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# A Ferrocement Digester: Biogas and Biomass Production

C. Polprasert*, W. Kanok-Nukulchai+, V. S. Rajput**

*This paper presents the detailed design and construction of four 3.5 $m^3$ biogas digesters using ferrocement. The digester is a fixed-cover type similar to the Chinese model, but a slurry mixing device was provided. Information about the biogas and biomass production from the digesters is included.*

## INTROCUCTION

Some of the serious problems facing developing countries are those pertaining to energy, food supply and disposal of human wastes. In recent years, the concept of renewable energy has received much attention because the energy produced would be relatively low-cost and available for various purposes. Biogas, a by-product of anaerobic fermentation of organic matter such as human, animal and vegetable wastes, is considered as one of the potential renewable energy sources. It largely consists of methane (~ 65%), carbon dioxide (~ 30%) and trace concentrations of other gases. Methane ($CH_4$) is the desired gas because of its high calorific value (890-1,070 BTU/$ft^3$) and can be used principally in heating, cooking and lighting. The integrated biogas technology (IBT) includes biogas production and utilization of the biogas digester slurry in biomass, such as algal and fish, production. The IBT can be beneficial in many ways because the human wastes are stabilized by the anaerobic fermentation process in the digester with the production of biogas, and the slurry, if applied at appropriate loadings to fish ponds, will result in the photosynthetic production of algae which consequently serve as food for the herbivorous fish. A schematic diagram of the IBT is shown in Fig. 1.

A research program has been underway at the Asian Institute of Technology for the past two years to develop appropriate waste recycling technologies for uses under tropical conditions. One of the schemes investigated involves the biogas production from human wastes (nightsoil) and the feeding of the digester slurry into fish ponds for the production of algae and herbivorous fish (Tilapia nilotica). This paper discusses the design of the biogas digester, its construction and cost using ferrocement, the digester performance, and some results of the algal-fish production in the fish ponds fed with digester slurry.

### Design of Ferrocement Biogas Digester

There are two major types of biogas digesters employed worldwide, namely, the movable cover or the Indian type [1] and the fixed cover or the Chinese type [2]. Although a considerable number of these biogas digesters have been installed, there have been numerous problems such as the high capital cost of construction and installation, temperature fluctuation, blocking of the inlet and outlet chambers, and no provision for mixing the contents of the digester [3, 4]. These factors, either individually or in combination, could lead to failure in $CH_4$ production and eventually to the abandoning of the biogas digester. Previous work was

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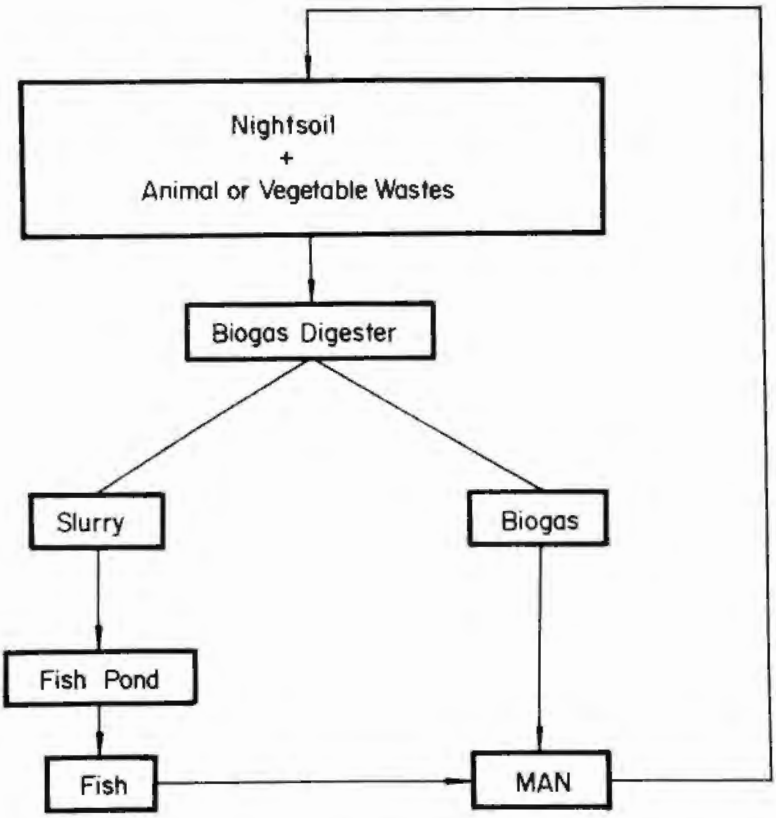


Fig. 1. Schematic diagram of integrated biogas technology.

undertaken to develop and modify the existing types of digester, and the size of the pilot scale digester (or the low-cost biogas digester) constructed was 60 litres [5]. In this study, the digester is similar to the low-cost biogas digester except with a few modifications. The digester size is 3.5 $m^3$ (Fig. 2). The main components of this biogas digester are described below and the construction details are presented in the following section.

1. **Inlet.** The raw materials (influent) are fed through this inlet into the digestion chamber. The inlet is made of 100 mm diameter PVC pipe fitted to the digestion chamber 100 mm above the digester bottom to allow for maximum contact between the organic matter in the influent and the anaerobic bacteria.

2. **Digestion Chamber.** The digestion chamber is made of a ferrocement cylinder with an inner diameter of 1500 mm and a height of 2000 mm. This chamber, where digestion of the organic matter occurs, is connected with the inlet, outlet and the water pressure tank connecting pipe. The chamber is placed 1300 mm underground to avoid excessive temperature fluctuation, and the exposed portion is painted black to absorb the solar heat during daytime.

3. **Gas Storage Chamber.** This is the free space in the top portion of the digestion chamber, the volume of which is subjected to changes due to gas pressure developed inside the chamber. The developed pressure will push the digester slurry up through the three openings, namely the inlet, the outlet and the water pressure tank connecting pipe.

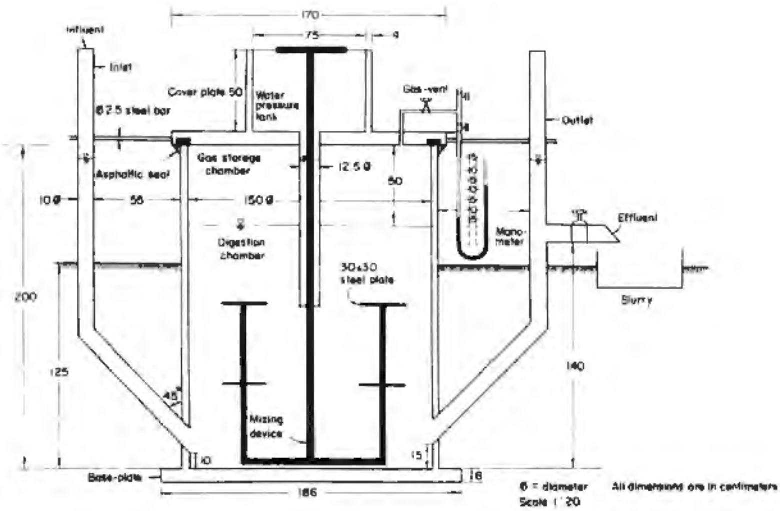


Fig. 2. Ferrocement biogas digester.

4. **Outlet.** The outlet is made of 100 mm diameter PVC pipe fitted to the digestion chamber at the level 150 mm above the digester bottom. A drainage pipe, made of 100 mm diameter PVC and incorporated to the outlet, is closed with a valve except when draining off the digester slurry.

5. **Water Pressure Tank.** The water pressure tank, a hollow square of concrete (700 × 700 × 500 mm: width × length × depth), is connected to the digestion chamber by a 120 mm diameter steel pipe inserted into the slurry about 1000 mm above the digester bottom. The slurry enters the water pressure tank when there is pressure developed in the digestion chamber and will stay there as long as the pressure in the gas storage chamber is higher than the atmospheric pressure. The level of slurry in the water pressure tank is used as a pressure head to force the gas in the storage chamber to flow through the gas vent to the gas facilities. Because the pressure head of slurry in the water pressure tank is equal to those in the inlet and outlet, the locations of these inlet and outlet should be high enough to avoid unnecessary spill of the slurry. The water pressure tank is necessary for storing the excessive slurry pushed up by the biogas pressure; otherwise, the sizes of the inlet and outlet have to be enlarged.

6. **Gas vent.** The gas vent, made of 20 mm diameter PVC pipe is equipped with a valve for controlling the gas flow rate. There is a manometer connected to the gas line for pressure measurement. The excessive gas produced is stored in a separate gas storage tank as shown in Fig. 3.

7. **Mixing Device.** A mixing device is consisted of a central steel pipe with a handle at its top and four 5 mm thick steel disks (300 × 300 mm): width × length) attached as shown in Fig. 2. Mixing is accomplished by rotary and vertical translatory motions of the central steel pipe. The disks agitate the slurry to provide better contact between the organic matter and the bacteria, and this operation prevents accumulation of the digested residues in the digestion chamber.

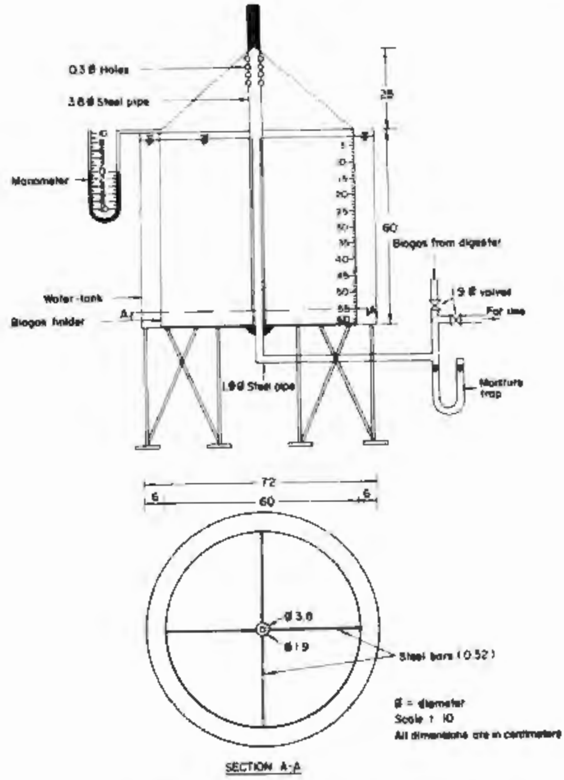


Fig. 3. Separate gas storage tank.

## Construction of Ferrocement Biogas Digester and Cost

Ferrocement is chosen for the construction of the biogas digester because of its superior crackproof property, which ensures a hermetically sealed biogas holder. The ferrocement cylinder is partially embedded underground; thus, the earth pressure is allowed to counter the exerting biogas and slurry pressures. From the structural point of view, this should lead to a more economic structure as the critical load is reduced. The base of the cylinder, made of ordinary reinforced concrete, is extended 150 mm from the cylinder wall. Therefore, the imposing weight of soil column above this cylinder toe will serve to prevent possible up-lifting when the cylinder is empty.

Structural details of this ferrocement cylinder are given in Fig. 4. The ferrocement design has followed the guidelines suggested in reference [6]. A rigorous thin shell analysis [7] was conducted to ensure serviceability of the structure under any critical loading. The cylinder is assumed to be fully clamped at the base and subjected to different combinations of slurry, biogas and earth pressures. Both the critical tensile and compressive stresses developed in the ferrocement body are found to be well below the corresponding yield strengths of the composite.

Since the emphasis of this section is to be concerned with various stages of the practical biogas digester construction, the detailed presentation of structural analysis and design will be deferred to future paper.

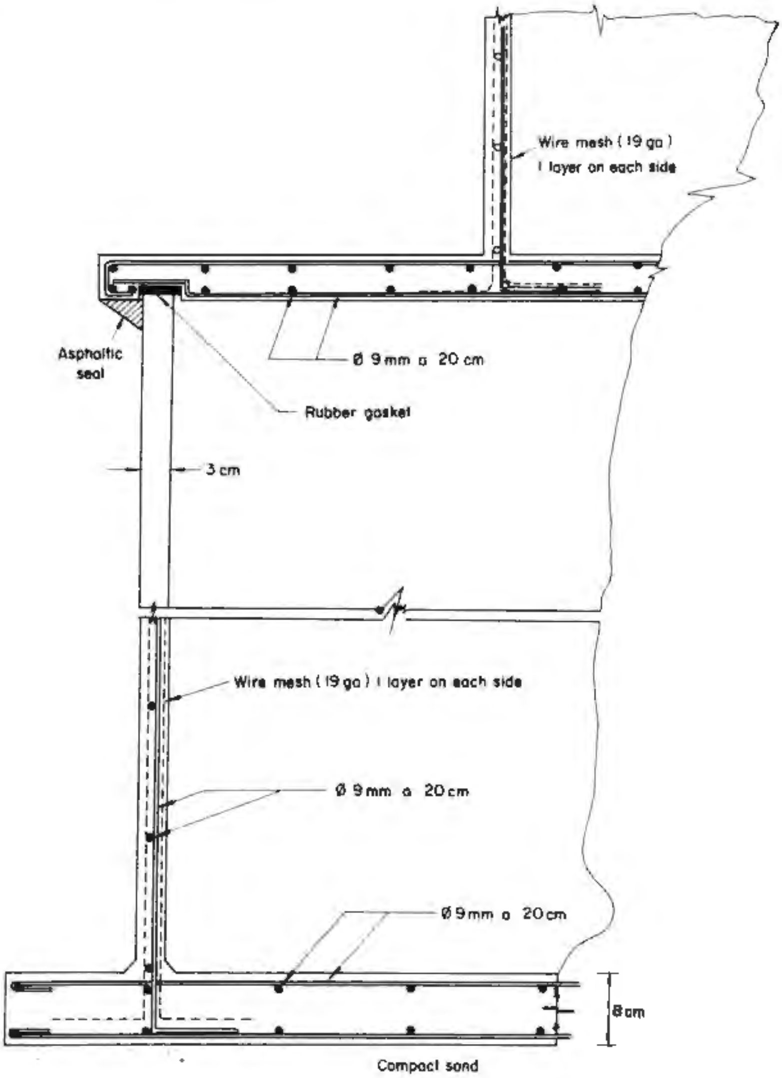


**Fig. 4. Structural details of the ferrocement biogas cylinder and the water pressure tank.**

Major steps involved in the construction of the ferrocement biogas digester are the following:

1. Site preparation. The biogas digester should be erected on soils with adequate bearing capacity. After the site is chosen, a hole of about 1.5 m deep and 2 m in diameter is excavated. A layer of sand about 250 mm thick is laid and firmly compacted.

2. Prefabrication of the skeletal steel cylinder cage. The skeletal steel cage is framed with $\phi$ 9 mm steel bars at 200 mm spacing both in the circumferential and the longitudinal directions. For the base, two layers of reinforcing steel bars of the same size and spacing are placed along any two orthogonal directions. Then, the 19 gauge chicken wire mesh is wrapped around and tied to the skeleton, one layer on each side. Skeletal bars and wire mesh from the cylinder wall also extend into the base to provide necessary continuity.

3. Plastering. After the cage is moved into the excavated hole, mortar is poured to cast the reinforced concrete base. Curing is allowed for a day before plastering starts. Meanwhile, the lid and pressure tank component can be fabricated separately under the usual procedure.

Prior to plastering, all accessory attachments such as the inlet and outlet sockets are prepared. The mix proportion used in this job is 1 : 1.75 : 0.35 for cement : sand : water by weight.

4. After the ferrocement cylinder has developed sufficient strength, the lid and pressure tank component completed with all accessory attachments can be lifted to sit on the cylinder rim. A ring of rubber gasket is used at the contact to ensure airtightness. Seams between the lid and the cylinder lip can be sealed with fresh concrete paste or any other sealant. After proper curing, all accessory attachments are to be completed. The digester should then be tested to ensure that there are no leaks. Finally, the exposed surface of the digester is coated with black paint and the ferrocement biogas digester should be ready for service.

The material quantities and cost breakdown for constructing one of this ferrocement biogas digester are estimated in Table 1. This estimation is based on the local market price in Bangkok during August 1981. The total cost of the 3.5 $m^3$ ferrocement biogas digester is about 4900 Baht (US $ 215).

Table 1. Cost estimation of the ferrocement digester.

| Item | Quantity required | Unit Cost (B*) | Cost (B*) |
|---|---|---|---|
| a) Ferrocement wall and pressure tank | | | |
| Portland cement | 380 kg | 1.60 | 608.00 |
| Sand | 0.4 $m^3$ | 180.00 | 72.00 |
| Wiremesh | 22.5 $m^2$ | 20.00 | 450.00 |
| Steel bars | 61.5 kg | 9.00 | 553.50 |
| Sub-total | | | 1683.50 |
| b) R.C. base and lid | | | |
| Mortar | 0.4 $m^3$ | 1000.00 | 400.00 |
| Steel bars | 130.0 kg | 9.00 | 1170.00 |
| Sub-total | | | 1570.00 |
| c) Labour | | | |
| Skilled (man-hours) | 20 | 15.00 | 300.00 |
| Unskilled (man-hours) | 80 | 8.00 | 640.00 |
| Sub-total | | | 940.00 |
| d) Miscellaneous | | | |
| Coating | | | 200.00 |
| Accessory piping | | | 500.00 |
| Sub-total | | | 700.00 |
| TOTAL | | | 4893.50 |

* 1 US$ = B 22.70; Cost figures in August 1981 for Thailand.

**Ferrocement Biogas Digester Performance**

Four 3.5 $m^3$ ferrocement digesters were constructed adjacent to four fish ponds (each with dimensions 10 m × 20 m × 1 m: width × length × depth), all located at the Regional Engineering Experiment Center, AIT campus. The digester slurry produced was collected and stored in a 1 $m^3$ storage tank to make a composite slurry sample prior to feeding to the fish ponds. The schematic layout of this system is shown in Fig. 5 and a picture of the ferrocement digester in operation is shown in Fig. 6.

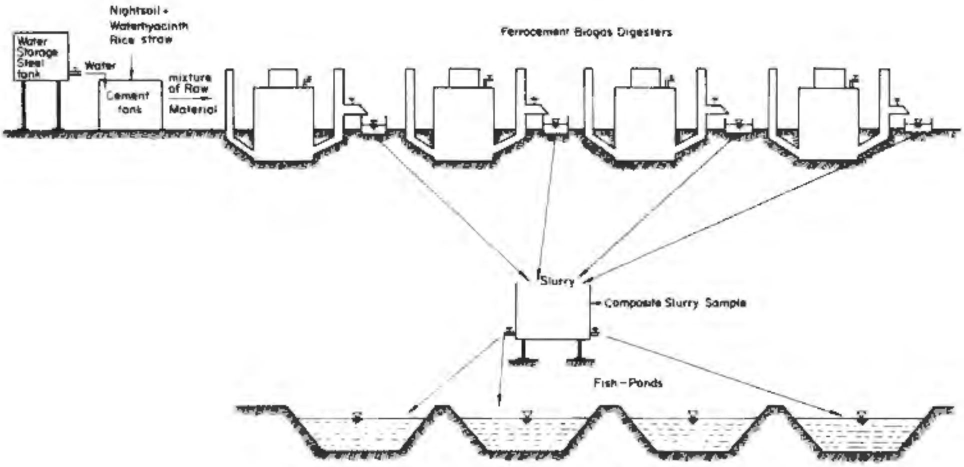


Fig. 5. Schematic layout of ferrocement biogas digester-fish pond system.

Fig. 6. Ferrocement biogas digester in operation.

The raw materials used as influent to the digesters were a mixture of nightsoil, water hyacinth (Eichhornia crassipes) and rice straw. The nightsoil was obtained from a jail in Patumthani province, the water hyacinth and rice straw were available in abundance nearby, and some characteristics of these raw materials are presented in Table 2. Because the optimum C/N ratio of the food for anaerobic digestion is between 20:1 to 35:1 [8], the influent mixture was prepared in such a proportion as to produce a C/N ratio of 25:1 and its moisture content adjusted to be about 90%. Feeding of the digesters was undertaken daily while mixing was conducted twice daily, i.e. before and after the feeding. All digesters were operated at the hydraulic detention time of 50-70 days, and the quantity of slurry withdrawn was made equal to that of the influent fed in order to maintain this operating conditions. Because the four digesters had the same operating conditions, they yielded similar performance in terms of biogas-production and organic stabilization, and only the average results are reported herein.

Table 2. Some approximate characteristics of raw materials fed to ferrocement biogas digesters.

| Raw materials | Carbon, % by weight | Nitrogen, % by weight | Moisture content, % by weight | Volatile solids g/kg | C/N ratio |
|---|---|---|---|---|---|
| Water hyacinth | 45.5 | 1.6 | 23.0 | 820.0 | 29:1 |
| Night Soil | 47.9 | 4.2 | 87.6 | 861.9 | 11.5:1 |
| Rice Straw | 47.5 | 0.7 | 12.3 | 855.9 | 68:1 |

Each digester was started up with the batch process for 50 days by loading with 3.0 $m^3$ of the raw material mixture to acclimatize the anaerobic bacteria, then followed by continuous feeding for 3 months. The biogas production, after the acclimatization period, was found to range from 0.18 - 0.35 $m^3/kg$ VS added - day which is satisfactory when compared with the previous results of Kreatidadpanya [9]. The percent $CH_4$ content of the biogas was about 60% similar to those reported in the literature [10]. There was some fluctuation in the biogas production. This was due mainly to variation in the organic loadings because of the problems involved with nightsoil collection and transportation. Temperature and pH of the slurry in the digesters were about 30°C and 7, respectively, the levels favourable for the anaerobic digestion and biogas production. It should be noted that initially there was gas leakage at the joint between the ferrocement cylinder and the top cover, but this problem was overcome by applying an epoxy tar to the joint.

After about two months of operation, there was scum accumulation at the upper part of the slurry inside the digesters causing difficulty with the mixing and influent feeding. This problem was solved by (a) releasing the pressure inside the digester, (b) rigorous mixing of the slurry content, (c) withdrawal of parts of the slurry, and (d) feeding of the slurry and mixing of the slurry again. Another problem worth mentioning was the excessive pressure development inside the digesters due to the biogas production which could cause gas leakage especially at the joints or connecting parts of the ferrocement structure. This problem could be overcome by diverting this excessive gas to be stored in the separate gas storage tank as shown in Fig. 3 and 6. Because, in practice, the produced gas will be continuously used in cooking, heating and lighting, the need for this separate gas storage tank may not be essential. Apart from these two problems, the ferrocement degesters were found to function efficiently and satisfactorily.

**Biomass Production**

As can be seen from Table 3, the digester slurry still had high organic and nutrient contents based on the COD and volatile solids, and N and P concentrations, respectively. The percent reduction of COD, total solids and volatile solids ranged from 89-90, 58-91 and 70-95, respectively, indicating a high stabilization efficiency of the anaerobic process in this study. There were about 15-61 and 31-61 percent reduction of total nitrogen and phosphorus, respectively, which were due mainly to cell metabolism of these substances, their precipitation to the digester bottoms, and conversion of parts of the total nitrogen into nitrogen and ammonium gases. If this slurry is applied at facultative loadings to a pond, it will result in the algal bacteria symbiotic reactions in which the bacteria aerobically stabilize the organic matter with the production of $CO_2$ for the algae to photosynthetically produce the $O_2$ for the bacteria. These reactions result in the production of bacterial and algal biomass which can be used as food for the higher trophic organisms such as herbivorus fish. For a waste recycling pond which involves fish culture, the organic loading should be less than those of the facultative ponds or properly controlled so that the pond water dissolved oxygen (DO) does not reach zero at dawn due to algal respiration during dark periods. Fish normally become suffocative if subjected to low DO for a certain period of time.

Table 3. Some chemical characteristics of influent and effluent of ferrocement biogas digester.

| Parameters, all values in mg/1, except PH | Influent | Effluent | Percent Reduction |
|---|---|---|---|
| COD (total) | 26,220-88,780 | 2,850-8,420 | 89-90 |
| Total Solids | 39,170-55,500 | 5,240-19,850 | 58-91 |
| Volatile Solids | 29,170-44,500 | 2,100-11,000 | 70-95 |
| Total Nitrogen (N) | 760-1,610 | 598-863 | 15-61 |
| Phosphorous (P) | 140-195 | 79-100 | 31-61 |
| pH | 7.0-7.9 | 7.1-7.4 | |

In this study the organic loadings to the fish ponds were varied at 25, 50 and 100 kg COD/ha-day, the fourth pond was used as control in which no slurry was added into. Since the slurry had high COD concentrations, only its small quantities were applied to the fish ponds, and canal water had to be added periodically to top up the water loss due to evaporation. The 20 mm long Tilapia nilotica fry were initially put into the ponds and cultured there for 6 months until harvesting. It was found that the fish yield varied with the organic loading, the highest yield was extrapolated to be about 3 tons per hectare per year (individual fish weight = 45 g), while the control had a yield of about 0.7 tons per hectare per year (individual fish weight = 10 g). There were no serious DO problems encountered in the four ponds during the experimental period. Only a few fish mortality was observed periodically in each of the ponds which were considered to be normal. A public health study of the biogas fish pond system was undertaken concurrently, and the details are presented elsewhere [11].

## SUMMARY

Biogas production should be more emphasized especially in the developing countries because of its potential as a renewable source of energy. The ferrocement biogas digester as described in this paper was found to function satisfactorily in terms of biogas production and organic stabilization. It is relatively easy and low-cost in construction, corrosion-free, and convenient in operation and maintenance. The utilization of the digester slurry by feeding it into the fish ponds resulted in algal cell production which served as food for Tilapia nilotica. The biogas-fish pond is considered to be valuable because the aims of pollution control and food production can be achieved. Plans are underway to implement this scheme into the rural areas and the detailed results will be reported in a later stage.

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