Fig. 1 - The laboratory where plants are assembled

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TECHNICAL, SOCIO/ECONOMICAL AND ENVIRONMENTAL ASPECTS OF BIOGAS GENERATION USING RURAL HOUSEHOLD WASTE

Anaerobic digestion of vegetable waste daily produced by small households in Alotenango, Sacatépequez-Guatemala generates biogas sufficient for their daily cooking. This rural, most efficient technology results in significant economical advantages and avoids wood burning, smoke hazards and contamination due to abusive disposal of waste in land fills and rivers. The only limit to the widespread application of the technology is its unfamiliarity to a large number of potential users. Our bottom-up approach to solve this problem is outlined.

Comprehensive surveys of biogas technology are presented in the classical book by Chawla [1] (covering developments until 1985) and in more recent literature [2]. Pioneering studies on anaerobic digestion started in the early 30's [3] and were followed by the installation of large and medium-sized plants in Europe for the treatment of agricultural and sewage residues, and for energy generation [4]. Small-scale anaerobic digesters were also early developed in rural communities in India, China, and other developing countries in Asia, Africa and South America [5]. The science and technology of anaerobic digestion was the subject of extensive investigation particularly in India, and basic analytical and microbiological studies and plant design were elaborated [1, 3]. The overwhelming emphasis was then on cattle dung, only a minor consideration being given to vegetable, household waste.

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Renewed interest on biogas technology has recently been associated to economical and environmental considerations, to the global energy shortage, to the need for waste control, to atmospheric and water pollution [2]. In this context, it has been relevant to tackle the production of organic waste from medium-sized establishments (condominium, hospitals, hotels) [6] and, particularly, from rural villages down to the limit of single households. In fact, the majority of population in developing countries lives in villages, and up to 65% of the overall organic waste daily produced derives from animal and plant residues [7]. Moreover, sewage control, garbage collection, and open-fire burning are particularly critical in villages of developing and third world countries.

We describe in this report a successful initiative carried out in Guatemala in the village of San Juan Alotenango-Sacatepéquez where an anaerobic system, based on a typical floating-dome plant fed with organic kitchen waste, produced biogas in a yield sufficient for the daily needs of small households. Details of the system and its operation are described below, followed by socio/economical and environmental considerations. The assembly of the plant was done in a laboratory established in the center of Alotenango (Fig. 1). The optimization of results was achieved in a field study of the structural and operational variables of the system, constantly involving the interest and cooperation of household's members.

Design and operation

Design of biogas plant

The biogas plant consists of two polyethylene tanks following the original ARTI design [8]. A lower digester has a nominal capacity of 750 liters and the upper gas reservoir has a capacity of 450 liters (Fig. 2). The tanks are commercially available water tanks modified for biogas use. Treatments of the inner surface of the lower digester were considered. The weight of the reservoir assured a minimal gas pressure corresponding to a few centimeters water column (cf. ref. 1, p. 60). An inlet pipe is used for adding waste to the bottom of the digester. An outlet pipe allows removal of digested waste from the top of the digester. The gas reservoir is fitted with a guide frame to ensure its smooth and vertical movement. The vertical displacement of the reservoir allows the measurement of biogas produced, and delivered to the stove through a valve. The biogas generated by the daily digestion of kitchen wastes is burned in a locally produced biogas stove according to the ARTI model (Fig. 3). Large holes at the gas inlet and at the surface of the burner are the main features of the stove. This allows for an efficient combustion of biogas, which contains a significant portion of CO_2 and is delivered under a minimal pressure [1]. Mixing of components (cf. ref. 1, p. 53) was achieved by a fine dispersion of the feed and by daily rotatory motion of the reservoir. The temperature was in the mesophylic range (~25 °C, cf. ref.1, p. 37) and pH was in the order of 7.0. Reported results were obtained using two similar plants installed in two different neighborhoods.

Initial feeding

The digester is filled with a homogeneous mixture of ~300 liters cow dung and an amount of water resulting in a ~600 liters total digesting volume. A 5 to 10% inoculum rich in active bacteria is added to hasten the fermentation process (cf. ref. 1 p. 61). The 1:1 volume ratio of dung and water is generally regarded as the optimal ratio for anaerobic digestion of cattle excreta [1, 8]. A two week digestion allows for a substantial production of bacteria and initial biogas. The origin of cow dung appeared to have a significant effect on the rate and amount of initial biogas generation. This is primarily attributed to differences in total solid content (TS) and possibly cattle type and feed (cf. ref. 1, p. 51).

Daily feeding

The daily feeding of kitchen waste started nightly following a substantial generation of biogas from the cow dung. Flushing out the first gas was necessary. The daily feeding consisted of organic kitchen wastes produced by a family of three and including banana peels, papaya skins, dried tortillas, other fruit wastes and food leftovers in random proportions. Optimized parameters found to maximize biogas yield were as follow.

Fig. 2 - The assembly platform

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Fig. 3 - The biogas burner

The average volume of daily waste was about 500 ml. A 38% dry matter was analytically estimated, amounting to ~200 g TS in the feed. The waste mixture was blended in a food processor along with 250 ml water (a negligible cost for electricity being involved). The paste was then mixed with 750 ml water and fed to the biogas plant. The dry matter (200 g) included in the total volume of feed (1,500 ml) corresponds to a composition of 13% at which good rate of bacterial digestion is expected (cf. ref. 1. p. 48). Note, however, that over 50% solids are destroyed during anaerobic digestion at large retention times (average time the feed remains in the digester, cf. ref. 1 Table 12). An amount of digested waste corresponding to the 1,500 ml feed was expelled from the outlet pipe. A large retention time of the daily feed is revealed by the volume ratio of digester to feed (HRT: cf. ref. 1, p 133). The digested waste is an excellent fertilizer usable in the small garden of the household.

Amount of gas produced

The maximum daily gas production from our plant was in the order of 100 liters (reflecting a total displacement of ~15 cm over a 24 hrs period of the 86 cm diameter reservoir). This result can be compared to the extensive data of Taiganides [9] predicting a gas production between 0.40 and 0.75 m^3/kg TVS (TVS, total volatile matter, ~80% TS) at 25 °C for animal waste digestion. For a feed containing 200 g TS, the corresponding yield is between 60 and 120 liters of gas, in line with the production actually observed with our plant. The optimized parameters allow therefore the attainment of quite a satisfactory biogas yield from vegetable waste.

Usage schedule

The type, quantity and frequency of meals determine the cooking time requirements. For the particular families involved in the present study, the average daily cooking time (3 times/day) was in the order of 1 hour (full flame, corresponding to the complete consumption of the daily biogas production). Occasionally, an increase of gas pressure was achieved by adding a weight to the top of the reservoir.

Socio/economical and environmental considerations

Although family-size plants using animal waste are extensively developed in India and in China, only a limited number of small plants using kitchen waste are described in the literature [8], and their socio/economical impact is not adequately documented.
A characteristic feature of the present study is the total involvement of local users in the assembly and operation of the plant. The families handling the two plants of the present study were carefully selected for interest, dedication and genuine curiosity toward the generation of biogas. Their precious experience in the advantages and limitation of biogas technology makes them the best advocates for a bottom-up diffusion of additional plants through the community. In fact, four new plants are currently being distributed and the selection, the installation and training of the new users is essentially made by established ones (Fig. 4). The four new plants are already spreading additional interest and demand, extending to neighboring villages.
The most significant advantage which attracts the interest of new users is the above documented observation that the kitchen residues of a small family produce enough biogas to cover their daily cooking need. The families participating in the study used a combination of wood-burning stoves and propane cylinders before including biogas to their daily routine. They report that wood burning can now be greatly reduced, and propane is only occasionally used. A propane cylinder will now last for about four months as opposed to one cylinder per month before biogas was started. The non-negligible saving corresponds to about 100 USD per year. Moreover, the members of the household have developed a sense of pride for their new activity which attracts the interest of the community (extending to local media, public and private organizations) and relieves them from carrying wood to the house and depending from energy providers. At the present time the cost of the plants (in order of 250 USD ea) is entirely supported by

the Foundation which initiated the pilot project. It is projected that cost will eventually be lowered by an increasing demand, and shared in equal parts by families, Municipality and Foundation.

Additional advantages of biogas technology are manifested in a reduced contamination of the ecosystems. The families necessarily acquire the habit of separating the organic matter from metal, glass and plastic residues that are purchased and recycled by specialized companies. In fact, the gasification of organic matter represents a most efficient approach to the disposal of garbage, which is otherwise commonly discharged in non-regulated land fills and rivers. Furthermore, avoiding wood burning protects vegetation around villages, and prevents the occurrence of fumes and fires inside the houses. The indoor air pollution is known to constitute a most serious health hazard in rural households [8].

Some problems encountered in the diffusion of biogas technology in rural villages should also be considered. Potential users are primarily concerned about:

1) handling the initial cow dung charge,
2) selection and treatment of daily feed,
3) safety regarding the gas stored in the reservoir,
4) odors.

The households involved in the present study have been able to surmount these problems noting that: 1) cow dung can usually be donated from local farms or neighbors. 2) isolation of the non-vegetable components of garbage is an unavoidable process allowing recycling, being performed even in developed countries, 3) methane is not toxic and the reservoir (performing as a conventional gasometer) allows its escape only

Fig. 4 - Plant in operation in a rural house

through the burner where combustion with oxygen produces CO_2. A direct global warming contribution of methane is thus ruled out [10]. Moreover, methane flammability can occur only over a small concentration range (5-15%) in air, and the gas at room temperature is lighter than air; 4) odors are manifested only during the initial feed with cow dung and when the first gas is produced. This gas does not burn (due to a large CO_2 component) and needs to be evacuated through the gas valve. Once burning of biogas begins the odors disappear.

Scaling down, scaling up

The plants described above could store an amount of biogas considerably larger than the amount produced by the organic waste of either households. Tailoring the plants to the actual need of the users is an important consideration in plant design. The rather modest consumption of biogas for the daily cooking (~100 liters) is a reflection of local habits and specific requirements of each household. It is relevant to note that the main staple of the community (corn tortillas and black beans) is traditionally cooked over wood stove; no other heating source would be acceptable. The size of the plant suitable for these household could therefore be considerably scaled down and we are currently planning a 300 liter plastic digester and an upper plastic reservoir having a 70 cm diameter (expecting a ~25 cm displacement for the same amount of waste currently used). A smaller plant would also be advantageous from the point of view of cost and maneuverability.

The amount of gas daily produced could on the other hand be scaled up for larger households or whenever larger amounts of digestible residue are available. Suitably larger digesters and reservoirs could be designed. Whenever more gas is necessary and no alteration of the amount of vegetable waste is possible, the production of biogas from human excreta might be considered. Chawla (ref. 1, p. 80) reports that biogas production from night soil is larger than from cow dung, and pathogens are being destroyed during the digestion. He suggested the addition of human excreta to cow dung or, better, the attachment of toilets to digesters. We have been exploring an alternative approach that would be more consistent with the habits of our community: mixing the gas but not the excreta. However, coupling our plant to a plastic septic tank has not so far produced good results. Two main problems are involved in such an attempt. One is the design of conventional septic tanks aiming at the formation of two rather well distinct phases: a prevalently solid and a prevalently liquid one. The other problem is the

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Fig. 5 - Biodigesters serving new condominiums in India (Mailhem Group)

large amount of water customarily used to flush, which contrasts the need to achieve the composition for desirable rate of bacterial digestion.

Additional plant designs could be considered (e.g. fix domes, under ground cement digesters, movable iron domes). Our selection of a plastic biodigester-reservoir system for the current pilot study proved to be advantageous for maneuverability, cleaning and rapid visual assessment of biogas produced.

Biogas generation is the overriding need in rural villages of developing countries. However, the anaerobic digestion technology is attracting renewed interest even in developed countries as an efficient approach to waste control. Small and medium sized digesters are a common feature of new condominiums in India (Fig. 5), where a law requires the local treatment of organic waste [6]. Similar approaches may soon become necessary in Europe.

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ABSTRACT

Aspetti tecnici, socio-economici e ambientali della generazione di biogas da rifiuti domestici rurali

La digestione anaerobica di rifiuti vegetali prodotti dai piccoli insediamenti rurali di Alotenango, Sacatepéquez-Guatemala genera una quantità di biogas sufficiente per cucinare quotidianamente. Questa tecnologia, molto efficiente, porta a significativi vantaggi economici ed evita inoltre di bruciare legna, il rischio incendi e il rischio di inquinamento di terreni e fiumi a causa di evenuali discariche abusive. Il grosso limite è la sua scarsa diffusione dovuta alle difficoltà di utilizzo. Nell'articolo viene delineato un approccio per risolvere questo problema.