DECENTRALISED ANAEROBIC DIGESTION OF KITCHEN AND MARKET WASTE IN DEVELOPING COUNTRIES – "STATE-OF-THE-ART" IN SOUTH INDIA

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SUMMARY: In the rapidly growing cities of the developing world, problems and issues of Municipal Solid Waste Management (MSWM) are of major importance (Zurbrügg, 2002). Anaerobic digestion of the organic fraction – which can make up to 70% of the Municipal Solid Waste – is seen as a promising treatment option in tropical countries. This paper provides an overview of the actual "state-of-the-art" of the numerous operating biogas plants fed by kitchen and market waste in South India. Experience from an evaluation study conducted in August 2007 reveals the potential and challenges of dissemination of this rather new treatment option of the organic fraction of MSW in developing countries.

1. INTRODUCTION

Inadequate solid waste management (SWM) is the most serious environmental and health problem in many cities of developing countries. Urbanisation and population growth lead to an increase in waste quantities in urban areas. Since the mostly inefficient waste collection schemes generally serve only a limited section of the urban population, waste is often dumped on streets and in uncontrolled dumpsites. Up to 70% of the Municipal Solid Waste (MSW) in developing countries is composed of organics. Various problems, such as soil, surface and groundwater pollution through leachate, attraction of animals or the uncontrolled methane production are the results of inadequate treatment of the organic fraction of MSW. The disposal of biodegradable material is thus of particular importance in any waste management scheme. Besides composting or direct animal feeding, anaerobic digestion and biomethanation of organic solid waste are considered promising treatment options for this particular waste fraction. Anaerobic digestion is a natural biological process that converts biomass into energy (biogas) in the absence of oxygen. Biogas – a mixture of CO2 and methane (CH4) – can be used as a renewable energy source for cooking, lighting or to generate electricity, thereby replacing other fuel sources. Biogas digestate is a nutrient-rich fertiliser that can be used like compost.

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2. ANAEROBIC DIGESTION IN DEVELOPING COUNTRIES

The process of anaerobic digestion has been practised for decades in developing countries. The first anaerobic digester was built in Bombay, India in 1859. Since then, the technology has become widespread throughout Asia. As early as 1975, China and India implemented large government-backed schemes for adaptation of small biogas plants (typically 6–8 m^3 digester size) used in rural households for cooking and lighting (Wikipedia, 2008).

In Nepal, the Biogas Support Programme BSP, launched in 1997, set up 172 833 biogas plants by December 2007 (BSP Nepal, 2008). In Africa, where anaerobic digestion is also known but less prevalent, a similar initiative was launched in May 2007. This so-called "Biogas for Better Life" initiative aims at installing two million biogas plants in the next ten years (Biogas for Better Life, 2008). In Latin America, apart from small biogas plants for rural households, many agricultural waste projects have been implemented and biogas extracted from landfills.

According to the Worldwatch Institute (2007), some 25 million households worldwide receive energy for lighting and cooking from small-scale biogas digesters. This figure includes 20 million households in China and 3.9 million households in India. Some analysts estimate that more than 1 million biogas digesters are now being produced each year in China, and the government has set targets for 30 million digesters by 2010 and 45 million by 2020. Beyond household scale, a few thousand medium and large-scale industrial biogas plants are operating in China, with a recent national biogas action plan expected to expand the numbers of such plants.

In the past, the biogas support programmes focused on rural families with few cattle, using animal manure and human faeces as feedstock. The main goals were to reduce the use of firewood by providing people with biogas, improve soil fertility and reduce indoor air pollution. A lot of experience was gained in optimising the biogas technology. However, as regards anaerobic digestion as a waste tratment option for urban settings, where predominantly kitchen or market waste is used as feedstock, there is little accessible knowledge and information on technical and operational feasibility, challenges and opportunities. This lack of knowledge and information is astonishing, given the enormous waste disposal problems faced by most urban areas in low and middle-income countries.

The more complex substrate of MSW and varying volume streams are a significant challenge for the technology in terms of reliability, operational consistency and durability (Aichberger, 2008). While anaerobic digestion of organic household waste in centralised high-tech plants in industrialised countries has become increasingly popular in recent years, most regions of developing countries still lack appropriate low-tech options.

3. SITUATION ANALYSIS IN SOUTH INDIA

3.1 Overview

A literature and Internet search conducted by Sandec revealed that among low and middle-income countries, India is the most experienced in anaerobic digestion of kitchen/market waste and organic household waste (Mueller, 2007). Since a few years, different biogas plants treating various types of organic solid waste have been implemented throughout the country.

During an assessment and evaluation study conducted in August 2007, 16 biogas plants were examined in various South Indian cities. All the plants visited were developed by Indian research institutes, private companies or local NGOs and especially designed to treat organic solid waste instead of liquid manure. All the plants, except one, are based on the floating dome system – the most common system in India. The plants' operational scale varied from household level (1–5 kg/d) to institutional and municipal level (up to 3 t/d). Large centralised facilities with capacities up to 100 t/d are also prevalent in India. The feedstock consists of kitchen waste from households, canteens, restaurants, market waste (vegetable, fish), slaughterhouse waste and, in certain plants, also toilet waste. Table 1 provides an overview of the visited plants.

3.2 Legal Framework in India

In India, solid waste management falls under the jurisdiction of the municipal authorities (World Bank, 2007). The Indian Municipal Solid Waste (Management and Handling) Rules 2000 require waste segregation at source and prohibit landfilling of biodegradable waste. Such materials have to be processed by composting, vermicomposting, anaerobic digestion or any other appropriate biological treatment for waste stabilisation. The municipal authorities are responsible for implementing these rules and for all infrastructural developments related to collection, storage, segregation, transport, processing, and disposal of municipal solid waste. Though compliance is still extremely limited to date, this legal framework should help promote the use of biogas plants and also receive the support of the municipal authorities currently lacking in most areas.

Since the early 1980s, the Indian Ministry of New and Renewable Energy has been promoting household-scale biogas plants in rural areas by providing subsidies and financing to construct and maintain biogas plants, train, raise public awareness, build technical centres, and support local implementing agencies. The well-known Khadi and Village Industries Commission also backs biogas plants (Worldwatch Institute 2007).

3.3 Incentives for Biogas Plant Use

The incentives for building and operating biogas plants differ at household and institutional level. Households in India are not compelled by law to separate their organic waste at home, and there is also no incentive scheme for waste reduction and recycling. Thus, motivation to invest in and operate a biogas plant is not related to factors of waste treatment but rather to the economic advantages of substituting biogas for Liquid Petroleum Gas (LPG) (or other energy sources). Given the investment costs and current fuel prices, the cost of domestic biogas plants, such as the models of ARTI or BIOTECH, can be recovered within four years.

On the institutional level, the primary motivation is waste treatment. Municipalities, which are responsible by law for adequate solid waste treatment and disposal, are increasingly under pressure to solve the waste problem in their cities. As landfilling is prohibited, biogas plants are one option to treat the organic fraction. In some cases where a new neighbourhood is planned, the municipalities enforce the legal requirement by requesting the house builders to submit the plans for treating organic waste – a prerequisite for obtaining the necessary building permits. In these instances, biogas plants can be an option to meet these requirements since they are primarily perceived as a waste treatment plant and only secondarily as a biogas producer. Similarly, restaurants in Pune are obliged to dispose of their food waste separately in green bags and pay a monthly fee of INR 500. Avoiding these fees can be an incentive to invest in a biogas plant. Given the impending energy crises, the school in Jankalyam Niwasi, located in a rural area near Latur, installed a biogas plant mainly to gain independence from other energy sources. At canteens and vegetable markets, motivation to install a biogas plant is a combination of both appropriate waste treatment and energy production.

3.4 Operation

Mixing of organic waste with water and filling it manually into the digester are the main daily prerequisites to operate a biogas plant. BARC is the only operator who uses solar energy to heat the water prior to filling the organic waste into the digester, thus accelerating the decomposition process. Moreover, the question pertaining to reducing the waste to small pieces (by hand or electrical mixer) before filling it into the digester remains controversial. Small pieces will decompose more rapidly and the digestion process might be more stable. However, a mixer consumes additional energy and thus reduces the plant's energy efficiency.

One to two persons are needed to operate the institutional plants assessed (up to 5 t/d). Additional staff is required if the waste has to be collected from households and sorted at the plant. At household level plants, the housewife or servants normally feed the food leftovers to the digester on a daily basis.

3.5 Maintenance

In general, no regular but only minor maintenance work is reportedly required. All the systems are low-tech options devoid of stirring or heating devices or pumps. This makes the biogas plants more suitable for low and middle-income countries. Nonetheless, since the gasholder of all institutional plants (floating drum systems) is made of steel, regular painting is recommended to prevent corrosion. In the event of system failure, maintenance service is generally provided on a contractual basis by the organisation that installed the plant. Though maintenance is allegedly minimal, MAILHEM and BARC find it increasingly difficult to provide it due to the already large number of plants installed. According to MAILHEM, good engineers interested in waste management are difficult to find. BARC intends to train students in engineering technology in plant maintenance. According to most operators, sludge emptying of the plants is not required as long as the plant is operating well. Some plants have been operated for five years without any desludging. Nevertheless, MAILHEM recommends annual emptying of the digester. These contradicting views still need to be resolved.

3.6 Gas Production and Use

The amount of gas generated per tonne of feedstock varies from 80 to 200 m^3/t. Bibliographic references reveal that these differences in biogas yield are normal (Fachagentur Nachwachsende Rohstoffe, 2006). However, the database is rather limited due to the lack of monitoring programmes at the plants.

According to biogas plant size and location, the gas is used for different purposes. At household level, the gas is always directly used for cooking. According to BIOTECH, 5 kg of food waste produces about 1 m^3 of biogas, which is sufficient for two hours of cooking on a gas stove. If the plant is installed right next to a canteen or restaurant, cooking is the simplest form of gas use. The gas produced by plants located at markets is used to generate electricity and for street lighting. The survey revealed that the use of gas can be a problem if the plant is sited at new housing complexes or in slum areas. An even distribution of gas to all households for cooking is not feasible, and gas production may be too low to generate electricity. Use of the gas for lighting appears to be the only suitable option. In some cases, where the plant is primarily regarded as a waste treatment installation, the gas produced is not recovered but only burned.

3.7 Use of Digester Effluent

A distinction has to be made between solid and liquid effluent residues. According to some operators, all the solids are digested and the remaining effluent is only liquid. The amount of solids accumulated in the digester is not known. The liquid is either used as a fertiliser in gardens, reused in the biogas plant or discharged via the drainage. Where the plant is connected to latrines to treat human faeces, the outlet is connected to a septic tank or drainage system.

At plants where solids remain, the sludge is normally used as a fertiliser in the surrounding area. An NGO operating a BARC plant in Mumbai can sell the sludge as fertiliser for INR 20 per kg. The effluent quality and fertilising effect are reportedly very good, however, analyses of the nutrient or heavy metal content are scarce. According to BARC's analyses, the C:N ratio is rather low (11:1) and the phosphorus content of 0.06% is far below the Swiss and Indian quality standards for digestate. However, the analysed sludge is free from weed seeds and does not contain any heavy metals (Mehetre, S.T. and Kale, S.P., undated).

3.8 Economic Aspects

The initial investment for ARTI and BIOTECH's domestic biogas plants amounts to some INR 10,000 (Euro 150), including the stove. According to ARTI, a typical urban household can save 100 kg of LPG or 250 litres of kerosene every year. One cylinder of LPG (14.2 kg) costs INR 306 for residential use. Seven cylinders of LPG amounting to totally INR 2142 (Euro 32) can be saved per household every year. This concurs with BIOTECH's figures, which reveal that INR 2280 can be saved annually by replacing LPG. Of all the organisations visited in South India, only the household biogas plants of BIOTECH in Trivandrum receive subsidies from the National Ministry of Non-conventional Energy Sources and from local and district councils. These subsidies cover about half of the sales costs. The ARTI plants will also be subsidised as soon as turnkey plants are manufactured.

The costs for the larger institutional plants seem to differ considerably.

Organisation	Capacity	Investment costs without land costs (INR)	Costs per kg (INR)	Remarks
BARC	5 000 kg/d	2 000 000	400	
BARC licensee	1 000 kg/d	1 000 000	1 000	Incl. operation & maintenance for one year
BARC licensee	5 000 kg/d	3 500 000	700	Incl. operation & maintenance for one year
Deepak Kanhere	170 kg/d	550 000	3 235	
TIDE	50 kg/d	125 000	2 500	
BIOTECH	250 kg/d	2 000 000	8 000	

INR 1 000 = Euro 15

Cost savings vary from one plant to another, depending on gas use. As mentioned earlier, biogas generation is not always the main objective, since many plant operators consider appropriate solid waste management as their major task. Therefore, the cost-saving factor for the municipalities incurred by lower waste collection and transport costs and extension of the lifespan of landfills have to be taken into consideration.

Moreover, anaerobic digestion qualifies as a CDM project under the Kyoto protocol (avoiding uncontrolled methane emissions from dumping waste at solid waste disposal sites). CDM investments may thus further boost development and implementation of biogas facilities in developing countries.

3.9 Socio-Cultural Aspects

Though anaerobic digestion is not a new technology in rural areas of India, biogas plants in urban settings have been implemented only recently. Acceptance of the technology does not seem to pose a problem, as the use of biogas for cooking is well-established. Since people already cook on gas stoves using LPG, a change to biogas will not alter their habits decisively. Only one of the visited biogas plants was connected to school latrines. No objections were identified regarding the use of biogas generated from faeces for cooking in the canteen. However, in other regions, this is a most delicate and sometimes inconceivable issue for users.

MAILHEM insists that waste segregation at household level is not practicable and prefers to collect the mixed household waste and sort it at the plant. On the other hand, BIOTECH in Kerala promotes waste segregation at household level by awareness raising campaigns. BARC also runs awareness programmes (house-to-house information) at some locations. However, according to TIDE's negative experience with municipal waste-fed plants, anaerobic digestion is a very good treatment option for industrial waste (e.g. coffee pulp), where organic waste is accumulating uncontaminated but probably not a viable option for organic household waste.

4. CONCLUSIONS

The experiences from South India indicate that anaerobic digestion of organic solid waste is a promising technology for developing countries with a tropical climate. The potential for biogas plants treating canteen, market and segregated household waste in India is enormous. Though most municipalities do not support the initiatives, neither financially nor ideologically, many private investors are convinced that this rather new treatment option will solve the urban waste problems and also produce energy. The primary reason for establishing and operating these facilities is the need for a waste treatment solution. Biogas is often only an added value by-product in the waste treatment process.

The current database proved rather limited. Sandec's future research will therefore focus on biogas plant performance to obtain more accurate information on gas production, effluent quality, as well as on the economic feasibility and social aspects of this waste treatment method. African countries are particularly deficient in research, development and implementation of biogas plants. Preliminary monitoring results from a household biogas plant in Dar es Salaam, Tanzania are expected for summer 2008.

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Table 1.1. Overview of the visited biogas plants in South India

Organisation	Location	Feedstock	Daily load	Use of gas	In operation since
ARTI, Pune	Pilot plant at ARTI office, Pune	Kitchen waste	1 – 2 kg/d	Cooking	2003
ARTI, Pune	Home of ARTI employee	Kitchen waste	1.5 kg/d	Cooking	2004
ASTRA, Bangalore	Indian Institute of Science, pilot plant	Leaves	Irregular	Not used	1995
BARC, Mumbai	BARC Campus, Mumbai	Canteen waste & segregated household waste	1 – 1.2 t/d	Cooking	2002
BARC, Mumbai	Hiranandani, Thane	Source segregated household waste	1.5 – 3 t/d	Not used; burned down (electricity generation intended)	December 2004
BARC, Mumbai	Shatabdi Hospital, Mumbai	Food waste from hotels	2.5 – 3 t/d	Water heating for biogas plant; electricity generation in testing phase	May 2003
BIOTECH, Trivandrum	Centre for Rehabilitation of the Disabled, Trivandrum	Canteen waste plus toilet waste from 150 people (connected to latrines)	250 kg/d food waste; approx. 20 kg excreta and 220 l water	Cooking	2000
BIOTECH, Trivandrum	PMG Office (Postal Live Insurance), Trivandrum	Kitchen waste	30 kg/d	Cooking	February 2007
BIOTECH, Trivandrum	Kadakkal, Grama Panchayath, Kollam District	Market waste and slaughterhouse waste	250 kg/d	Electricity generation for running an incinerator and lighting	2003
BIOTECH, Trivandrum	Kottarakara, Grama Panchayath, Kollam District	Market waste (vegetables and fish)	Initial phase; planned for 250 kg/d	Electricity generation for lighting	August 2007
BIOTECH, Trivandrum	Sreekariyam, Grama Panchayath, Trivandrum District	Market waste (vegetables and fish)	100 kg/d	Electricity generation for lighting	2005
Kanhere Deepak, Pune	School in Latur (Jankalyam Niwasi)	Canteen waste from school	Initial phase; planned for 170 kg/d	Cooking	July 2007
Kanhere Deepak, Pune	Hotel Basaveshwar, Pune District	Kitchen waste from 6–7 hotels in the area	Unknown	Cooking and electricity generation	2005
MAILHEM, Pune	Kirloskar Oil Engines LTD, Khadki, Pune	Canteen waste	350 kg/d	Cooking	2003
MAILHEM, Pune	Magarpatta City, Pune	Mixed household waste (sorted at plant)	2 t/d	Electricity generation	2005
TIDE, Bangalore	Space Centre, Bangalore	Canteen waste	50 kg/d	Cooking	February 2007