Trans. Nat. Acad. Science & Tech. (Phils.)
1988: 10: 117-130

EVOLUTION OF INDUSTRIAL ANAEROBIC DIGESTERS AT MAYA FARMS

Felix D. Maramba, Sr., Enrico Obias, Calixto Taganas and Pacifico Pangilinan
Maya Farms Division, Liberty Flour Mills, Inc.
Liberty Building, Pasay Road, Makati, Metro Manila
Philippines

ABSTRACT

Industrial size anaerobic digesters are not scaled-up family-type digesters. Disposing of the manure of 60,000 pigs require radical changes in design, construction and operation. There are now over 100 such digesters at Maya Farsm with biogas production at 9,000 cu.m. per day. This paper presents the evolution of such industrial-scale anaerobic digesters, illustrated with engineering details.

Introduction

Maya Farms began its work on anaerobic digestion in 1972, before the imposition of the petroleum oil embargo. At that time, fuel was still cheap and readily available. The work, however, was initiated primarily to determine whether anaerobic digestion could be a more efficient process for pollution control as compared with the the lagooning systems commonly used by large livestock farms for disposing the animal manure and wastewater.

The first anaerobic digesters built at the farm were working models adapted from designs used in other countries. The combined capacity of small digesters was sufficient to process the farm wastes of a pig population numbering a few hundred. While these digesters succeeded in eliminating the foul smell as well as the swarm of flies that usually pervade animal farms, the research and development (R&D) team started designing large-scale digesters to suit the fast expanding animal population in the farm.

Today, the industrial anaerobic digesters at Maya Farms take in a daily input of a hundred tons of manure plus over a thousand cubic meters of wastewater. Aside from controlling pollution, the digesters produce enough fuel gas to provide the power needs of the integrated livestock farm and meat processing enterprise, making operations totally independent from the Manila Electric Company.

Review of Literature

Biogas is produced by anaerobic digestion. The term anaerobic digester or simply "digester" is given to the container or tank where the process takes place. There are reports of many early studies on biogas production but hardly any attention has been given to the construction of digesters.

It appears that the earliest known largescale biogas production involved sewage in Matunga, India, in 1897. At this instance, the sewage tanks served as digesters (Sathianathan, 1975). Gas from sewage tanks was also reportedly used to light some lamps in Exeter, England, in 1895 (Tietjen, 1975). Development of digesters in India led to the Gobar gas designs (Patel 1951, Acharya 1954, Rajopalan and Pathak 1962, Idnani and Singh, 1963, etc.).

In Algeria, the French developed some basic designs of digesters (Ducellier & Isman, 1941, 1942; Ducellier, 1950, 1958). In the USA, interest in biogas led to some digester designs for cornstalks and other farm wastes (Boruff and Bushwell 1929, 1930; Jacob 1934, Nelson *et al.* 1939, Taiganides *et al.* 1963). In Germany several designs of digesters were built during World War II like the Darmstadt System, the Schmidt-Eggersgluss System, the Poetsch system. In the United Kingdom, publications on biogas appeared beginning 1951 (Rosenberg). Digester designs from Taiwan (Chung Po, 1973) and from South Africa (Fry, 1973) departed from the usual cylindrical designs. In the course of digester development at Maya Farms, several more recent designs were eventually published (Alicbusan, 1974; Eusebio, 1975; Mardon, 1975; Valderia, 1974).

Discussion

The Working Models

The working models of anaerobic digesters were adapted from designs of small biogas plants mainly used in backyard operations in India, Taiwan, China, Africa and Europe. Established in 1973 were the following:

INDIA MODEL. 7.6 m^3 digester volume (Fig. 1) – The India model has an open-topped vertical cylindrical digester. The digester, constructed of hollow blocks, has an inlet and an outlet pipe on opposite sides. A baffle wall between the inlet and outlet prevents the short-circuiting of the slurry material. A cylindrical steel tank of a smaller diameter is integrated upside down over the digester to collect the biogas produced by the action of anaerobic bacteria on the organic materials in the digester slurry. The gasholder tank floats over the slurry, rising when it is filled with biogas, and sinking when the biogas is used. Operation of the digester is on continuous process. The daily charging of fresh slurry through the inlet pipe disloges an equal volume of spent slurry or sludge through the outlet pipe.

TAIWAN MODEL. 9.0 m^3 digester volume (Fig. 2) – The Taiwan model has a horizontal digester with two compartments. The primary compartment has

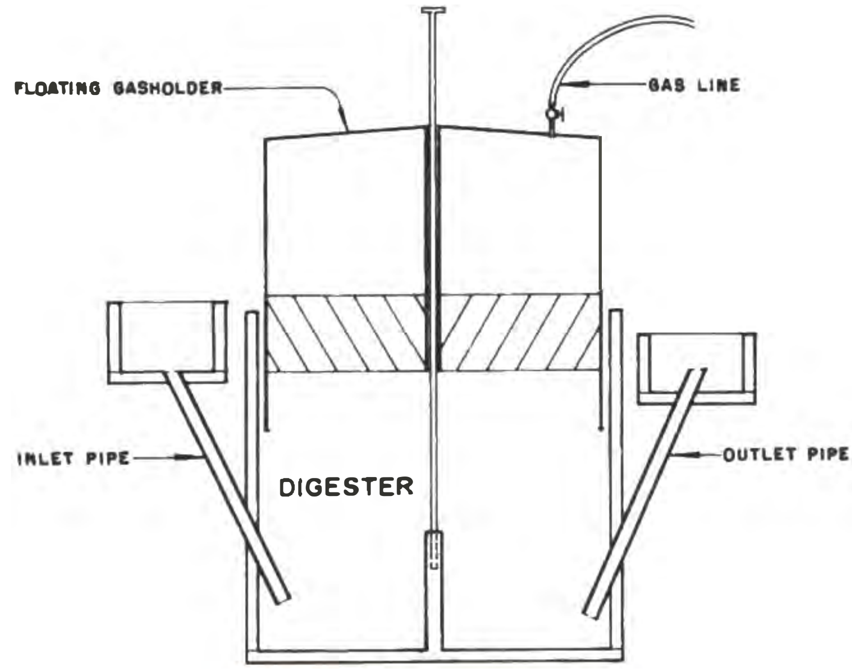

Figure 1. India Model.

double-walling and an open-top. The secondary compartment is single walled and has a closed top. A cubical steel tank is integrated over the primary compartment to serve as the floating gasholder. The sides of the tank are dipped in water, and placed between the double-walling. This makes the operation neater and more sanitary, though the double-walling makes the digester more expensive and harder to maintain in case of leakages. Like the India model, the Taiwan model operates on a continuous process. The digester slurry passes from the primary to the secondary compartment through a transfer pipe.

CHINA MODEL. 4.7 m^3 digester volume (Fig. 3) – The China model has a vertical cylindrical digester with an open-topped auxiliary chamber. A fixed-dome gasholder is integrated over the digester. As biogas collects under the dome, the gas pressure pushes part of the digester slurry into the auxiliary chamber. When the biogas is used, the displaced slurry flows back into the digester. The operation is neat and clean but a good portion of the biogas could not be recovered because the

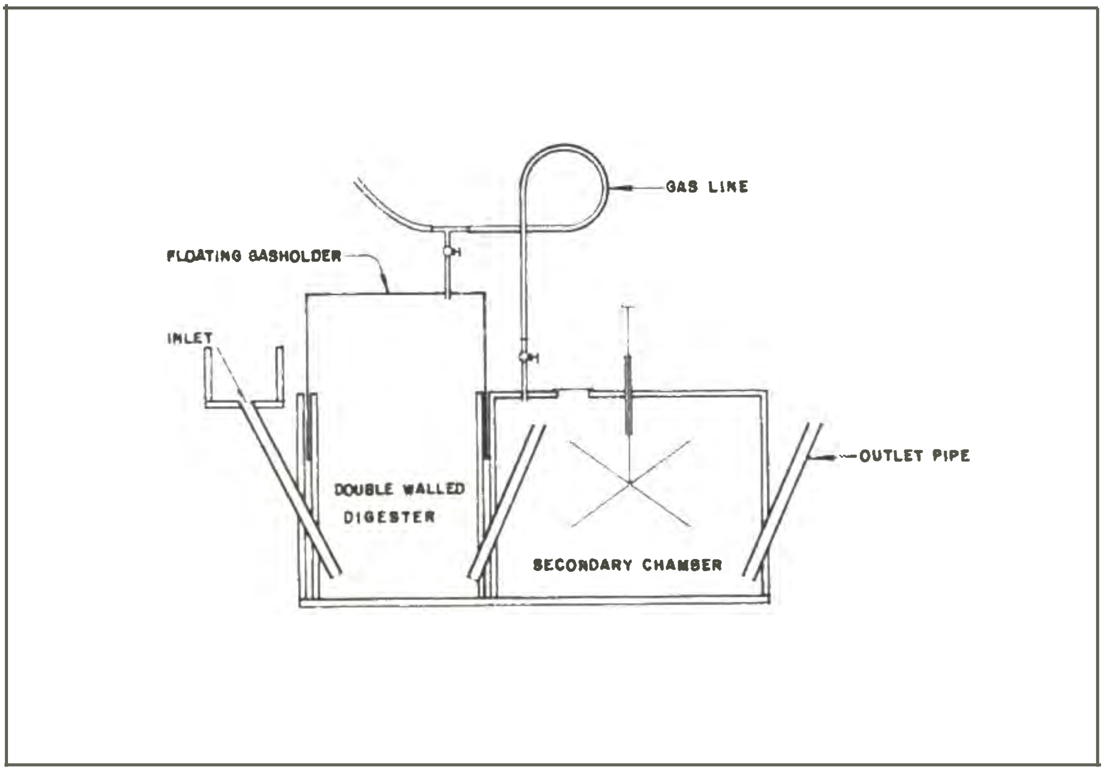

Figure 2. Taiwan Model.

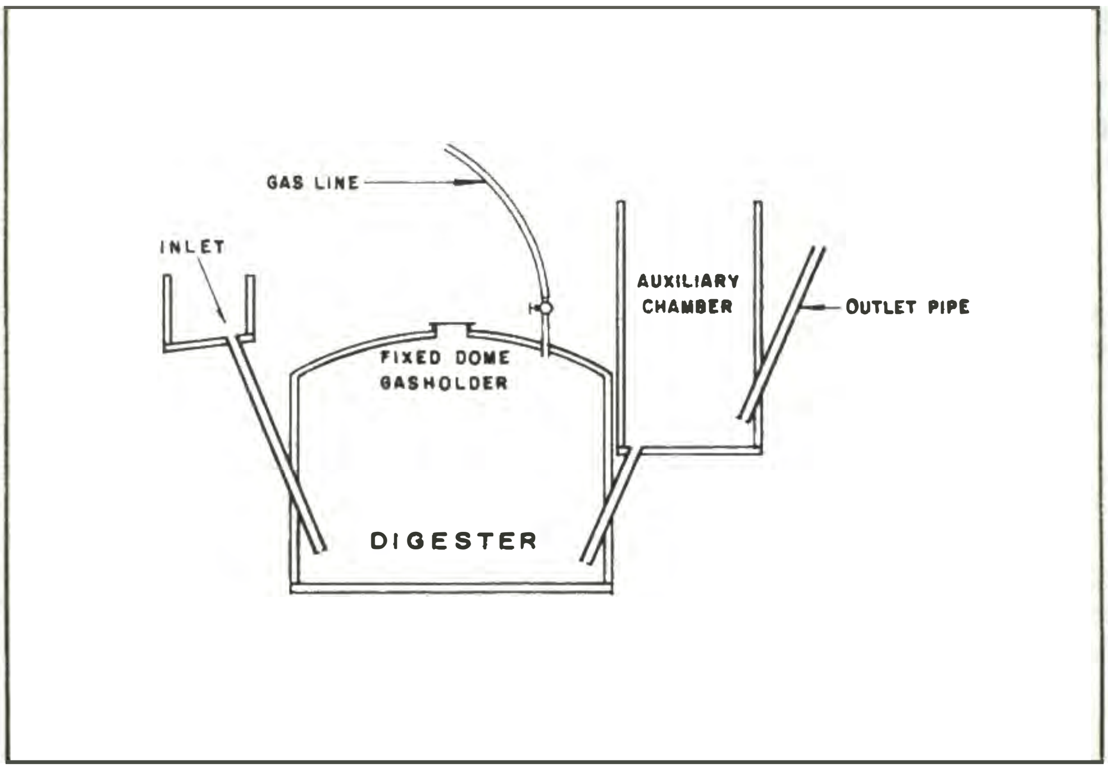

Figure 3. China Model.

gas produced by the slurry in the auxiliary chamber escapes to the atmosphere. The Chinese farmers operate their digesters on a combination batch and continuous processes. The crop residues are loaded in batches and taken out after a few months when they are needed as compost. In the meantime, a slurry of pig manure is charged daily.

AFRICA MODEL. 2.0 m^3 digester volume (Fig. 4) – The Africa model has a vertical digester with an integrated floating gasholder. It is built above ground and is operated by batch. It is used mainly for vegetable wastes.

WESTERN MODEL 4.2 m^3 digester volume (Fig. 5) – Western designs are typically of the split type, i.e., the digester is separate from the gasholder. The working model at Maya Farms has a fully covered cubical digester. The separate gasholder consists of a concerte water tank with an inverted steel tank floating over the water. Operation of the digester is on a continuous process.

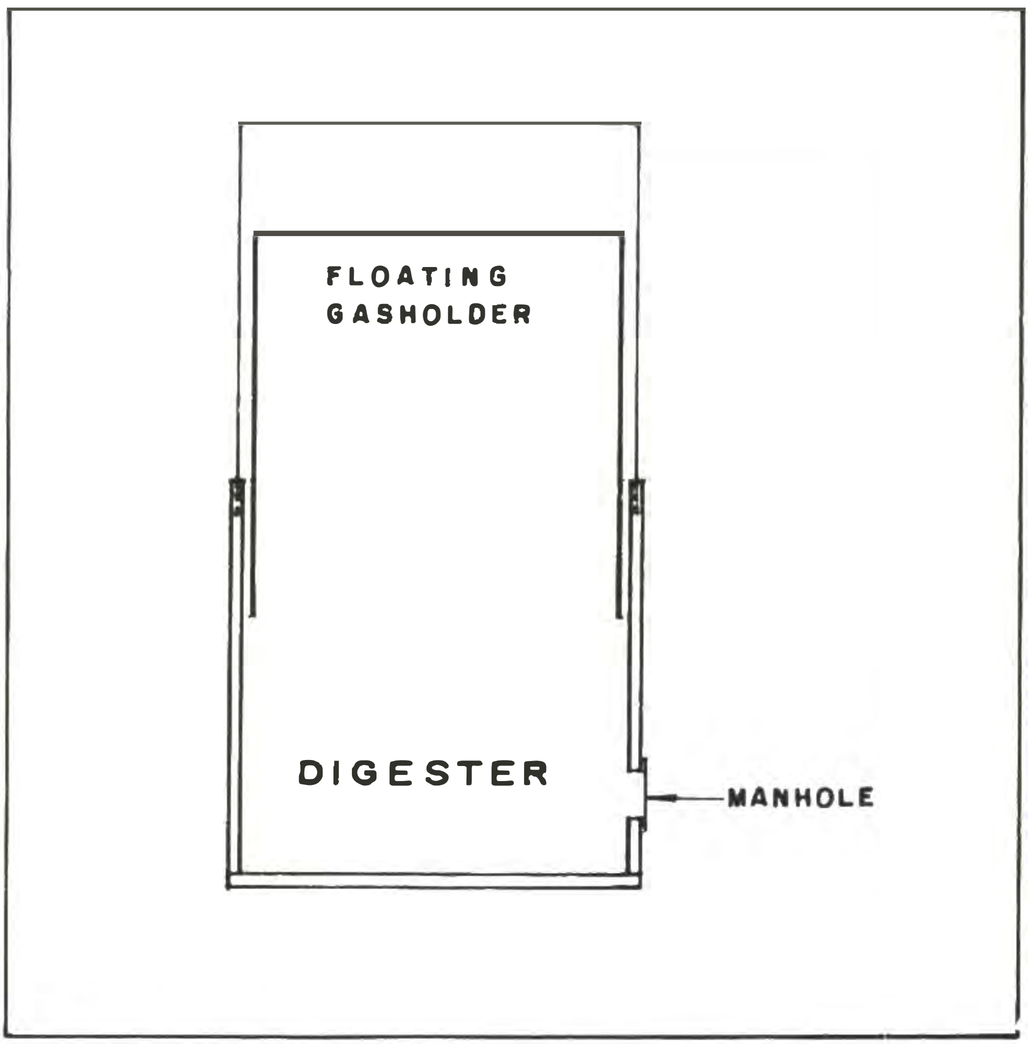

Figure 4. Africa Model.

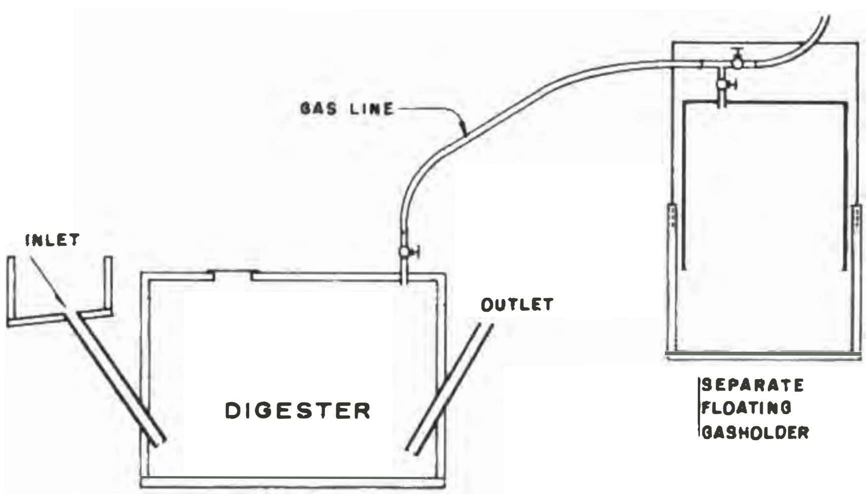

Figure 5. Western Model.

The Pilot Plants

While the biogas operation effectively controlled air pollution improved sanitation by getting rid of the swarms of flies, the R&D team of Maya Farms designed, for fuel gas operations, two pilot plants. One pilot plant had batch digesters, the other, a continuous digester.

Eight batch digesters were built in a cluster above the ground (Fig. 6). The total digester-volume was 32.6 m^3. One gasholder, a steel tank floating over a concrete water tank, served the eight digesters. The digesters were loaded one at a time, every week, so that it took 56 day before each digester is unloaded and reloaded. (The normal practice in India and other countries is 60 days retention time).

The continuous digester was horizontal and had two compartments (Fig. 7). Unlike the Taiwan design, the primary compartment, which received the fresh manure slurry, was fully covered and the floating gasholder was integrated over the secondary compartment. There was no need for double-walling because the digester slurry in the secondary compartment no longer had an offensive smell and most of the solid particles settled at the bottom.

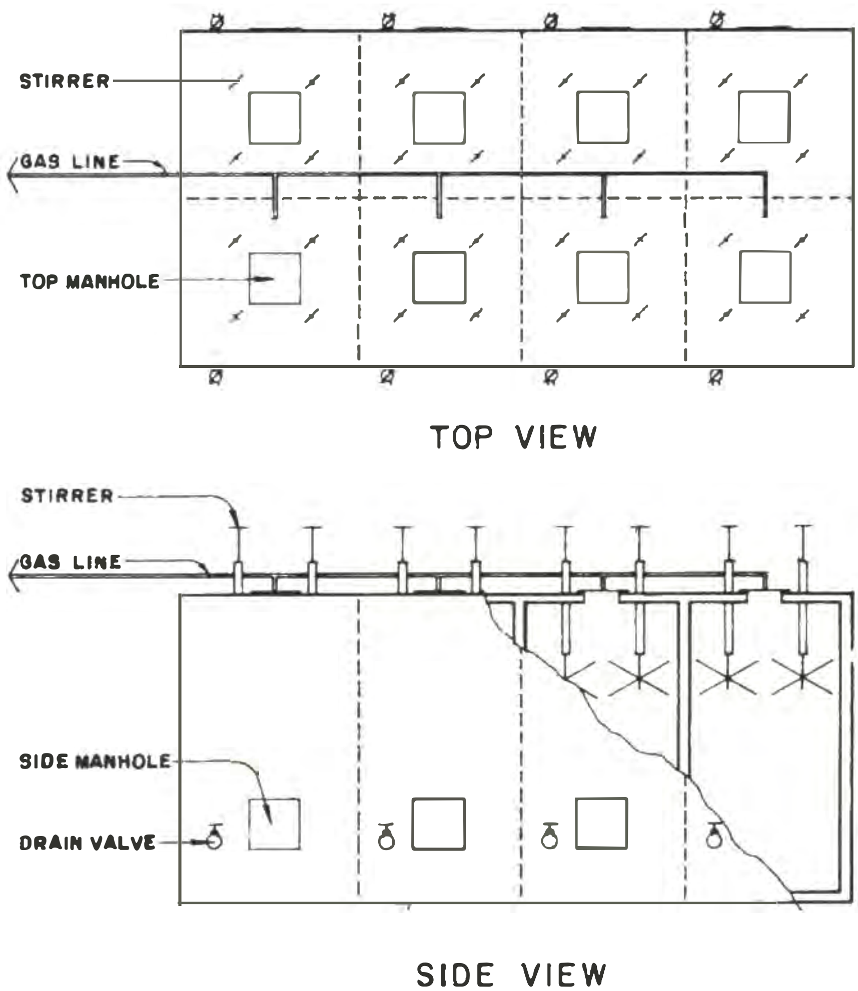

Figure 6. Pilot Batch Digesters.

The pilot plants were operated for six months before the increasing pig population required more digester capacity. To go on industrial scale, the first choice was the batch digester. With fully covered digesters and gas tanks floating on water, control of pollution and sanitation has been very effective. Moreover, work in the research laboratory had shown that biogas production could be increased by adding crop residues like corn stalks and rice straws to the manure slurry. This would be workable with batch digesters but could clog up continuous digesters. The interest on biogas was triggered by the rising costs and supply problems of fuel resulting from the petroleum oil embargo. Although the batch digesters were more expensive to construct and more laborious to operate, the environmental control and fuel consideration took precedence.

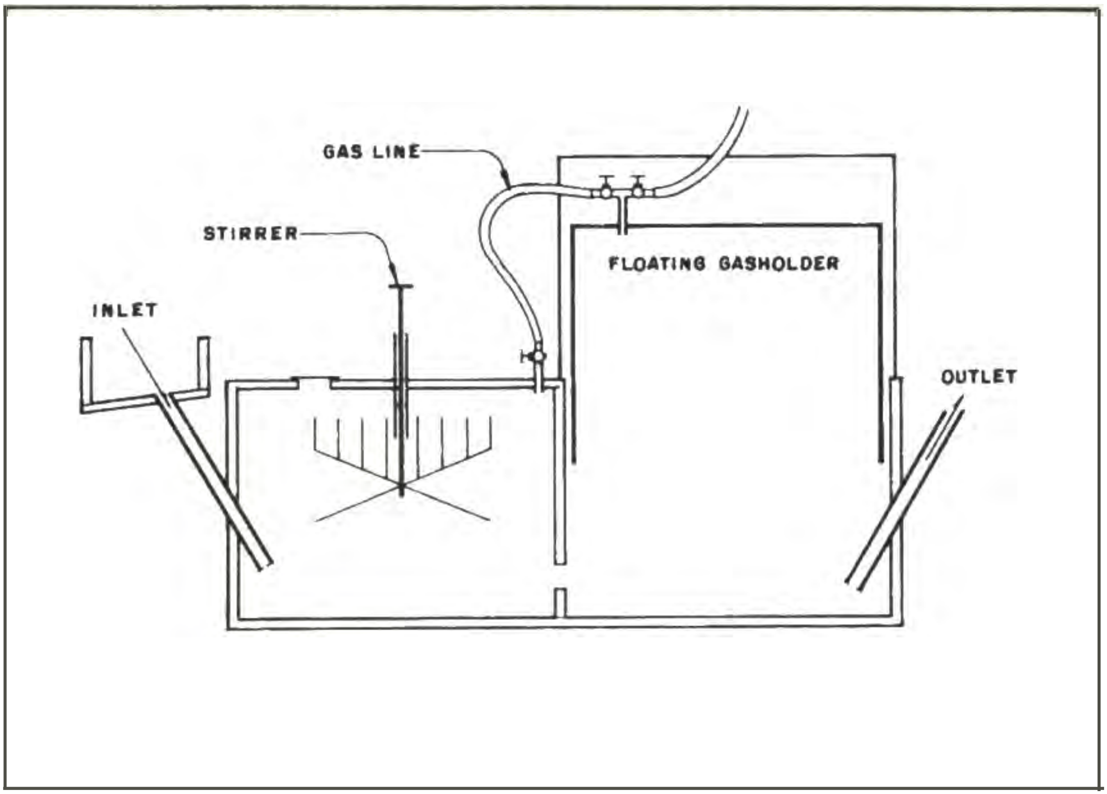

Figure 7. Pilot Continuous Digester.

The Industrial Batch Digesters (Fig. 8)

Maya Farms built its first industrial anaerobic digesters in 1974.The cluster of 24 vertical concrete digesters were built above ground. Each digester was 3m x 3m x 2.4 m. Each had a covered manhole on top for loading and a covered manhole on one side for unloading crop residues and for cleaning purposes. An outlet valve near the side manhole was used for unloading the sludge. Each digester also had four manual stirrers to effect some mixing and to break the scum that formed on the surface of the digester slurry.

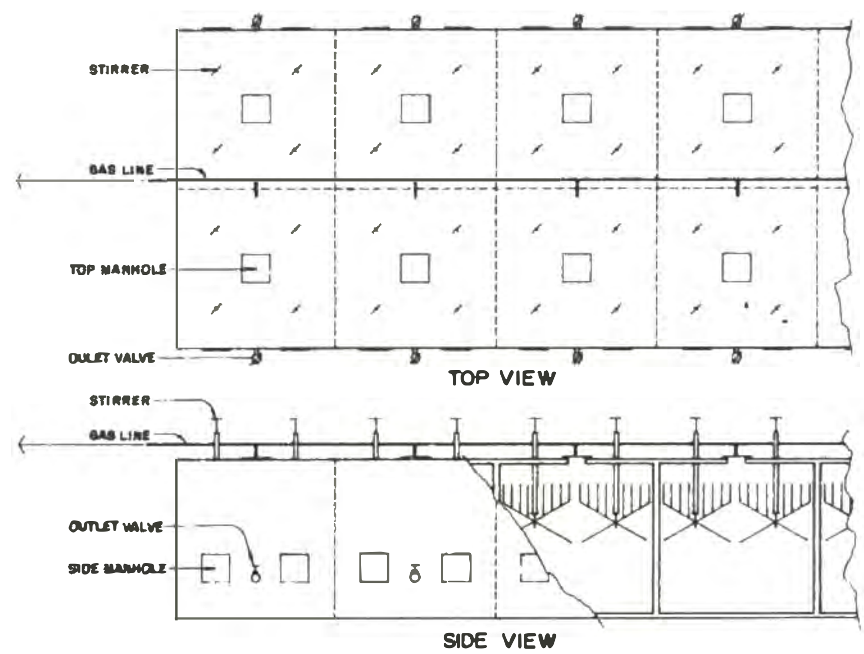

Figure 8. Industrial Batch Digester.

The digesters were loaded sequentially, one every other day, so that it took 48 days before each of the 24 digesters are unloaded and reloaded. Loading was done by pumping the slurry from a slurry collecting sump, then adding chopped corn and stalks and rice straws. Unloading was accomplished by attaching a plastic pipe to the side outlet valve and draining the sludge, then opening the side manhole to remove the stalks and straws.

The system worked well. However, the rising cost of fuel was causing the increase in prices of of everything else, particularly of the construction materials. The R&D team thus concentrated on how to reduce the cost of constructing additional biogas plants which would be needed to accommodate the continued expansion of the piggery. Bench scale studies showed that with a good inoculant, 80 to 85% of the biogas could be produced on the first 23 days of anaerobic fermentation. It was also found that with 23 days fermentation, the sludge was already non-pathogenic and no longer has an offensive smell. Thus it was decided to reduce the retention time to 23 days. Biogas recovery would be 15 to 20% less but the cost of constructing and operating digesters would be cut by half. The 24 digesters which were built to process the manure of 2500 pigs could now take care of 5000 pigs. Instead of loading them every other day, they were loaded every day, sequentially.

Building digesters above ground and painting them black provided for better absorption of heat from the sun. This is supposed to improve biogas production because anaerobic fermentation proceeded faster at higher temperatures. However, building above ground required stronger side walls unlike digesters built underground. The savings on reinforcing bars as well as on paint could be considerable.

On this premise, the next biogas plant unit at Maya Farms with its cluster of 24 digesters were built underground with the top at ground level. Loading of the manure slurry was by gravity flow. The crop residues were added in bundles so that they could easily be hooked out in unloading. The sludge was discharged by pumping. Subsequent checks on temperatures showed insignificant difference between the digester slurries inside the digesters above ground and the underground digesters.

The Industrial Continuous Digester (Fig. 9)

As the prices of construction materials continued to escalate, the economic viability for new biogas plants was getting critical. The R&D team had to fall back on the continuous digester design which cost much lower because the long horizontal digester has only two compartments; had less partition walls; and less manholes. To attain the same efficiency in environmental control, the digester was also fully covered, and the design of the separate floating gasholder used with the batch digesters was adapted. With the cropfields taken over by the expanding piggery, there were no more crop residues to process.

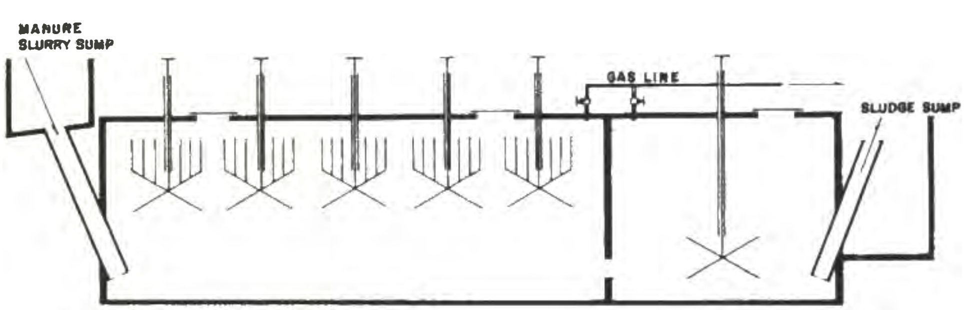

Figure 9. Industrial Continuous Digester.

The continuous digester had a double row of stirrers along its length. Slots in the partition wall allowed the transfer of slurry from the first to the second compartment. The collection sump for fresh manure slurry was built over the head end of the digester so that charging was done by simply pulling out the plug from a drain hole at the bottom of the sump. As the fresh slurry drained into the head end, an equal volume of spent slurry or sludge overflowed through the outlet pipe at the other end of the digester. As biogas was produced, the pressure created inside the digester pushed the gas through the gas line and into the separate floating gas-holder.

The construction cost of the continuous digester was around 25% less than that of a batch digester unit of the same capacity. The much simpler operation and maintenance reduced the labor and material costs roughly by half. From 1975 to 1982, 32 continuous digesters were built, bringing the total industrial digester volume to 4,700 m^3.

The Horizontal High-Rate Digester (Fig. 10)

By the early '80s, the very high price of energy was still going higher. Moreover, brown-outs were getting more frequent. The Maya Farms R&D team thus concentrated on increasing biogas production capacity. Actually, the biogas produced from the manure was far in excess of the energy required to run the live-stock farm, including pumping the water, mixing the feeds, brooding the piglets

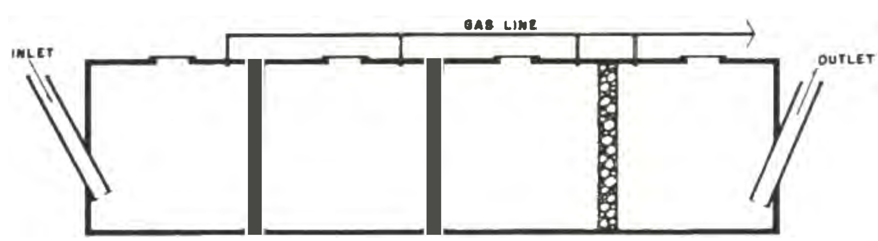

Figure 10. High Rate Digester.

and lighting the whole farm. The meat processing and canning operation was set up at the farm so the excess biogas could be used. Although the excess biogas was more than half of the total gas produced, it was not enough to provide the energy requirements for industrial processing.

In the livestock farm, the daily washing of the animal pens used a lot of water. The digesters that would be needed if all the water were to be processed at 23 days retention time would cost so much that the biogas operation would no longer be viable. What the R&D team did was to provide the slurry collecting sumps with a screened overflow valve so that the excess washwater could flow out while the manure solids would be retained in the sumps, thus leaving a more concentrated manure slurry for charging into the digesters.

The R&D team, however, found that the excess washwater still carried very fine organic waste materials which could produce a substantial volume of biogas. The problem was how to produce that biogas economically. A high rate digester design would reduce the required digesters to a reasonable volume but the normal design for high rate digesters was costly to construct and consumed a lot of power in operation. It had a filter bed which required expensive imported packing materials. Its operation required the pumping of the feed slurry into the vertical digestes. The enormous volume of excess washwater, moreover, would result in a lot of energy being wasted in the pumping operation.

To avoid wasting energy in pumping, Maya Farms designed a horizontal four compartment digester. Instead of importing the expensive packing materials, the R&D team used pebbles in packing the partition walls. With the concrete digester built underground, the excess washwater just flowed by gravity into the head end of the digester, passed through one filter-wall after another and overflowed out of the other end. There was no waste in energy. Meanwhile, the high concentration of methanogenic bacteria, which grew on the rough surfaces of the pebbles, fed on the entrained organic materials as the washwater filtered through them, producing biogas at a much faster rate. With four days retention time, the operation came out economically viable.

After the horizontal high rate digesters were built to process the excess washwater, Maya Farms was able to generate all the power required to run the integrated livestock farm and meat processing enterprise.

Summary

Starting with designs of small anaerobic digesters from India, Taiwan, China, Africa and the Western countries, Maya Farms gradually developed its own industrial digesters. The digesters were designed for efficient control of pollution while maximizing production of the biogas fuel and keeping costs to a minimum.

As of June 1988, the farm has 48 industrial batch digesters, 63 industrial continuous digesters and 45 horizontal high rate digesters, with a total capacity of 14,763 cu. These digesters process the manure of 60,000 pigs, 144,000 chicken layers and a few hundred heads of cattle. The 9000 cu. m. of biogas produced daily provide sufficient energy to run the integrated operations. Maya Farms has been operating totally on self-generated power since January 1984, when it cut off the power line from the Manila Electric Company. With a power cost savings of around ₱5 million a year, the anaerobic digesters have turned out to be a highly profitable venture.

APPENDIX

Industrial Anaerobic Digesters at Maya Farms
As of June 1988

	Date Established	*Digester Capacity (cu. m.)*
Industrial Batch Digesters		
24 (Biogas Plant I)	1974	544
24 (Biogas Plant II)	1975	544
48		1,088
Industrial Continuous Digesters		
4 Biogas Plant III)	1978	514
5 (Biogas Plant IV)	1979	644
6 (Biogas Plant V)	1980	823
4 (Biogas Plant VI)	1982	548
8 (Biogas Plant VII)	1982	1,160
5 (Biogas Plant VIII)	1982	686
3 (Biogas Plant XI)	1985	412
3 (Biogas Plant VIII)	1985	412
3 (Biogas Plant III)	1986	412
3 (Biogas Plant VII)	1986	360
3 (Biogas Plant IV)	1987	412
2 (Biogas Plant VIII)	1987	274
2 (Biogas Plant VIII)	1987	274
2 (Biogas Plant X)	1988	274
10 (Biogas Plant VI)	1988	1,371
63		8,576
Horizontal High Rate Digesters		
3 (Biogas Plant I)	1980	232
2 (Biogas Plant II)	1980	197
4 (Biogas Plant VIII)	1982	428
3 (Biogas Plant III)	1983	360
3 (Biogas Plant IV)	1983	360

Appendix (Continued)

	Date Established	Digester Capacity (cu. m.)
4 (Biogas Plant V)	1983	480
3 (Biogas Plant VI)	1983	360
2 (Biogas Plant II)	1985	214
4 (Biogas Plant VII)	1985	488
2 (Biogas Plant VIII)	1985	240
2 (Biogas Plant IX)	1985	188
2 (Biogas Plant III)	1986	240
2 (Biogas Plant IV)	1987	240
2 (Biogas Plant VIII)	1987	240
1 (Biogas Plant VIII)	1987	120
6 (Biogas Plant VI)	1988	720
45		5,107

Literature Cited

Acharya, C.N. and Juneja P.C. 1954. Combustible gas and manure from cattle dung. *Indian Sci. Cong. Asso. Proc.* 41: 246.

Alicbusan, R.V. 1974. Fuel Gas Production from Agr. Wastes. *Terminal Report: NIST Manila.*

Bushwell, A.M. and C.S., Boruff. 1930. Fermentation products from cornstalks. *Ind. Eng. Chem. (IEC).* 22: 931-33.

Chung, Po. 1973. Production of Methane from Manure. In proceedings of Interm Biomass Energy Conference. May 13-15.

Ducellier, G.L.R., and M.A. Isman. 1941. Brit. Pat. 621746, 621747. In Teitjen, C. 1975.

Eusebio, J.A. 1975. Recycling System in Integrated Farming. ESCAP Workshop on Biogas Technology. Manila, October 13-15.

Fry, L.J. 1973. Methane Digeesters. *The New Alchemy Institute.* 47 pp.

Idnani, M.A., and J. Singh. 1963. Some improvements in biogas plants. *Indian Farming.* 12(11): 24-25.

Jacobs, P.B. 1934. Heat & Light in the Farm. *Architect Rev.* 7-358.

Mardon, C.J. 1975. Production of Methane from Organic Wastes, CSIRO.

National, H.J. 1961. Report on a visit to Germany and Holand. National Inst. Agric. Eng. 18 pp.

Nelson, C.N. and others. 1934. Decomposition and gas production from cornstakes, *Iowa State J. Sci.* 13: 161:8.

Patel, J.J. 1951. Digestion of Waste Organic Matter for Production of Methane Gas. *Agric. Coll. Mag. (POONA).* 42(3): 150-160.

Rosenberg, G. 1951. Methane Production from Farm Wastes. *Agriculture (UK).* 58: 487:94.

Sathianathan, M.A. 1975. Biogas Achievements and Challenges. Assoc. of Voluntary Agencies for Rural Development, New Delhi. 192 pp.

Taiganides, E.P. and others. 1963. Anaerobic digestion of pig wastes. *J. Agric. Eng. Res.* 8: 327:33.

Tietjen, C. 1975. From biodung to biogas: a historical reivew of European experience. 7th National Agric. Waste Mgt. Conference, New York. April 16-18.

Valderia, B.V. 1974. Garbage Fermentation Tank, Philippine Patent No. MM-1371.