

## Field Scale, Night-Soil Based Biogas Digester Made from HDPE – A Case Study through Optimisation

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### ABSTRACT

*Waste disposal in a developing country such as India is a menace, due to the large quantity of waste generated and the poor suitability of methods available. The anaerobic method of digestion is one of the more viable modes of waste handling, although the efficiency is much lower than that achieved in the aerobic mode, in terms of suitability for disposal. However, the impending energy crisis coupled with ever increasing energy demands, seems to favour anaerobic methods of waste disposal, primarily for their ability to produce methane, which can be used as a non-polluting fuel.*

*In this paper the viability of using High Density Polyethylene (HDPE) as a biodigester material for anaerobic digestion of night-soil is discussed. Although the waste stabilisation is less, the generation of methane is 0.6 m<sup>3</sup> per m<sup>3</sup> of fed slurry per day (methane content 70%), which is higher than that reported in conventional biodigesters. Taking into account several characteristics of HDPE, and its inertness to waste slurry or methane gas, it can be advocated for use as a material for biodigesters.*

### INTRODUCTION

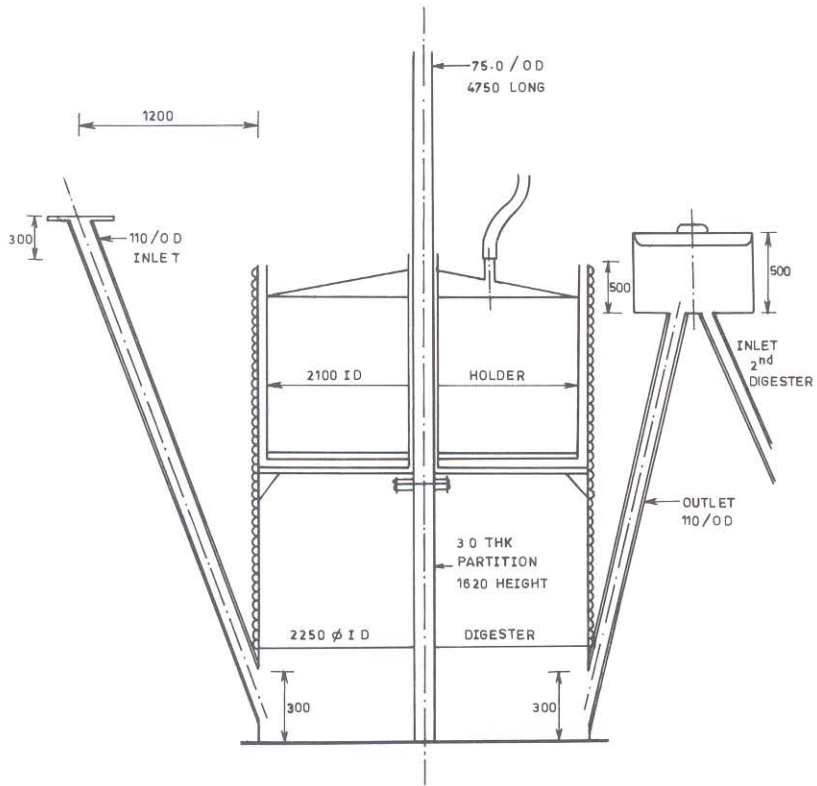
Although anaerobic decay is a common natural process, it has only recently attracted the attention of researchers. One of the prime reasons for this situation is the slow reproducibility of the methanogenic bacterial population, which is primarily responsible for the production of methane gas. From the energy point of view this process might not seem effective, but if an overall view with regards to waste disposal, hygiene and energy is considered, then anaerobic digestion is preferable to most other modes of waste handling.

Several designs have been tried and many more have been experimented upon, but two models, namely the floating dome and the fixed dome have been consistently propounded over the years. Biogas plants are chiefly constructed out of masonry work although the floating dome may be either of mild steel or of fibre glass. This paper presents the optimisation process of field scale biogas digesters made of High Density Polyethylene (HDPE) and utilising night-soil as substrate, for biogas production. By and large, in India, cattle dung is the only substrate used for biogas production. However, the principles of anaerobic digestion also apply to the digestion (degradation) of human night-soil (HNS). This application has a social relevance providing adequate sanitation and simultaneously obtaining fuel gas for cooking. Hence, it was felt necessary to carry out experiments on the use of HDPE to construct a biogas plant and to use HNS as the feed material. Moreover, within the city limits, it makes more sense to treat night-soil rather than cow dung, as a method for waste reduction.

### MATERIALS AND METHODS

#### Biogas Plants: Design and Construction

Four digesters each of capacity 12 m<sup>3</sup> and a floating dome capacity of 4 m<sup>3</sup> are connected in series. Strips of HDPE are spirally wound around a metallic drum (mandrel) of diameter 2.2 m. The strips are welded with the help of an extruder machine [1]. The result is the formation of a cylindrical tank of a specific height. In this case the height is 3.5 m. The strips of HDPE of width 120 mm are provided with a central hollow protrusion of inner diameter 32 mm. This accommodates the polypropylene (PP) tube to impart extra strength to the circular biodigesters. One end of the tank is sealed by using HDPE sheets. The centre of this cylinder has an HDPE pipe of diameter 75 mm, which acts as a guide pipe for the central partition wall, again an HDPE sheet. The guide pipe of the gas holder slides over the guide pipe of the digester resulting in the smooth sliding of the gas dome when gas is produced or utilised. The resulting biodigester is shown in Fig. 1.



All dimensions are in mm.

Fig. 1. Schematic drawing of a field scale biogas plant made from HDPE.

## Running of the Plant on Human Night-Soil

Night-soil is collected in a sump well and then pumped into the first digester, thereby it flows through the four digesters by gravity affecting a retention time of six days in totality. The initial charge was 10% cattle dung slurry and the plants were stabilised with respect to methanogenesis, on the same type of daily feed at 30 days hydraulic retention time (HRT). After this, night-soil was fed in increasing concentration. In four months time the plant received a daily feed exclusively of night-soil. Once the plant was stabilised with HNS it was run with definite loading conditions (Table 1) for a period of six months. The data presented in this paper was collected over a period of fifteen months during which the plant received only night-soil as the daily feed.

**Table 1. Operating conditions for anaerobic digestion of human night-soil.**

|  |  |
|--|--|
| Hydraulic retention time (HRT)                   | 6 days                                 |
| Loading rate (total solids)<br>(volatile solids) | 60 - 80 kg/day<br>40 - 50 kg/day       |
| Percent TS in influent                           | 0.75 - 1.0 %                           |
| pH of influent slurry                            | 6.8 - 7.0                              |
| Biogas produced                                  | 0.9 - 1.3m <sup>3</sup> /kg of fed COD |
| Methane content                                  | 62 - 72 %                              |

## Analysis

1. Quantity of gas produced daily was determined by measuring the height of each gas holder above the slurry level every day.
2. Percentage of methane in the biogas was determined by analysing the gas sample on a gas chromatograph (Chemito 3800) [2].
3. pH of the slurry was measured by using a pH meter (Control Dynamics, Bombay).
4. Total solids, total volatile solids, BOD and COD of influent and effluent slurry were measured by standard methods [3].
5. Volatile fatty acids were measured on a gas chromatograph (Chemito 3800) [4].
6. Temperature was measured by a thermocouple (Cr-Al).

## RESULT AND DISCUSSION

A few relevant characteristics of high density polyethylene are listed below (Table 2) [5]. These reflect the viability of HDPE being used as a material for biodigesters.

The thermal conductivity of thermoplastics like HDPE is around 0.0019 W/mK as compared to 54 W/mK for mild steel [6]. This property effectively protects the slurry within the digester from variations in external (atmospheric) temperature and thereby retaining the temperature of the digester. This is not the case in conventional digesters with gas holders made from mild steel. Temperature was found to be at one particular level, which facilitated faster hydrolysis of the long chain carbohydrates, fatty acids and proteins.

**Table 2. Characteristics of high density polyethylene (HDPE).**

|  |                               |
|--|-------------------------------|
| Specific gravity                             | 0.95 to 0.96                  |
| Transparency                                 | Nil                           |
| Tensile strength                             | 202 to 376 kg/cm <sup>2</sup> |
| Tensile modulus                              | 14 to 19 kg/cm <sup>2</sup>   |
| Impact strength                              | 12 Izod ft.lb/inch            |
| Maximum use temperature<br>(no load)         | 78°C to 120°C                 |
| HDPE is resistant to most acids and alkalis. |                               |

Since the strength of materials recorded in Table 2 is initial, no visible aberrations were observed with respect to surface morphology or impact bearing strength on the walls of the HDPE biodigester, after a period of twenty months.

The impact bearing capacity prevents the digesters (underground or partially overground) from collapsing inwards due to ground movements. The tensile strength of the HDPE material used is 202 kg/cm<sup>2</sup>. The physical quantity which decides the ability of the HDPE biodigester to remain in a circular (cylindrical) shape is known as 'ring stiffness value'. This value in the case of the present digester is 0.6 kN/m<sup>2</sup>. This determines the capacity of the HDPE wall to bear load or pressure from the external peripheral surrounding. Normal pressure exerted by the topology of the ground is less than this almost by the order of a magnitude. This reaffirms the potential of HDPE being used as a digester material. No visible distortion was observed on the HDPE digester over a period of twenty months. Moreover, the cylindrical shape and thickness of HDPE sheets (6.0 mm) coupled with the polypropylene core as support material makes the sheets resistant to mechanical loads. This is supported by the fact that no obstruction resulted in the dome movement in the digester from the onset of plant commissioning.

Impregnation of carbon black within HDPE prevents harmful effects of ultra violet rays. These rays are converted to less harmful infra red rays.

To increase the pressure on the gas produced for household distribution, gunny bags filled with sand were placed on the domes so as to affect a pressure of 4 to 5 inches water column pressure.

The characteristics of the night-soil pumped into the digesters can be briefly summarised as follows:

The total solids content in the input slurry was small, to the tune of 0.75 to 1.00%. The volatile solid fraction comprised of 50% to 60% of dry matter. The pH of the input slurry was in the range of 6.8 to 7.0. The undigestible lignin content was 4.17% of the total solid fraction and all the important volatile fatty acid fraction was 700 to 800 mg/l.

The effective retention time resulting due to pumping of the slurry through the four digesters was 6 days. During the first thirteen months there was a gradual increase in the degradation of organic matter as reflected by reduction in BOD and COD of the influent (Fig. 2). This process got well established towards the end of the thirteenth month and remained so. The reduction in Biochemical Oxygen Demand (BOD) of the influent was 75% and the reduction in Chemical Oxygen Demand (COD) was 89% (Fig. 2). Total biogas production from the waste showed more or less a similar pattern (Fig. 2). Biogas produced daily during the thirteenth to the fifteenth month was between 0.49 to 0.64 m<sup>3</sup> per m<sup>3</sup> of fed slurry per day, equivalent to 3.4 to 4.8 m<sup>3</sup> per day. Methane content in the gas was 62 to 72%.

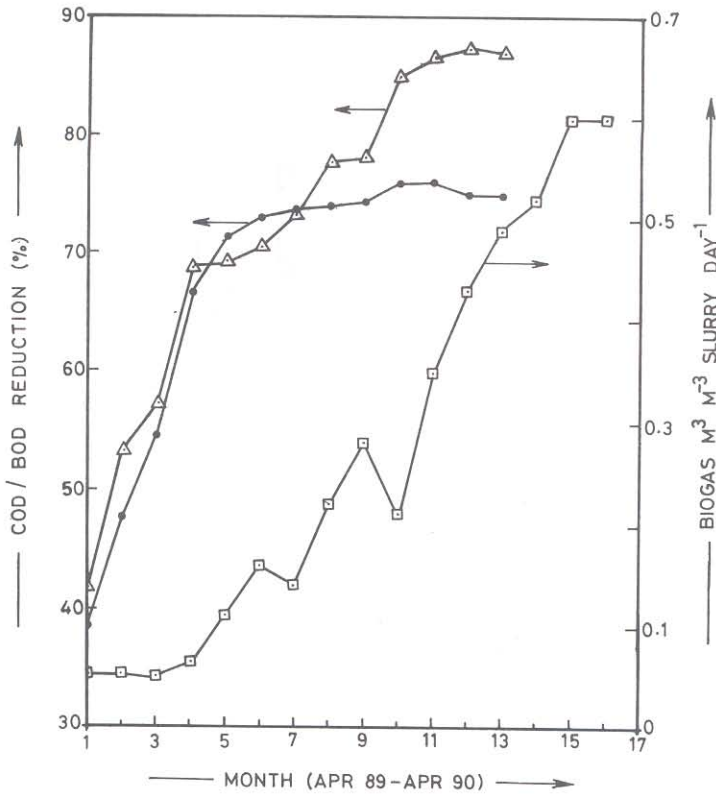


Fig. 2. Overall performance of biogas plant.

●—● % Reduction in BOD    ▲—▲ % Reduction in COD    □—□ Biogas produced

The results of the degradation of organic matter in terms of total volatile solids (TVS) and biogas produced in each plant when the digestion was stabilised are shown in Fig. 3. It is also seen from Fig. 3 that the degradation of organic matter was better in plants one and two. Conversion of organic matter, particularly of intermediate organic compounds resulting during degradation, into methane and carbon dioxide, i.e. biogas, was better in plants two and three.

Reduction in solid content was almost 50%. Gas production was  $0.2 \text{ m}^3 \text{ m}^{-3} \text{ slurry day}^{-1}$  (Fig. 2), once the optimisation was achieved. The methane content in the biogas also increased from 45% during the stages of optimisation to 72% once the digester was optimised. There are reports describing gas yield of about  $0.07$  to  $0.14 \text{ m}^3 \text{ m}^{-3}$  of fed slurry per day [7] and  $0.45 \text{ m}^3 \text{ m}^{-3}$  of fed slurry per day [8] for human night-soil. These experiments were conducted on a fixed dome type biogas plant and a completely stirred digester with separate gas holder, respectively. Similarly, methane yield obtained in the present studies was also higher (72%) as against from city sewage (50%) [9].

The initial optimisation period was for about a period of four months. This required daily feeding of cattle dung. But once the digester stabilised then cattle dung feeding was stopped and only night-soil was continuously fed. Tests conducted on HDPE after a period of twenty months showed no changes on the same with respect to its original properties, namely those shown in Table 2. There was no adverse effect on the anaerobic digestion within the HDPE digester also over the same period of time.

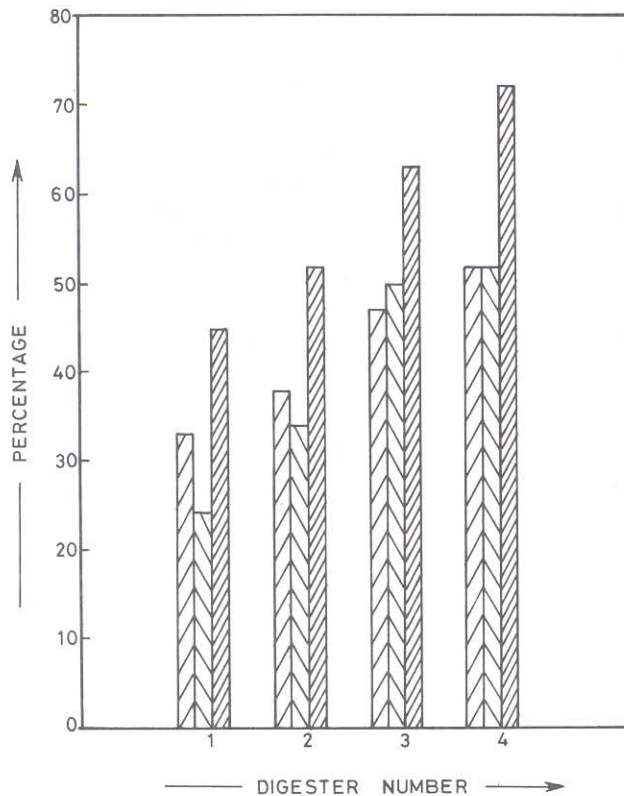





Fig. 3. Performance of individual biogas plant.

-  % Reduction in total solids
-  % Reduction in total volatile solids
-  % Methane in biogas produced

## CONCLUSION

From the results depicted, it is evident that HDPE is a suitable material for biogas digester construction. The cost of construction of an HDPE biogas digester (4 m<sup>3</sup> capacity) is Rs.60,000 (US\$ 1,900) along with installation charges and including excavation charges. The corresponding conventional cement concrete and steel dome digester costs around Rs.65,000 (US\$ 2,100) along with excavation charges. HDPE digesters can be above ground also, but the cost of cement digester, if to be constructed above ground, escalates the price due to extra reinforcement. However, considering the other advantages, namely consistency in methane generation over any seasonal variations and no corrosion effects on HDPE, these digesters seem to be definitely advantageous over conventional KVIC model biogas digesters made from conventional material. Although the retention time is low, gas production is quite high as compared to conventional digesters. However, weights need to be placed

on the gas holders to bring about a proper flame in the burners. But charge stabilisation is not satisfactory, due to the low retention time. Increasing the number of digesters or use of concentrated slurry as substrate to achieve further charge stabilisation is envisaged in the next phase of the present pilot plant.

## ACKNOWLEDGEMENT

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