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

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

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Abstract

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

Introduction

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

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

Key messages:

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

Figure 1: Hanging toilets

Figure 2: Toilet discharging into the backwaters

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

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

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

Methods

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

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

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

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

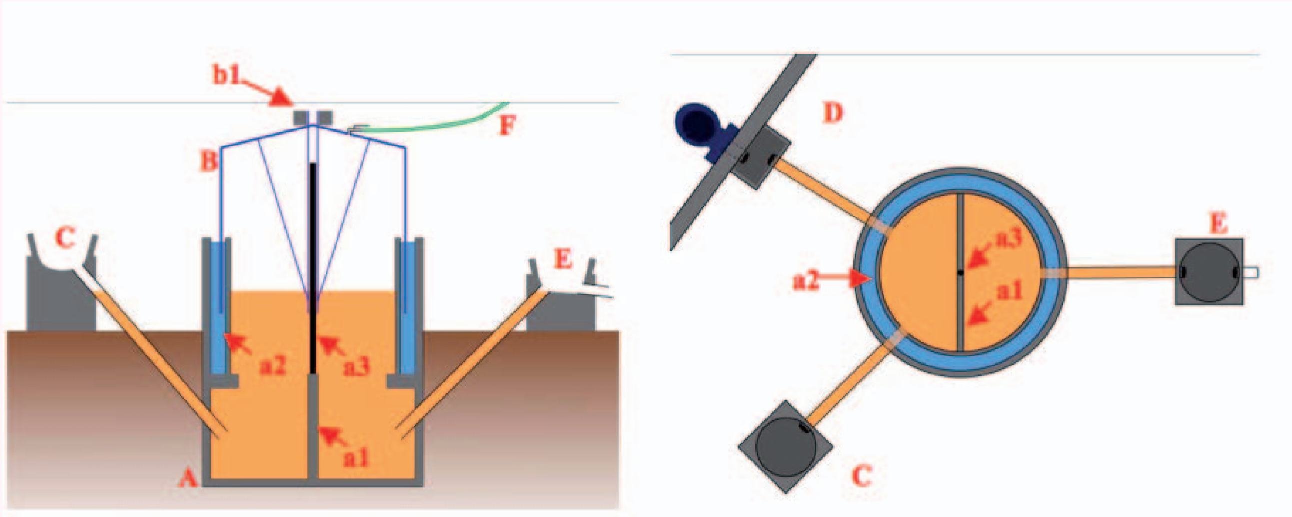

Figure 3: Cross section and top view of a toilet linked biogas plant

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

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

Specifications of biogas system and cost

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

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

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

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

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

Results and Discussion

Technical performance

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

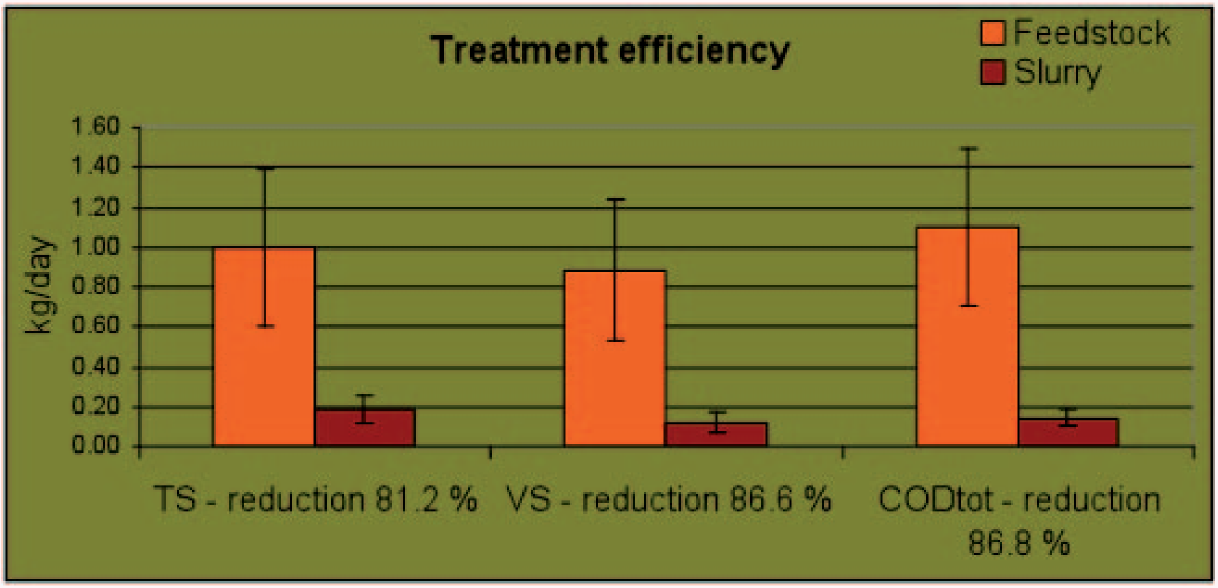

Figure 4: Treatment efficiency of TLBP plant

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

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

Quality of effluent

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

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

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

Figure 5: Biogas plant discharging directly into the backwaters

Economic feasibility

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

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

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

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

Social aspects

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

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

The majority of families are pleased with the amounts of biogas they can obtain on a daily basis. All use an additional cooking fuel when they want to cook faster or when they need a second stove.

User knowledge of operation and maintenance instructions were lacking. None of the families interviewed were aware of the recommended maximum daily load or on the recommended dilution of the feedstock. Only half of the users were aware that they shouldn't use chemicals to clean the toilets. Despite of these difficulties and challenges, all biogas plants were working well and the gas production was satisfactory.

Conclusions

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

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

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

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

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