and 2.

	Plant 1		Plant 2	
	Average value	Standard deviation	Average value	Standard deviation
CO_2 content [%]	35	1	39	1
Maximal CH_4 content [%]	65	1	61	1

Gas use

During the study, tests were carried out regarding the required cooking times for different Indian dishes. The results are shown in Table 19. As the amount of gas and the time required to boil water were similar for both plants, the other measurements were only carried out on one plant. The gas flow rate for both stoves was about 180 l/h in the morning. However, as the flow rate depends on the amount of gas in the gasholder, the cooking time increases when the gasholder empties and usually the families don't use the last 100 litres because the pressure gets too low.

Table 19: Average litres of biogas and time required to cook typical Indian items.

Items	Gas required [litres]	Time [min]
Boiled water		
1 litre water	30	10
3 litres water	75	25
Main part		
500g rice (3 litres water)	205	65
500g rice (3 litres water) with thermal cooker	105	35
10 rice pancakes ("appams")	70	25
2 steamed rice cakes	45	15
Accompaniment		
Dried accompaniment (500g veg.)	60	20
Liquid accompaniment (200g veg. + 300ml milk)	90	30
Fish accompaniment (100g fish + 200ml milk)	60	20

The survey (see 4.3.3) shows that on average, a family cooks about 3h 15min per day with biogas (Table 20). This corresponds to about 585L of biogas. Normally, the lunch is prepared in the morning together with the breakfast as the people take a "lunch box" to work.
With a daily gas production of 680L, a family has enough gas to cook the main dishes with biogas. It has to be mentioned that the last 100 litres can't be used because of too low gas pressure.

Table 20: Average daily gas consumption and cooking time for a typical family

Meal	Item	Gas required [L]	Time [min]
Breakfast	1 litre tea	30	10
	2 steam cakes	45	15
	1liquid accompaniment	90	30
	TOTAL	165	55
Lunch	500g rice	105	35
	1 dried accompaniment	60	20
	1 fish accompaniment	60	20
	TOTAL	225	75
Dinner	500g rice	105	35
	1 liquid accompaniment	90	30
	TOTAL	195	65

As it will be discussed in chapter 4.3.3, the families often use an additional LPG stove when they like to cook several items at the same time, but also because the cooking duration is longer with biogas than with LPG.

It could be observed that many families use a thermal cooker for rice cooking. This saves half of the biogas required for rice cooking and enables to cook other items on the stove while the rice is finished in the thermal cooker.

4.2. Economic feasibility

In this chapter, the economic feasibility of the biogas systems is evaluated. First, the investment costs, the operation and maintenance costs as well as the savings are exposed. Based on this, the amortization period for such plants is calculated and discussed. The amounts are given in Indian rupees (Rs) and in US dollars (USD) using the exchange rate of Rs45.5 = 1USD (11th May 2010).

4.2.1. Investment costs

Table 21 lists the different costs, the subsidies and finally the amount a family has to pay to acquire an ordinary 1m^3 plant or a 2m^3 toilet linked plant. As the prices and subsidies changed considerably between 2005-2006 and the year 2010, the figures are given for both periods. The increase in the plant price is due to the change in material from RCC to FRP. All information was obtained from the director of BIOTECH, except for the labour charges in 2005-2006, which were obtained in the survey.

Table 21: Charges, subsidies and final amount paid by the customers for 1m^3 ordinary and 2m^3 toilet linked plants in the years 2005-2006 and in the year 2010. (*) Average values calculated from the information obtained from the 27 visited families. The labour charges included the cement, the bricks, the cow dung and the excavation of a pit. (**) Estimates given by the director regarding the present price for the transport, the excavation of a pit and the cow dung.

		2005-2006		2010	
		Ordinary plant 1m^3	**Toilet linked plant 2m^3**	**Ordinary plant 1m^3**	**Toilet linked plant 2m^3**
Charges	Plant	9400	22700	15000	33000
	Labour charge	1300*	3400*	1000**	1000**
	Stove + pipe	included	included	1000	1000
	Latrines	-	included	-	not included
	Total [Rs]	10700	26100	17000	35000
Subsidies[13]	Kerala government (Tourism department)	5000	16000	-	-
	Central government (Ministry of New and Renewable energy)	2700	2700	4000	8000
	Kumbalanghi Panchayat	-	2000	-	-
	Total [Rs]	7700	27000	4000	8000
Paid by the customer	**Total [Rs]**	**3000**	**5400**	**12950**	**27000**
	Total [USD]	66	119	285	593

.

Information obtained by the families on their income corresponded to the information on their “ratio card”. As this card enables them to get food items at lower prices, they declare lower salaries than they really get. So, rough estimation on their incomes was done according to their occupation. Twelve families earn their living from the construction, three from slaughter shops, two from social work, one from the fishing, one from the painting, one from the furniture work, one from different small jobs and one was constituted of retired people. The

[13] Let’s notice that according to Biotech director the subsidies must be stable for the next few years. Last year there were subsidies of 3500 Rs for both plants.

incomes of all those families are about Rs3000-5000 and the investment costs for a biogas plant represents more than fives monthly wages. Regarding the other five families, they live from government occupations in two cases, from good private companies occupations in two and from an abroad occupation in the last case. Those families probably earn about 10000Rs per month (or more) and the investment costs represent about 3 monthly wages.
Thus, the purchase of a plant at the actual price represents a high investment for the families in Kumbalanghi. Probably, this restrains several families from buying a biogas plant as eight of the 27 families visited during the survey reported that they knew other families who were interested in buying a plant but could not afford the present high prices.

4.2.2. Operation and maintenance costs

The survey showed that the system is very robust.[14] To ensure the good functioning of the plant, the following simple and almost free maintenance works are regularly done by most of the 27 visited families:

- The water which accumulates in the tube connecting the gasholder to the stove is removed simply in lifting up the tube. Indeed, it enables to run the water into the gasholder or eventually make it go out through a disconnected extremity of the tube. The sixteen families which do it regularly (often once in a month) never had problems. Five of the eleven other families once had no more flame, but the problem could be solved costless by emptying completely the tube.
- The stove (especially the burner) is cleaned with a brush or textile and water or oil. That almost costless maintenance enables to remove the solid particles of carbon which block the passage of the gas. Except in one case, the stove of the visited families was working with a good flame.
- The mosquitoes, which are a problem for most families and for both kinds of plants, are killed or chased out by 21 families by using cheap and simple methods. This is done by adding a few drops of kerosene or another chemical in the rim between the gasholder and the digester (17 cases), in growing small fishes in the water jacket of the $2m^3$ plants (2 cases) or in applying a to-and-fro motion to the gasholder (2 cases).

Pieces which broke since the 27 families installed their plants 4-5 years ago are the followings:

- The stove knob (about Rs100) which broke in 5 cases.
- The piece behind the knob (about Rs70) which broke in 3 cases (changed 5-6 times in 2 cases)
- The metallic tube behind the knob (Rs125) in 1 case (changed 3 times)
- The burner (about Rs125) which was out of service in one case.
- The entire stove (Rs600) which was completely out of order in 1 case.
- The valve lever on the gasholder (unknown price) which was still broken in 3 cases at the moment of the visit (the families using a textile the rare times the wanted to turn the valve).

So, the costs for operation and maintenance are low and maintenance work relatively rare. It seems correct to say that an estimate of Rs150 per year is enough to maintain the good functioning of the plant in almost all cases, at least for the 4-5 first years.

[14] 15 out of the 27 families never had to call Biotech once the plant was installed.

4.2.3. Savings

A biogas plant enables to save money in three ways: through the substitution of the former cooking energy, the reduction of waste management fees, and the substitution of the former fertilizer. In the followings the saved amounts are exposed and discussed.

Substitution of former cooking energy

Before buying the biogas plant, 7 of the 27 families cooked with firewood, 7 with LPG and 13 families used firewood & LPG[15]. Those two fuels are, indeed, the most used in Kerala (see Annexe E). Even if none of the 27 families completely stopped to use their former fuel(s)[16], they could reduce its consumption to a great deal. In knowing the quantities of LPG or/and firewood used before and after the plant acquisition as well as the price of those fuels, the annual savings done thanks to the biogas could be calculated according to the following formula:

$$Savings[Rs/y] = LPGcylPRICE[RS] * (LPGcylBEFORE[nb/y] - LPGcylAFTER[nb/y])$$

$$+ WoodPRICE[Rs] * (WoodBEFORE[kg/y] - WoodAFTER[kg/y])$$

As families use LPG, firewood or both of them in different frequencies, the quantities and proportion of saved fuels vary quite a lot from one family to the other and not in a systematic way[17]. The calculations have been done separately for each family and the average values are given in Table 22. In the following, a few general comments are given for each parameter:

LPGcylPRICE[Rs]: The price of a LPG cylinder of 14.2kg is identical among the main companies delivering LPG in Kumbalanghi (about 330 Rs)[18]. However, as the price also depends on the transport, additional 10 – 30Rs have to be paid according to the place. An average of 350Rs per cylinder has been taken for the calculations.
LPGcylBEFORE[nb/y] *and LPGcylAFTER*[nb/y]: Irrespective of having additional firewood or not, a family saves on average 55% of LPG which represents on average 5 cylinders per year per family. This is similar for families owning a toilet linked biogas plant as well for the ones having an ordinary one.
WoodPRICE[Rs]: The families buying their firewood reported that the present price of a kilogram of firewood in Kumbanlaghi is 2.4Rs. Let's notice that 7 families do not buy their firewood but collect it in the surroundings.
WoodBEFORE[kg/y] *and Wood AFTER[*nb/y]: Irrespective of having additional LPG or not, the average quantity of saved firewood is about 500kg per year per family.

Table 22: Savings through substitution of former fuel.

	Ordinary 1m^3 plant	2m^3 toilet linked plant
Savings [Rs]	2120	1750
Savings [USD]	**46.6**	**38.5**

[15] Three families used kerosene and one family an induction cooker but they rarely used it and could not notice a difference of consumption since they got the biogas plant.
[16] Two families which used firewood and LPG before having the plant could stop to use firewood.
[17] Because she cooks more, a family with LPG and firewood save sometimes more money on the subsitution of LPG only than a family having only LPG.
[18] Net amount which is written on the bills showed by the families.

Reduction of waste management fees

None of the 27 families had to pay a fee to dispose of their organic waste before the acquisition of their plants. Indeed, the families disposed of their kitchen waste as shown in Table 23 (few families using many of them). So, in those cases of peri-urban families, the economical savings regarding the organic solid waste management is inexistent.

Table 23: Former way to dispose of kitchen waste

Former ways to dispose of kitchen waste	N° of families using this way
Dumping in the surroundings (trees, plants)	14
Dumping in the river	9
Dumping in a pit	6
Direct animal feeding	2
Composting	1
Dumping in a pond	1
In another biogas plant	1

From the 17 families owning a toilet linked biogas plant, 5 had no toilet facilities before and used to defecate and urinate into the backwaters. Twelve families had a septic tank or a system with a superposition of cement rings. As only five of those families had to pay to empty their facility before having the biogas plant (and had done it only 1-4 times), it is difficult to calculate an average value of savings. By asking also the families owning an ordinary plant about the emptying of their toilets facilities, it could be estimated that an average of Rs1000 is required to clean septic tanks or rings. A frequency of once in ten years seems to reflect the reality.
Being aware that it is only an approximation, it can be said that Rs100 (2.2USD) per year are saved regarding the fees for emptying the toilet facilities.

Substitution of former fertilizer

None of the families owning a toilet linked plant bought a fertilizer before getting the biogas plant, either because they did not need one or because they used kitchen waste or cow dung for free. Regarding the families owning an ordinary plant, only four of them used to buy a fertilizer which they could substitute by the effluent. So, very few families save money through that substitution and it is difficult and not really correct to calculate an average value of savings. Let's notice that the potential benefit the families could do in selling their effluent as a fertilizer is very important. Indeed, Biotech sells it at a price of Rs10/litre. A family owning a toilet linked biogas plant getting easily 30 litres of effluent per day[19] would get Rs300/day. A family with an ordinary plant getting about 7 litres of effluent per day would enable to earn Rs70/day. However, it is not very likely that they could sell so many litres and, as discussed in the chapter "4.3.2 Self-restraints to use toilet linked plants", the handling of the effluent is still problematic for many families.

[19] Based on the 17 visited families, the average food waste amount (included waste water) is about 8litres/day and the quantity of water per flush is about 5 litres. In assuming the families use the toilet 6-8 per day, even if the flush is not used every times, a total of 30 litres of waste should be fed by most of the families.

4.2.4. Amortization

Based on the costs and savings discussed above, the number of years required to amortize ordinary $1m^3$ plants and $2m^3$ toilet linked plants are exposed in Table 24. A comparison is done between the situation with ferro-cement plants which were installed in Kumbalanghi and the present situation with FRP plants[20].

Table 24: Amortization calculated according to the investment, the maintenance costs and the savings.

	2005-2006		**2010**	
	Ordinary $1m^3$	**Toilet linked plant $2m^3$**	**Ordinary $1m^3$**	**Toilet linked plant $2m^3$**
Costs				
Investment	3000	5400	12950	27000
Maintenance costs	150	150	150	150
Savings				
Subst. of former fuel	2120	1750	2120	1750
Red. of toilet waste management fees	-	100	-	100
Amortization				
Formula without effluent selling (x=number of years)	3000 + 150x = 2120 x	5400 + 150x = (1750+100) x	12950 + 150x = 2120 x	27000 + 150x = (1750+100) x
Amortisation period (number of years)	1.6	3.2	6.6	15.9

[20] It is assumed that the savings done through the substitution of former fuel(s) are the same in the case of FRP plants

4.3. Social acceptance by users

In this chapter, the acceptance of the toilet linked biogas plants by the users is exposed. A comparison with the feelings of ordinary plants owners enables to see if there are differences between acceptances of those two kinds of plants.

First of all, it is interesting to notice that 23 of the 27 visited families heard about the Biotech system by the Panchayat awareness programs, the others having heard about it by the local coordinator of Biotech (3 cases) or neighbours owning a plant (1 case).[21] Even if a survey of Kumbalanghi inhabitants having no plant would be needed to prove it, that result probably goes into the direction of what the ex-president of Kumbanlaghi Panchayat revealed: once an implementation project of waste management facilitates with attracting subsidies is undertaken, the families are interested and buy the technology.

4.3.1. The owners' general feeling regarding the system

The motivation to purchase given by the 27 families are listed in Table 25. Let's notice that the families gave their "own" motivations (no list of typical motivations was proposed) and sometimes gave several ones.

Table 25: Motivations of purchase given by the 27 visited families.

	Owners of toilet linked biogas plants [n=17]	Owners of ordinary plants [n=10]	Total [n=27]
Treatment of waste (Cleanliness of surroundings)[23]	9 (3)	9 (3)	18
Biogas Production (Savings through substitution of LPG)[24]	11 (3)	6 (3)	17
One same facility for food and toilet waste	3	-	3
Access to sanitation facility	3	-	3
Low price of biogas system	1	1	2
Effluent as fertilizer	0	1	1
Eco-friendly	1	0	1

The treatment of waste[22] and the production of gas[23] are the two main reasons given by the families for the purchase of their biogas plant. It is surprising to see that, for the 17 families owning a toilet linked biogas plant, the latrines were a motivation of purchase brought up in only six cases. Among them appear three of the five families who had no sanitation facility before having the plant. The fact to get free effluent from the waste as well as the eco-friendly sensibility are apparently not the first things the families thought about.

At the end of the questionnaire, the families were asked whether their expectations were fulfilled in giving a mark between 1 and 6. Out of the seventeen families owning a toilet

[21] The local coordinator was cited in total by 7 families. That shows that the system of Biotech to have employee living at the implementation place is certainly an excellent idea.
[22] It has been assumed that the motivation "cleanliness of the surroundings" can be included in the motivation "treatment of waste" as it is a consequence of that one.
[23] It has been assumed that the motivation "savings through substitution of LPG" can be included in the motivation "Biogas production" as it is a consequence of that one.

linked plant, eleven gave the maximal mark 6, three gave a 5 and four gave a 4. Out of the ten families owning an ordinary plant, eight gave a 6, one a 5 and one a 4.
The advantages given by the families correspond to the motivations of purchase. The treatment of waste (and the cleanliness as a consequence) as well as the biogas production (which enables to save money through the substitution of other fuels) are indeed the main cited advantages. Relatively surprisingly, the possibility to get free fertilizer was given by only two households and the toilet facilities by three families. The low time required to feed the plant were pointed out by two of the interviewees and the fact it is a productive job for housewives was underlined by one household.
The few disadvantages given by the families owning a toilet linked plant are the weak-points of the latrines buildings (3 cases), the smell of the effluent (2), the fact that the quantity of biogas was not enough to cook everything (2) and the slowness of the cooking with biogas (1).
It is worth to notice that 25 of the 27 families would recommend the plant and that 15 of them recommended it actively to relatives, neighbours or during inhabitants meetings. 20 families indicated that they know interested people. Let's notice, however, that the present price (8 cases), the required space (8), the fact to cook with biogas from faeces (2) and the smell of the effluent (1) were evocated as being self-restraints.

4.3.2. Self-restraints to use toilet linked plants

In this chapter, the self-restraints people can have regarding the use of a toilet linked biogas plant are discussed.
13 of the 17 families owning a toilet linked plant use the latrines and none of them has any concern to cook with the produced biogas. Only two families mentioned that a few guests were not comfortable in knowing the biogas comes from faeces. 4 families don't use the latrines due to the following reasons:

- the latrines are too close to the kitchen
- the latrines are constructed too high and therefore dangerous for old people and children (Figure 31)
- the family has concern with biogas from toilet waste and effluent disposal is a problem
- the family has concern with effluent from toilet waste

Figure 30: Accumulation of the effluent in the surroundings of the plant.

Whereas concerns regarding the biogas from faeces were reported by only one of the seventeen visited families, problems with the effluent seem to be more important. Indeed, eight of the seventeen households revealed that the slurry odour was problematic (or had been problematic, as two of them diverted it to the backwaters because of that reason). In comparison, all of the ten families owning an ordinary biogas plant said that there was no problem of bad smell. In addition, let's notice that only seven of the seventeen families owning a toilet linked plant used the effluent (or part of it) as a fertilizer while all of the ten families owing an ordinary plant do so. It is worth to add that concern regarding the effluent could be due to its more difficult management in the case of the biogas toilets. The important quantity of flushing water leads indeed to a huge amount of effluent that was, in five cases, accumulated in the surroundings of the plant (Figure 30) and in six cases diverted to the backwaters.

The ten families owning an ordinary plant were asked if they would have concern to have toilet linked plants. Five of them said that they wouldn't feel comfortable, two of them specifying the concern regarding the biogas and three of them the one regarding the effluent.

Let's mention that, besides the family which doesn't use the latrine because of its difficult access (Figure 31), another household reported that, for the same reason, the grandparents couldn't use the latrines. In Kumbalanghi, the high water level makes this construction necessary. According to the director of Biotech, the FRP plants, because of their high resistance to salt water, enable now to build more convenient latrines in places like Kumbalanghi.

Figure 31: BIOTECH latrines having a difficult access.

Thus, concerns regarding the use of biogas from faeces seem to be rare whereas the effluent odour and the management of its huge quantity are much more problematic and would require improvement. FRP plants should enable to solve the small problems of latrines at a too high level.

4.3.3. Convenience of cooking with biogas

In the following, the convenience of cooking with biogas is discussed based on the information obtained from the 27 visited families.

For the toilet linked biogas plants, the average daily cooking time reported by the families is 3 hours and 15 minutes[24] (about 2h in the morning and 1h15 in the afternoon/evening). For the ordinary plants, the average is about 3 hours[25] (about 2 hours in the morning and 1 hour in the evening). Those values are, of course, only indicative but show that the time of cooking is sizeable[26] and that the available gas is almost the same with a $2m^3$ toilet linked plant and a $1m^3$ ordinary plant[27].

All 27 families used an additional (or two) fuel(s) to cook besides the biogas. It was firewood in 3 households, LPG in 10 households and firewood & LPG in 14 households.[28]
The families need those other fuels (Figure 32) especially when they have to cook quickly (in the morning and for celebrations). Except for one household, all families revealed that it takes longer to cook with biogas than with LPG or firewood. Most of

Figure 32: Typical kitchen in Kumbalanghi with the single biogas stove and the double LPG stove.

[24] The standard deviation is of about 1 hour.
[25] The standard deviation is of about 50min.
[26] Savings through the substitution of energy are given in the chapter "4.2.3 Savings".
[27] The total food waste average (solid + liquid part) is of about 8.6kg for an ordinary plant and 7.6kg for a $2m^3$ toilet linked plant. Knowing in the second case there are the excreta in addition, the quantity of organic waste is approximately the same for both cases.
[28] Three families also had kerosene and one an induction cooker but use them very rarely.

them said that LPG was 1.5 to 2 times slower than LPG and 2 times slower than firewood.[29] The families also use a second fuel when they want to prepare two items at the same time, as the biogas stove has only one burner.
Due to these different cooking habits, it is difficult to evaluate if the available biogas would be sufficient to cook all the daily dishes. However, twelve families said that they emptied the gasholder completely every day besides using other LPG or firewood. This shows that the daily produced biogas would not be enough.

The families said that all different kinds of food can be cooked on the biogas. However, because of the time factor, 11 families never use biogas to cook rice and use LPG or firewood instead[30]. Let's notice that this time factor seems to be a problem for only 4 families.
It is interesting to see that many families solved the problem of the time-consuming rice cooking by buying a thermal cooker (Figure 33). After 30min cooking on the biogas stove, the pot containing the rice (500g) and the water (3L) is put into the thermal cooker which enables to finish the rice cooking. It saves half quantity of gas and enables to cook other items on the biogas stove during that time. The price of such a utensil is Rs375, Rs800 or Rs975 for capacities of 3L, 6.4L and 7.5L respectively.

Figure 33: A thermal cooker

Three families underlined that having a biogas flame which is less hot than the LPG flame or firewood was an advantage. Indeed, it is more convenient to cook fragile food items (like vegetables) on a low heat. Four families using also firewood said that biogas, though slower, is more convenient and avoids ashes on the walls of the house. Two families which used to use firewood (besides LPG) before having the biogas plant could stop to use it completely.

4.3.4. Application of the given instructions and effective use of the plant

In the following chapter, the families' awareness of the instructions given by Biotech[31], their motivation to apply them and the effective use of the plant are exposed. In addition, a few personal initiatives showing the owners' intention to maintain a good functioning of the plant and to maximize its gas yield are given.

Food waste

In order to increase the gas production, most families add organic waste water from the kitchen in addition to the food waste.[32] Indeed, 26 families add rice water, 21 the rice cleaning water and 19 the fish cleaning water. 14 families regularly collect food wastes from neighbouring households and 5 families collect organic waste from small shops. To get more biogas, 6 families keep the waste for more than 24 hours in order to start decomposition.. Even if the majority of the families (16) reported to spend less than 15 minutes to feed the plant, five families spend 30 minutes and six families even spend 60 minutes per day or more to maintain their plant.

[29] In order to have a better flame, four families put extra weight on the gasholder to get a higher pressure
[30] About 65min are required to cook 500g rice on biogas whereas 20-25 min on LPG are sufficient
[31] In Kumbalanghi, in 2005-2006, Biotech gave only oral instructions.
[32] The solid food waste is similar in all the families and consists of rice leftovers and wastes of vegetable, fruit, fish and meat.

According to the local coordinator in Kumbalanghi, BIOTECH gives two main instructions regarding the feedstock, this is:

1) To not exceed the maximum loads:
- 4-5kg of solid waste and 25-40 litres of waste water for a toilet linked plant
- 2kg of solid waste and 20-25litres of waste water for an ordinary plant

2) To not feed the plant with orange, lemon, tamarind or other acid items.

When families were asked about the instruction regarding the quantity of food and its dilution, fourteen families said that no instruction had been given or that they didn't remember if instructions had been given. The instructions mentioned by the thirteen other families were not very accurate and often differed. In the case of the toilet linked plants, instructions like "10kg of solid waste + 10kg of liquid", "5kg of solid waste", "not too much water" or "same amount of water and solid waste" were given by the families. In the case of the ordinary plant, families evocated instructions like "5kg of solid waste + suitable amount of water", "maximum of 15kg waste", "enough water to pull the waste into the plant", "5kg of solid waste + 2 buckets of water".
It is difficult to know whether the families did not pay attention to the instructions or if BIOTECH did not inform them clearly enough. In fact, none of the families owning a toilet linked plant seem to overfeed the plant[33] whereas three families owning an ordinary plant clearly exceeded the limit of 2kg and three other feed slightly too much food waste[34].
Regarding the second instruction, nine families said they never feed these acid items.

Toilet waste

The main instruction given by BIOTECH regarding the use of the toilets is to not pour chemicals into the plant. In addition, the quantity of flushing water should not be too high in order to not exceed the maximal load of 25-40litres of waste water.
Out of the 13 families using the latrines, eight said that they received the instruction not to put chemicals whereas the five others said that no instructions had been given or that they didn't remember if instructions had been given. Two families also mentioned that they were requested not to use too much water.

Actually, 5 families clean the latrines with chemicals which go into the plant, although two of them are aware of the instruction not to do so.
Regarding the quantity of flushing water going into the plant, it seems to be in the range of the waste water which can be treated. Indeed, the latrines are used only by the family's members (not the neighbour) and most of the time during the school and working hours only by the housewife. In addition, the families use small quantities of water to clean the toilets. Only two households which use huge amounts of flush water (20 and 11 litres) exceed the limit.

Effluent

The main instruction given by BIOTECH concerning the use of the effluent is to dilute it with water before using it as a fertilizer.

[33] As 11 of the 17 families fed the plant whenever they had waste, the amount of daily feedstock could only be estimated. An average of 8kg waste is daily fed in which about 3kg are solid waste.
[34] An average of 8.5kg waste is fed every day in which about 4kg are solid wastes.

Out of the 27 families, 13 said that no instruction had been given or that they didn't remember if instructions had been given. They others said that they were instructed to dilute the effluent, namely by the same amount of water in 3 cases, by the double amount of water in 4 cases and without other details in 6 cases.

In reality, out of the 7 families owning a toilet linked biogas plant and using the effluent as a fertilizer, three use it without dilution, three after double or threefold dilution and one in putting the effluent on the roots followed by water. Out of the ten families owning an ordinary plant, three use the effluent directly whereas the other ones dilute it by two times or more. Let's mention that all families put the effluent (diluted or not) on the roots and do not spread it on vegetables.

All families using the effluent as a fertilizer said that they can see a better growth of their plants. They gave the example of healthier trees, plants with more flowers, bigger vegetables and fruits.

5. Conclusions and Recommendations

In the following, the evaluation of the toilet linked biogas plant compared to an ordinary plant is recapitulated according to the four main objectives of the study: the technical performance, the quality of the effluent, the economic feasibility and the social aspects. Future perspective and recommendations are given for each of those points.

5.1. Technical performance

The monitoring of the ordinary biogas plant and the toilet linked biogas plant showed that both plants are working satisfactorily regarding their technical performance. The pH was very stable and always in the optimal range between 6.5-7.5, and also the temperature inside the digester was stable, although slightly below the optimum of 32-42°C. The high amount of flushing water in plant 2 leads to a very low concentration of VFA and a short hydraulic retention time. However, this doesn't seem to affect the treatment efficiency of TS, VS and COD_{tot} as these values are similar as for plant 1. Also, the gas composition is similar for both plants and the methane content is in the range given in literature.
The daily gas production of 680L is sufficient to cook the main dishes of a family. The low concentration of VFA shows that more solid food waste could be added without impairing the digester activity. This would further increase the gas yield. However, this would mean an additional effort for the families to collect more food waste from neighbouring households.

5.2. Quality of the effluent

The nutrient content in the effluent is similar in both plants, with a rather high content of nitrogen and potassium compared to phosphorus. However, it is difficult to evaluate its quality as a liquid fertilizer as this depends very much on the plants where the fertilizer is applied.

The toilet linked plant shows a very high reduction in pathogen content, but still, the concentration of E. Coli and total Coliforms only allows for restricted irrigation according to the WHO-guidelines for "safe use of waste water, excreta and greywater". This study couldn't evaluate if an increase in the retention time would further reduce the pathogen content. The families have to be careful if using the effluent as a fertilizer and only use it for vegetables that are not eaten raw. The effluent has to be applied directly on the roots and should not be spread on top of the vegetables. It seems appropriate to use the effluent for banana and coconut trees. In addition, contact with mouth or wounds have to be avoided and hands must be washed after use.

The survey revealed that several families discharge the effluent directly into the backwaters. This has to be avoided as the values for CODtot and Ntot exceed by far the environmental standards for discharge of environmental pollutants given by the Ministry of Environment & Forests (Government of India). An additional treatment step would be needed (e.g. filter bed) in order to further reduce the organic load of the effluent.

5.3. Economical feasibility

As it was shown in chapter 4.2.1, the investment costs nowadays are much higher than during the period 2005-2006, when most of the biogas plants in Kumbalanghi were installed. The increase in the price is due to a change in material as well as to a decrease in subsidies by the government and the Panchayat. About five monthly salaries have to be invested to purchase a 2 m^3 toilet linked biogas plant. Taking into account the savings from former fuel substitution and septic tank emptying, the amortization period amounts up to 16 years whereas before it was only a bit more than 3 years. For an ordinary plant, the amortization period is 6.6 years compared to 1.6 years before.

The economic feasibility of the BIOTECH systems is thus rather weak. The investment costs have to come down considerably, otherwise only wealthy families can afford such a biogas plant. Mass production and higher subsidies would be required to reduce investment costs.

A very positive aspect is the almost maintenance free operation of the systems, which turned out to be very robust and broken pieces are rare. If regular maintenance is done, such as condense water removal in the gas tube and cleaning of the gas stove, a good functioning of the system is assured.

5.4. Social aspects

The survey showed that the acceptance of the biogas systems is in general very good and most families would recommend it to others. The improved waste management and the production of biogas were mentioned as the main advantages. The smell of the effluent from toilet linked biogas plants, not enough biogas, longer cooking time with biogas and the difficult access to the latrines were mentioned as a disadvantage in some single cases.

Regarding the use of biogas from faeces, only one family has objections to using the gas for cooking. More problematic is the odorous effluent from toilet linked plants and only half of the families use it as a fertilizer. In comparison, all families owning an ordinary plant use their effluent and didn’t report any concern regarding the odour.

The families are generally pleased with the quantity of biogas they have daily available. In spite of that, they use an additional cooking fuel when they want to cook faster or when they need a second stove.

Regarding the instructions given by BIOTECH concerning operation and maintenance, they were not well memorized by the users. None of the families was aware of the maximum daily load or the recommended dilution of the feedstock. Only half of the families with toilet linked biogas plants were aware that they shouldn’t use chemicals to clean the latrines. Despite of that, all biogas plants were well working and the gas production was satisfactorily. This shows that the system is very robust in terms of food waste input.

6. Acknowledgments

I would like to extend my warm thanks to all the persons who helped me during that study. I thank in particular to:

- Yvonne Vögeli from Sandec for supervising the project, for her understanding and help.

- Chris Zurbrügg from Sandec for enabling me to live that rich professional and human experience.

- Urs Baier from Zurich University of Applied Sciences for his invaluable help and advice during the whole project.

- Mr. Saji Das from BIOTECH for his collaboration and support.

- All BIOTECH staff for their welcome and especially Mr. Poduval for the logistic and Miss Dhanya for the translations and professionalism during the survey.

- Florian Heeb, Christian Lohri and Tenzing Gyalpo for their precious advice and for sharing their experience in anaerobic digestion.

- Stefan Koetzsch, and Max Reutlinger from EAWAG for their help in microbiology and providing essential material.

- The Sandec members for their welcome, their uncountable pieces of advice and their encouragement.

- The families of Mr. David, Mr. Johny and Mr. Benjamin in Kumbalanghi for their incredible hospitality and their great contribution to that project.

- The Dr. Rani Joseph and the PhD student Mr. Ajileshnair from the Cochin University of Science and Technology for their work, help and advice.

- My family and friends for their so precious presence despite the distance.

7. Reference

Chen Y., Cheng J. J., Creamer K. S. (2007): *Inhibition of anaerobic digestions process: A review, Bioresource technology*; vol 99, pp 4044-4064.

Deublein D. Steinhauser A. (2008): *Biogas from waste and renewable resources: an introduction*, Willey, Wienheim.

Drangert, J.O. (1998): *Fighting the Urine Blindness to Provide More Sanitation Options, Water South Africa*, Vol. 24, No. 2, April

Express News Service (2007): *Tourism Project facing death*, Express, 23 september 2007.

Feachem R.G., Bradley D.J., Garelick H., Mara D.D. (1983): *Sanitation and Disease. Health aspects of excreta and wastewater management.* World Bank studies in water supply and sanitation, John Wiley and Sons, New York.

Haridas A. (2007): *Tourism in limbo at Kumbalanghi*, The Hindu, 12 September 2007.

Heeb F. (2009): *Decentralised anaerobic digestion of market waste, Case study in Thiruvananthapuram, India*, Eawag/Sandec. Switzerland.

CDPK - City Development Plan of Kochi (2006). Kochi Municipal Corporation and Local-Self Government Department Government of Kerala, Jawaharlal Nehru National Urban Renewal Mission.

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 Sciences) in collaboration with Eawag, ZHAW, Wädenswil.

Lohri C. (2009): *Evaluation of biogas sanitation systems in Nepalese prisons*, Eawag/Sandec. Switzerland.

Mata-Alvarez J. (2003): *Biomethanization of the organic fraction of municipal solid waste*, IWA Publishing, London.

Ministry of Environment and Forest (undated): *Environmental Standards – General standards for discharge of environmental Standards*, Government of India, Delhi.

Niwagaba C. (2009): *Treatment Technologies for Human Faces and Urine*, Doctoral Thesis No. 2009:70, Faculty of Natural Resources and Agricultures Sciences, Uppsala.

Census of India (2001). Office of the Registrar General & Census Commissioner, Government of India, Ministry of Home Affairs.

Schouw N.L., Danteravanich S., Mobaek H., Tjell J.C. (2002): *Composition of human excreta–a case study from Southern Thailand*. Science of the Total Environment Journal, 286(1-3), pp. 155-166.

Salminen E., & Rintala J. (2002): *Anaerobic digestion of organic solid poultry slaughterhouse waste – a review*, Bioresource Technology, vol 83, no. 1, pp. 13-26.

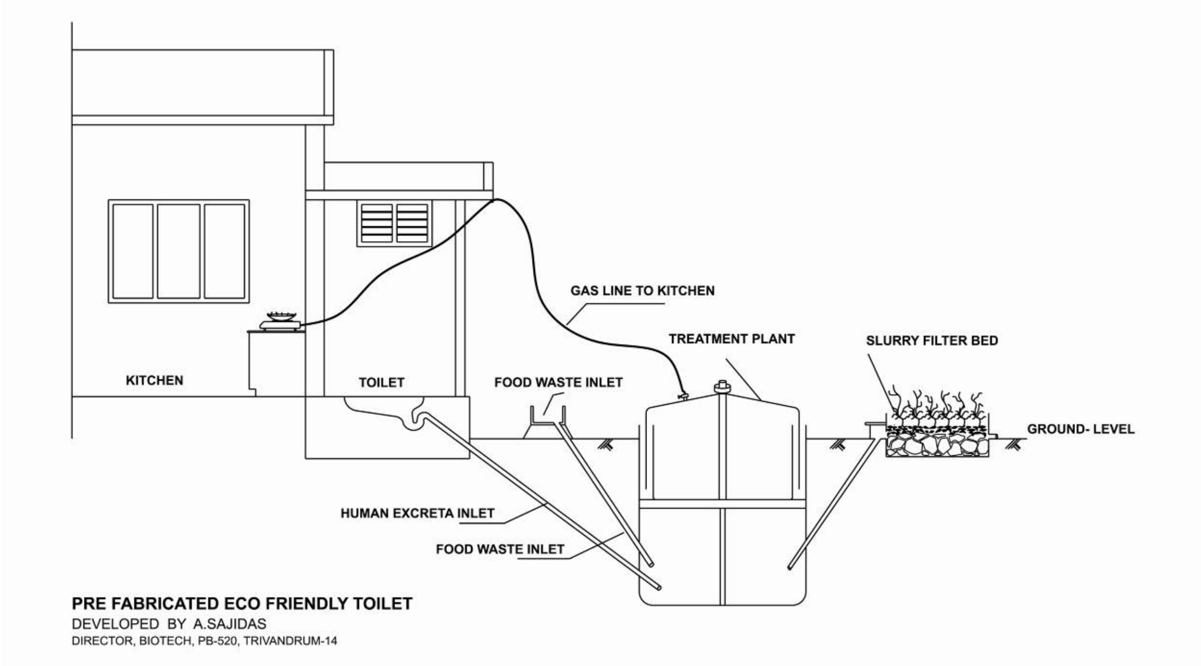
Sharholy M., Ahmad K., Mahmiid G. & Trivedi R.C. (2007): *Municipal solid waste management in Indian cities - A review,* Waste Management, vol 28, pp. 459-467.

Sinclair Knight Merz (2005): *Kerala sustainable urban development project, Final report, volume 2- city report, Kochi*, Asian Development Bank Technical Assistance Consultant's Report.

World Health Organization (2006): *WHO guidelines for the safe use of wastewater, excreta and greywater*; Volume 4: Excreta and greywater use in agriculture.

Appendix

A) Sketch of the BIOTECH pre fabricated eco friendly toilets



B) Detailed method for the TS, VS, VFA and A/TIC ratio measurements

Total Solids Dried at 103-105°C (TS)

- Heat clean porcelain crucibles (ca.35ml content, 6cm diam.) to 103-105°C for 1h. Weigh immediately before use.
- Transfer a measured volume of well-mixed sample to preweighed dish and weigh the filled crucible. Dry sample for at least 24h in an oven at 103-105°C. Cool dish to room temperature in desiccator and weigh.
- Calculation: mg total solids/L: ((A-B)*1000)/sample volume [ml]
  A=weight of dried residue + dish [mg], B=weight of dish [mg]

Volatile Solids Ignited at 550°C (VS)

- Ignite clean crucible at 550 +/- 50°C for 1h in a muffle furnace.
- Ignite residue produced by TS-method to constant weight in a muffle furnace at a temperature of 550°C. Have furnace up to temperature before inserting sample.
- Weigh after crucible has cooled down to room temperature in desiccator.
- Calculation: mg Volatile Solids/L= ((A-B)*1000)/sample volume [ml]
  A=weight of residue + dish before ignition [mg], B=weight of residue + dish after ignition [mg]

Volatile Fatty Acids / Total Inorganic Carbonate (A/TIC)

Analysis description of 4-point-titration according to Kapp (Buchauer, 1998)

- Before analysis, the sample needs to be filtered.
- Filtered sample (20-50ml) is put into a titration vessel, the size of which is determined by the basic requirement to guarantee that the tip of the pH electrode is always below the liquid surface.
- Initial pH is recorded
- The sample is titrated slowly with 0.1N sulphuric acid until pH 5.0 is reached. The added volume A1 [ml] of the titrant is recorded.
- More acid is slowly added until pH 4.3 is reached. The volume A2 [ml] of the added titrant is again recorded.
- The latter step is repeated until pH 4.0 is reached, and the volume A3 [ml] of added titrant recorded once more.
- A constant mixing of sample and added titrant is required right from the start to minimise exchange with the atmosphere during titration.
- Calculation scheme according to Kapp:

$$Alk = A * N * 1000 / SV$$

Alk = Alkalinity [mmol/l], also referred to as TIC (Total Inorganic Carbon)
A = Consumption of sulphuric acid (H_2SO_4, 0.1N) to titrate sample from initial pH to pH 4.3 [ml]. A = A1 + A2 [ml]
N = Normality [mmol/l]
SV = Initial sample volume [ml]

$$VFA = 131'340 * N * B / SV - 3.08 * Alk - 10.9$$

VFA = Volatile fatty acids [mg/l acetic acid equivalents], in A/TIC also referred to as A
N = Normality [mmol/l]
B = Consumption of sulphuric acid (H_2SO_4, 0.1N) to titrate sample from pH 5.0 to pH 4.0 [ml], due to HCO_3/CO_2 buffer. B = A2 + A3 [ml]
SV = Initial sample volume [ml]
Alk = Alkalinity [mmol/l]

C) Questionnaire for User of BIOTECH–Compact Biogas plant in India

1) Date: ……………………………………………………………………………………………………...................
2) Name of Interviewee: ……………………..……………………….……………………...
3) Position: ....
4) Location: ………………………………………………………………………………………….................
………………………………………………………………...
5) Tel: ...……………………………...

General information

6) Size of household (+ age of children): ………………………………………………………………......................
………...................
7) Volume Digester: …………………………………..
8) Volume of Gasholder: …………………………...
9) Date of Installation: ……………………………...………..............................
10) Cost: …………………………………………...
11) Motivation of purchase: ………………………………………………………………………………….....................
....
....
12) Where did you hear from BIOTECH-system: …………………………………………………………..............................

Feedstock (except toilet waste):

13) Composition: …................................………………………...
....
14) Origin (other families?): …………………..………...
....
15) Pre-treatment: …………………………...…………………………………………………………………………
....
16) Daily amount: ………………………………………...
....
17) Time of feeding: ………..……………………………………………
....
18) Amount of Water added to the feedstock (Dilution): ………………………………..........……………..........................
....
19) Instructions given by BIOTECH regarding feedstock and amount of water: ....
....
20) Responsible person for feeding: ...…………………………………………………………………...
....
21) Daily time effort for feeding: ……………………………………………………………………………………………
....
22) Former way of disposing waste: ………………………………………………………………………………………
....
23) Payment/effort time for the former way: ………………………………………………....…………………………
....

Toilets:

24) Number of people using them (+ age of children): ....

....

25) How many times per day do you use the toilet?

Working day: Urine: .... Faeces: .... ………………

Weekend: Urine: ....Faeces: ....

26) Use by the men (do they always use them to urinate? if not where do they urinate?): ....

....

27) How much water do you use for flushing and cleaning? ....

....

28) Amount of water for cleaning the toilets: ....

....Number of times: ....

29) Use of products for cleaning the toilets (chemicals, soap): ....

....

30) Instruction given by BIOTECH regarding the amount of water that should be used for flushing/ cleaning and use of cleaning agent: ....

....

31) Former latrine: ....

....

32) Payment/effort time for emptying the former latrine: ....

....

Gas

33) Daily production (showed on the gasholder): …………………...…………………………………………………………

....

34) Responsible person for cooking: ....

....

35) For how many hours per day can you cook with biogas: ………………………………………….....................................

....

36) When do you use biogas for cooking (time)? …………………………………..

....

37) Food cooked: …………………………………………..

....

38) For how many people: ………………………………...

....

39) Application of weight on gasholder: ………………………………………………………………………….....................

....

40) Gasholder ever totally emptied: …………………………………………………………………………….......................

....

41) Do you have any concern regarding the use of biogas from faeces (smell, health)? ....

....

....

....

....

Energy:

42) What kind of cooking fuel did you use before the biogas? ……………………………………………………………………

………

43) Amount of substitution (kg,l): …………………………………………………………………………………

………

44) Cost savings through substitution: ……………………………………………………………………………

………

45) Biogas sufficient for cooking: …………………………………………………………………………………

………

46) Which additional energy is used: ……………………………………………………………………………

………

47) Expenses for wood/charcoal/LPG per month: ……………………………………………………………

………

48) Differences in cooking with BG & charcoal/wood/LPG (time, smoke): ………………………………………

………

Effluent

49) Use/handling (irrigation, sewer): ……………………………………………………………………………

………

50) Irrigation practice (How is it done? top irrigation?) ……………………………………………………

………

51) Experiences (better growth?): ………………………………………………………………………………

………

52) Instructions given by BIOTECH regarding to use of the effluent: ……………………………………………

………

53) Former fertilizer: ……………………………………………………………………………………………

………

54) Amount of substitution: ……………………………………………………………………………………

………

55) Cost savings through substitution: ……………………………………………………………………………

………

Problems

56) Leaks: ………………………………………………………………………………………………………

57) Broken parts: ………………………………………………………………………………………………

58) Blockages: …………………………………………………………………………………………………

59) Stove: ………………………………………………………………………………………………………

60) Stop of BG-production/restarts: ……………………………………………………………………………

61) Seasonal changes/rainy season: ……………………………………………………………………………

62) Flies/mosquitoes: …………………………………………………………………………………………

63) Bad odour:……………………………………………………………………………………………………

64) Other problems: ……………………………………………………………………………………………

65) Contact/Service Biotech in case of problem: ………………………………………………………………

………

Various

66) Expectations fulfilled (1 to 6 mark): ……………………………………………………………………………………

67) Why (not): ……………………………………………………………………………………

68) Would you recommend it:: ……………………………………………………………………………………

69) Why (not): ……………………………………………………………………………………

70) Interest of other people: ……………………………………………………………………………………

71) Suggestions for improvement: ……………………………………………………………………………………

Others

……………………………………………………………………………………

D) Summary of the monitoring results

D1) Feedstock of plant 1

	Average			Date											
	Days with chicken	**Usual days**	**Combined feedstock**	**17.1.10**	**20.1.10**	**24.1.10**	**27.1.10**	**31.1.10**	**3.2.10**	**7.2.10**	**10.2.10**	**14.2.10**	**17.2.10**	**21.2.10**	**24.2.10**
TS [g/l]	**94**	**37**	**45.4**	130.4	38.2	78.5	31.8	53.7	19.2	100.8	57.4	97.8	38.8	103.1	38.1
TS [kg/d]	**1.77**	**0.48**	**0.67**	3.1	0.6	1.7	0.3	1.0	0.3	1.8	0.7	1.3	0.5	1.7	0.5
VS [g/l]	**86**	**33**	**40.6**	119.0	33.5	70.3	27.4	48.1	15.9	92.1	53.1	90.3	35.3	95.6	32.8
VS [kg/d]	**1.62**	**0.426**	**0.6**	2.866	0.568	1.507	0.301	0.928	0.216	1.623	0.643	1.234	0.430	1.539	0.401
VS [%TS]	**91.22**	**88.47**	**88.86**												
CODtot [mgO2/L]	**167751**	**53194**	**69559**	227352	50464	194488	45808	81852	35172	180912	74260	153608	55540	168296	57920
COD [kg/d]	**3.20**	**0.69**	**1.05**	5.475	0.855	4.168	0.502	1.579	0.478	3.187	0.899	2.099	0.677	2.710	0.709
COD [gO2/gTS]	**1.81**	**1.42**	**1.57**												
CODdiss [mg/L]	**25262**	**16087**	**17397**		14060		19660	19220		40940			14540		18436
CODdiss [kg/d]	**0.546**	**0.210**	**0.258**		0.238		0.215	0.371		0.721			0.177		0.226
CODdiss [%CODtot]	**17.05**	**30.64**	**24.69**												
Ntot [gN/L]	**5242**	**1036**	**1637**	4672	739	8064	959	3126	541	5797	1396	4704	1718	5680	1062
Ntot [kg/d]	**0.101**	**0.014**	**0.026**	0.112	0.013	0.173	0.011	0.060	0.007	0.102	0.017	0.064	0.021	0.091	0.013
Ntot [%TS]	**5.68**	**2.81**	**3.90**												
NH4-H [mgN/L]	**82**	**54**	**58**	102		80					44	72		76	
NH4-H [kg/d]	**0.002**	**0.001**	**0.001**	0.002		0.002					0.001	0.001		0.001	
NH4-H [%Ntot]	**1.58**	**3.95**	**2.64**												
Ptot [mgP/L]	**423**	**161**	**198**	490	207	596	102	210	143	486	202	416	132	497	302
Ptot [kg/d]	**0.008**	**0.002**	**0.003**	0.012	0.004	0.013	0.001	0.004	0.002	0.009	0.002	0.006	0.002	0.008	0.004
Ptot [%TS]	**0.478**	**0.441**	**0.455**												
Flow rate [L]				24.08	16.94	21.43	10.96	19.30	13.58	17.62	12.10	13.66	12.20	16.10	12.24

D2) Effluent of plant 1

	Average	Date											
		17.1.10	20.1.10	24.1.10	27.1.10	31.1.10	3.2.10	7.2.10	10.2.10	14.2.10	17.2.10	21.2.10	24.2.10
TS [g/l]	**6.2**	7.9	6.1	7.2	5.6	6.3	5.5	6.9	5.7	6.2	6.0	6.1	5.0
TS [kg/d]	**0.101**	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
VS [g/l]	**3.975**	5.5	3.8	4.8	3.7	4.3	3.2	4.8	3.6	4.0	3.8	3.7	2.7
VS [kg/d]	**0.065**	0.131	0.064	0.103	0.041	0.083	0.044	0.084	0.043	0.055	0.046	0.060	0.032
VS [%TS]	**65.17**	69.1	61.2	66.7	66.4	68.3	58.3	69.2	62.4	64.8	62.5	60.4	53.4
CODtot [mg/L]	**6211**	7788	7328	7276	5316	7292	5960	6732	5692	6380	5708	5004	4052
COD [kg/d]	**0.102**	0.188	0.124	0.156	0.058	0.141	0.081	0.119	0.069	0.087	0.070	0.081	0.050
COD [gO2/gTS]	**1.01**												
CODdiss [mg/L]	**2209**		2586		1680	1736		1484			1348		1020
CODdiss [kg/d]	**0.025**		0.044		0.018	0.033		0.026			0.016		0.012
CODdiss [%CODtot]	**24.68**												
Ntot [mg/L]	**2222**	1523	1999	2168	2582	2493	2366	2491	2261	2238	2522	2070	2206
Ntot [kg/d]	**0.035**	0.037	0.034	0.046	0.028	0.048	0.032	0.044	0.027	0.031	0.031	0.033	0.027
Ntot [%TS]	**34.47**												
NH4-H [mg/L]	**1406**	1325	1406	1368	1446	1399	1327	1453	1406	1307		1202	1318
NH4-H [kg/d]	**0.02**	0.032	0.024	0.029	0.016	0.027	0.018	0.026	0.017	0.018		0.019	0.016
NH4-H [%Ntot]	**63.05**												
Ptot [mg/L]	**78**	79	83	78	76	78	74	75	78	69	75	69	70
Ptot [kg/d]	**0.001**	0.002	0.001	0.002	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Ptot [%TS]	**1.19**												
Ktot [mg/L]	**2535**		1954		2404		2336		2106	1846	3778		1926
Ktot [kg/d]	**0.030**		0.033		0.026		0.032		0.025	0.025	0.046		0.024
Ktot [%TS]	**29.87**												
VFA [mg/L]	**657**	872	1124	705	514	598	926	721	698	560	469	339	362
A/TIC	**0.094**	0.13	0.16	0.10	0.07	0.09	0.13	0.10	0.10	0.08	0.07	0.05	0.05
Flow rate [L]		24.08	16.94	21.43	10.96	19.30	13.58	17.62	12.10	13.66	12.20	16.10	12.24

D3) Kitchen waste of plant 2

	Average	Date											
		17.1.10	20.1.10	24.1.10	27.1.10	31.1.10	3.2.10	7.2.10	10.2.10	14.2.10	17.2.10	21.2.10	24.2.10
TS [g/l]	**45.4**	43.5	77.9	54.0	54.8	45.9	23.1	27.0	36.1	38.7	37.0	69.0	37.5
TS [kg/d]	**0.73**	0.69	1.24	0.96	0.88	0.96	0.22	0.42	0.55	0.81	0.49	0.78	0.78
VS [g/l]	**40.9**	39.4	70.3	45.8	50.0	44.0	20.3	23.6	32.0	34.5	34.4	63.2	33.1
VS [kg/d]	**0.659**	0.629	1.119	0.816	0.807	0.918	0.194	0.367	0.488	0.723	0.452	0.713	0.684
VS [%TS]	**90.07**												
CODtot [mg/L]	**51100**	55828	68584	58424	57936	47600	24396	31232	48412	53212	40900	76180	50496
CODtot [kg/d]	**0.830**	0.892	1.091	1.041	0.935	0.993	0.234	0.486	0.737	1.116	0.536	0.859	1.044
CODtot [gO2/gTS]	**1.13**												
CODdiss [mg/L]	**19576**		33530		24470	15440		10280			20180		13557
CODdiss [kg/d]	**0.326**		0.533		0.395	0.322		0.160			0.265		0.280
CODdiss [%CODtot]	**39.24**												
Ntot [mg/L]	**916**	826	1248	872	1461	695.6	281	624	1068	1106	493	1421	896
Ntot [kg/d]	**0.015**	0.013	0.020	0.016	0.024	0.015	0.003	0.010	0.016	0.023	0.006	0.016	0.019
Ntot [%Ntot]	**2.04**												
NH4-H [mg/L]	**43**	21		40					31	61		59	
NH4-H [kg/d]	**0.001**	0.000		0.001					0.000	0.001		0.001	
NH4-H [%Ntot]	**4.65**												
Ptot [mg/L]	**153**	88	158	249	253	119	58	139	121	185	64	214	192
Ptot [kg/d]	**0.003**	0.001	0.003	0.004	0.004	0.002	0.001	0.002	0.002	0.004	0.001	0.002	0.004
Ptot [%TS]	**0.348**												
Flow rate [L]		15.975	15.905	17.815	16.140	20.860	9.581	15.555	15.230	20.980	13.115	11.280	20.670

D4) Toilet waste of plant 2

	Average	Date											
		17.1.10	20.1.10	24.1.10	27.1.10	31.1.10	3.2.10	7.2.10	10.2.10	14.2.10	17.2.10	21.2.10	24.2.10
TS [kg/d]	**0.240 - 0.296***												
VS [%TS]	85*												
CODtot [mg/L]	**4459**		4199		3495		4008		8428		3037		
CODtot [kg/d]	**0.100**		0.106		0.074		0.085		0.145		0.064		
CODtot [gO2/gTS] min	**0.337**												
CODtot [gO2/gTS] max	**0.416**												
CODdiss [mg/L]	**1111**		1097		869		992		1580		1018		
CODdiss [kg/d]	**0.023**		0.028		0.018		0.021		0.027		0.022		
CODdiss [%CODtot]	**23.230**												
Ntot [mg/L]	**427**		591		303		341		503		497		
Ntot [kg/d]	**0.010**		0.015		0.006		0.007		0.009		0.011		
Ntot [%TS] min	**3.29**												
Ntot [%TS] max	**4.06**												
NH4-H [mg/L]	**129**		170		91		136		123				
NH4-H [kg/d]	**0.003**		0.004		0.002		0.003		0.002				
NH4-H [%Ntot]	**30.879**												
Ptot [mg/L]	**37**		49		22		25		48		28		
Ptot [kg/d]	**0.001**		0.001		0.000		0.001		0.001		0.001		
Ptot [%TS] min	**0.282**												
Ptot [%TS] max	**0.348**												
E. Coli [CFU/100ml]	**2.1E+08**		8.0E+08		2.3E+08		1.5E+08		1.6E+08		5.7E+07		1.9E+07
Coliforms [CFU/100ml]	**2.5E+08**		8.7E+08		2.5E+08		2.3E+08		2.2E+08		3.3E+07		3.3E+07
Flow rate [L]		23.2	25.2	21.2	21.2	17.2	21.2	21.2	17.2	23.2	21.2	19.2	21.2

D5) Combined feedstock of plant 2

	Average	Date											
		17. 1. 10	20. 1. 10	24. 1. 10	27. 1. 10	31. 1. 10	03. 2. 10	07. 2. 10	10. 2. 10	14. 2. 10	17. 2. 10	21. 2. 10	24. 2. 10
TS [g/l]	**26.6**	24.358	36.460	31.343	30.635	31.995	15.642	18.508	24.964	24.281	21.721	34.060	24.745
TS [kg/d] min	**0.972**	0.934	1.479	1.203	1.124	1.198	0.461	0.660	0.790	1.053	0.725	1.018	1.016
TS [kg/d] max	**1.028**	0.990	1.535	1.259	1.180	1.254	0.517	0.716	0.846	1.109	0.781	1.074	1.072
VS [g/l]	**23.7**	21.8	32.7	26.7	27.6	30.0	13.6	16.1	22.0	21.4	19.7	30.7	21.7
VS [kg/d] min	**0.863**	0.833	1.323	1.020	1.011	1.122	0.398	0.571	0.692	0.927	0.656	0.917	0.888
VS [kg/d] max	**0.911**	0.881	1.370	1.068	1.058	1.170	0.446	0.618	0.739	0.975	0.703	0.965	0.935
VS [%TS] min	**88.6**	89.2	89.5	84.8	89.9	93.7	86.3	86.4	87.6	88.1	90.4	90.1	87.4
VS [%TS] max	**88.4**	88.9	89.3	84.8	89.7	93.3	86.1	86.3	87.5	87.9	90.0	89.8	87.2
CODtot [mg/L]	**24599.4**	25406	29271	29100	27574	28104	10664	15789	25100	27610	18386	31001	27186
CODtot [kg/d] min	**1.070**	1.132	1.331	1.281	1.175	1.233	0.474	0.726	0.977	1.356	0.776	1.099	1.284
CODtot [kg/d] max	**1.126**	1.188	1.387	1.337	1.231	1.289	0.530	0.782	1.033	1.412	0.832	1.155	1.340
CODtot [gO2/gTS] min	**1.10**												
CODtot [gO2/gTS] max	**1.10**												
CODdiss [mg/L]	**8212**		13655		11208	8965		4992			8399		
CODdiss [kg/d]	**0.322**		0.556		0.418	0.345		0.183			0.288		
CODdiss [%CODtot]	**30**												
Ntot [mgN/L]	**604**	590	745	630	874	574	382	510	728	749	452	795	659
Ntot [kgN/d]	**0.023**	0.023	0.030	0.025	0.033	0.024	0.012	0.019	0.026	0.033	0.016	0.026	0.028
Ntot [%TS] min	**2.271**												
Ntot [%TS] max	**2.402**												
NH4-H [mgN/L]	**92**	85		88					83	97		103	
NH4-H (kgN/d)	**0.004**	0.003		0.004					0.003	0.004		0.004	
NH4-H [%Ntot]	**15.80**												
Ptot [mgP/L]	**79**	58	84	134	130	82	43	80	76	107	47	102	113
Ptot [kgP/d]	**0.003**	0.002	0.003	0.005	0.005	0.003	0.001	0.003	0.003	0.005	0.002	0.003	0.005
Ptot [%TS] min	**0.305**												
Ptot [%TS] max	**0.323**												
E. Coli [CFU/100ml]	**1.5E+08**		4.9E+08		1.3E+08		1.0E+08		8.5E+07		3.5E+07		9.6E+06
Coliforms [CFU/100ml]	**1.7E+08**		5.3E+08		1.4E+08		1.6E+08		1.1E+08		2.0E+07		1.7E+07

D6) Effluent of plant 2

	Average	Date											
		17.1.10	20.1.10	24.1.10	27.1.10	31.1.10	3.2.10	7.2.10	10.2.10	14.2.10	17.2.10	21.2.10	24.2.10
TS [g/l]	**5.0**	4.7	4.2	6.2	4.8	4.6	3.9	4.7	4.4	9.3	4.0	4.4	4.4
TS [kg/d]	**0.19**	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.1	0.4	0.1	0.1	0.2
VS [g/l]	**3.1**	3.8	2.4	3.9	3.0	3.0	1.9	3.1	2.7	6.5	2.2	2.6	2.4
VS [kg/d]	**0.12**	0.147	0.097	0.153	0.113	0.113	0.060	0.115	0.087	0.288	0.076	0.080	0.102
VS [%TS]	**63.4**	80.8	55.4	63.1	63.4	64.4	49.9	66.0	60.9	70.3	55.2	59.3	54.9
CODtot [mg/L]	**3785**	3460	3326	5096	3414	3240	3072	3500	2900	7838	2608	2924	4045
CODtot [kg/d]	**0.14**	0.136	0.137	0.199	0.127	0.123	0.095	0.129	0.094	0.346	0.089	0.089	0.169
CODtot [gCOD/gTS]	**0.77**												
CODdiss [mg/L]	**446**		442		360	426		428			648		374
CODdiss [kg/d]	**0.017**		0.018		0.013	0.016		0.016			0.022		0.016
CODdiss [%CODtot]	**11.709**												
Ntot [mg/L]	**871**	831	834	1104	862	922	946	874	894	974	873	626	718
Ntot [kg/d]	**0.032**	0.033	0.034	0.043	0.032	0.035	0.029	0.032	0.029	0.043	0.030	0.019	0.030
Ntot [%TS]	**17.248**												
NH4-H [mg/L]	**420**	500	453	441	446	424	429	433	394	393		293	
NH4-H [kg/d]	**0.016**	0.020	0.019	0.017	0.017	0.016	0.013	0.016	0.013	0.017		0.009	
NH4-H (%Ntot)	**48.1**												
Ptot [mg/L]	**61**	61	59	63	60	61	59	59	55	78	65	52	
Ptot [kg/d]	**0.002**	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.003	0.002	0.002	
Ptot [%TS]	**1.202**												
K [mg/L]	**766**		878		824		754		951	654	916		387
K [kg/d]	**0.028**		0.036		0.031		0.023		0.031	0.029	0.031		0.016
K [%TS]	**14.989**												
VFA [mg/L]	**82**	34	nil	180	nil	43	nil	76	136	70	71	49	nil
A/TIC	**0.031**	0.01	nil	0.06	nil	0.02	nil	0.03	0.05	0.03	0.03	0.02	nil
E. Coli [CFU/100ml]	**3.E+05**	5.E+05	2.E+05	2.E+05	3.E+05	6.E+05	2.E+05	3.E+05	2.E+05	4.E+05	2.E+05	1.E+05	4.E+05
Coliforms [CFU/100ml]	**4.E+06**	1.E+06	3.E+06	2.E+06	2.E+06	2.E+06	1.E+06	1.E+06	7.E+06	5.E+06	5.E+06	7.E+06	7.E+06

D6) On-site measurements - plant 1

	Av	Date														
		17.1.10	19.1.10	20.1.10	22.1.10	23.1.10	24.1.10	26.1.10	27.1.10	29.1.10	30.1.10	31.1.10	2.2.10	3.2.10	5.2.10	6.2.10
pH	7.44	7.36	7.40	7.36	7.53	7.46	7.43	7.44	7.44	7.48	7.38	7.40	7.43	7.42	7.50	7.51
Temperature [°C]	28.5	27.0	27.9	28.2	27.7	27.8	27.5	28.1	28.6	28.3	27.9	27.3	27.8	28.3	27.7	27.6
CO_2 [%]	35	35.3	36.3	36.0	36.0	34.0	35.0	34.3	37.0	34.3	34.7	37.3	33.7	35.0	34.7	33.3
CH_4 max [%]	63	64.7	63.7	64.0	64.0	66.0	65.0	65.7	63.0	65.7	65.3	0.0	66.3	65.0	65.3	66.7
Gas production [L]	684	737	744.5	756	745	717	699	688.5	678	615	569	633	673	716	578	595

	Date														
	7.2.10	9.2.10	10.2.10	12.2.10	13.2.10	14.2.10	16.2.10	17.2.10	19.2.10	20.2.10	21.2.10	23.2.10	24.2.10	26.2.10	27.2.10
pH	7.40	7.43	7.44	7.37	7.43	7.43	7.44	7.44	7.48	7.45	7.42	7.48	7.54	7.42	7.44
Temperature [°C]	27.2	27.6	28.8	28.3	29.1	28.7	29.6	29.6	28.9	29.0	29.9	29.2	30.1	30.4	29.8
CO_2 [%]	34.3	36.0	35.0	36.7	36.7	34.7	35.0	34.0	33.3	34.3	35.0	34.0	34.3	34.0	36.0
CH_4 max [%]	65.7	64.0	65.0	63.3	63.3	65.3	65.0	66.0	66.7	65.7	65.0	66.0	65.7	66.0	64.0
Gas production [L]	602	647	663	723.5	715	691	719.5	660	657.5	649	714	658.5	683	809	741

D7) On-site measurements - plant 2

	Av	Date														
		17.01.10	19.01.10	20.01.10	22.01.10	23.01.10	24.01.10	26.01.10	27.01.10	29.01.10	30.01.10	31.01.10	02.02.10	03.02.10	05.02.10	06.02.10
pH	**6.93**	7.05	6.84	7.04	6.82	6.94	6.96	6.98	6.87	6.95	6.89	6.93	6.99	7.06	7.04	6.97
Temperature	**29.7**	29.30	29.47	28.93	27.67	28.13	28.20	28.70	28.17	29.57	29.00	29.33	30.00	29.93	29.87	28.40
CO2 [%]	**39**	40.0	40.0	40.0	40.3	39.0	38.3	40.0	38.7	38.7	41.3	40.7	39.7	39.7	39.3	38.3
CH4 max [%]	**61**	60.0	60.0	60.0	59.7	61.0	61.7	60.0	61.3	61.3	58.7	59.3	60.3	60.3	60.7	61.7
Gas production [L]	**684**	1156	816	732	906	932	559	738	492	531.5	531.5	898	1117	914	763	755

	Date														
	07.02.10	09.02.10	10.02.10	12.02.10	13.02.10	14.02.10	16.02.10	17.02.10	19.02.10	20.02.10	21.02.10	23.02.10	24.02.10	26.02.10	27.02.10
pH	7.01	6.83	6.88	6.97	7.01	6.91	6.93	6.95	6.94	6.84	7.01	6.70	6.78	6.81	6.92
Temperature	28.70	28.33	29.57	30.17	30.43	29.50	31.07	31.50	31.03	31.50	31.77	30.03	30.20	30.57	31.50
CO2 [%]	37.3	38.0	40.7	38.0	36.3	37.3	36.0	37.0	36.7	39.0	41.0	38.3	39.7	39.0	38.7
CH4 max [%]	62.7	62.0	59.3	62.0	63.7	62.7	64.0	63.0	63.3	61.0	59.0	61.7	60.3	61.0	61.3
Gas production [L]	417	517	531	890	604	686	631	742	672	766	802	818	749	686	524

E) Type of fuel to used for cooking in Kerala

		Total	%	Rural	%	Urban	%
U	Type of fuel used for cooking:						
U.1	Total	6,595,206	100.0	4,942,550	100.0	1,652,656	100.0
U.2	Fire-wood	5,107,552	77.4	4,153,466	84.0	954,086	57.7
U.3	Crop residue	116,947	1.8	91,654	1.9	25,293	1.5
U.4	Cowdung cake	3,814	0.1	2,784	0.1	1,030	0.1
U.5	Coal, lignite, charcoal	3,204	0.0	2,222	0.0	982	0.1
U.6	Kerosene	113,890	1.7	46,828	0.9	67,062	4.1
U.7	LPG	1,168,536	17.7	589,189	11.9	579,347	35.1
U.8	Electricity	6,285	0.1	4,184	0.1	2,101	0.1
U.9	Biogas	50,078	0.8	35,160	0.7	14,918	0.9
U.10	Any other	5,926	0.1	4,531	0.1	1,395	0.1
U.11	No cooking	18,974	0.3	12,532	0.3	6,442	0.4

ource: Table H-11 India: Census of India 2001