Biogas production from organic wastes: Nigerian efforts

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History of biogas development

Earlier records credit Pliny for mentioning the mysterious appearance of flickering lights and flames emerging from below the surface of earth. These were believed to be produced by the local dragon. Romans called these mysterious dancing flames *ignis fatuus*. English novelists referred to them as "will-o-the-wisp". In 1630, Van Helmont recorded the emanation of an inflammable gas from decaying organic matter. In 1667 Shirley described this gas more precisely. However, the first person to be credited with the phenomenon of biomethanation was Alessandro Volta of Italy. In 1776 he wrote to a friend that "combustible air" was being produced continuously in lakes and ponds in the vicinity of Como in northern Italy. He observed that whenever he disturbed the sediment of the lake bubbles of gas rose to the surface. He also observed that if the sediment contained copious plant material, more bubbles appeared and the gas exploded when mixed with air.

In 1806 William Henry showed that Volta's gas was identical with methane gas. Humphrey Davy in the early 1800's observed that methane was present in farmyard manure piles and conducted the first laboratory experiment to produce methane by anaerobic fermentation of wastes (Dodson and Meynall, 1981). Towards the end of the 19th century, methanogenesis was found to be connected to microbial activity. Becamp, a student of Louis Pasteur, said that an unspecified organism was responsible for methane production from ethanol. In 1876, Herter, a collaborator of Hoppe-Seyler reported that acetate in sewage sludge was converted to equal amounts of methane and carbon dioxide. In 1884, Gayon fermented manure at 35^0C obtaining 100 litres of methane per cubic meter of manure. A company 'Compagnie des Omnibus' in Paris requested Gayon to design an installation in which the manure of their many horses could be digested to produce methane to be used for street lighting. However, Gayon declined saying that his work was still preliminary (Van Brakel, 1980).

In 1895 Exeter in England commissioned the first biogas plant used for streetlights. French scientists propagated this technology for fuel purposes in the French colonies in Africa during the 2nd World War. During this period fuel-starved French and Germans used biogas as a fuel for vehicles and farm tractors. Following the war, several nations such as England, USA, Canada, Russia, Japan, China, Kenya, Uganda, South Africa, New Zealand and India showed interest in this technology. Energy shocks during 1970s made this technology popular among countries such as China, India, Philippines and Nepal. Some cars have been designed using biogas as fuel.

In Nigeria, biogas technology was introduced with mixed success. Professor Adesogan built one unit in the Department of Chemistry in the early 1980s with a view to generate gas for laboratory use. Professor Odeyemi of Obafemi Awolowo University, Ile-Ife, put up some small scale plants at Ile-Ife and Esa-Oke, using animal and food wastes. The unit provided at the General Hospital in Osogbo is relatively large in size. The International Institute of

Tropical Agriculture developed a plant based on the use of cassava waste at Moniya, near Ibadan where a Women's Association integrated this technology into cassava processing. A UNDP supported project promoted low cost biogas technology in Kano using cow dung. Friends of the Environment used pig waste in Lagos. The Energy Research Centre at Nsukka built a plant. However, most of these have not been sustained in the long run. Sridhar and Aikhomu of the University of Ibadan, more recently designed a plant using the normal plastic water storage tank with some modification. This unit is promising at household level for animal and food waste. Various feed formulae are being tried to adopt it to urban and peri-urban needs.

Biogas process

Biogas is the product of the anaerobic decomposition of organic wastes. The decomposition occurs in three steps: hydrolysis, acidogenesis and methanogenesis. These three steps are mediated through various groups of microorganisms. Complex polymeric organic materials such as polysaccharides, proteins and lipids are broken into simpler units by a group of organisms. A second group then ferments these degradation products into hydrogen and simple organic acids such as acetic acid which will then be converted into methane and carbon dioxide by the third group of organisms. Methane gas is highly insoluble and stable. The simple reaction is given below:

$$\text{Organic matter} + H_2O + \text{Nutrients}$$
$$\downarrow$$
$$\text{New cells} + \text{resistant organic matter} + CO_2 + CH_4 + NH_3 + H_2S + \text{Heat}$$

A number of plant designs have been developed over the years. A simple way of classifying them is, "movable drum type" and "fixed dome type". Both these models have merits and demerits. Fixed dome designs as practised in China are becoming more popular. The floating type is popular in India and other parts. The designs are also classified based on whether they are batch fed or continuously fed. Digesters can be connected in series and can be vertical or horizontal.

For efficient running of biogas plants the anaerobic digestion should go on without any external control. Some of the conditions listed below will have an impact on gas production.

- Effect of agitation – mixing helps in steady generation of gas, as it prevents stratification in the tank
- Start-up and seeding – introduction of enriched culture of mixed microorganisms will enhance the starting process. Generally, sewage sludge will provide all the required organisms in an active state.
- Effect of pH – during anaerobic fermentation, microorganisms require a neutral to slightly alkaline environment. Carbon dioxide and volatile fatty acids contribute to acidic conditions which will retard gas generation. A pH of 7 to 8.5 is adequate for optimal reaction to take place. Usually pH stabilizes as the digester starts producing the gas and there is no need to adjust.
- Effect of loading rate – loading rate is the amount of waste material fed per unit volume of digester capacity. Gas yield is expressed as m^3 of gas produced per Kg of volatile solids destroyed. It is common to maintain a loading rate of 0.48 to 1.6 Kg of volatile solids per m^3. For a particular size plant, the optimal feed rate has to be established. A daily loading rate of 16 Kg of volatile solids produces 0.04 to 0.074 m^3

gas per Kg of raw dung fed (Mohanrao, 1974, 1975).

- Hydraulic Retention Rate – the average time spent by the input slurry inside the digester before it comes out. It usually varies between 20 to 120 days.
- An optimal C: N ratio of 25 to 30: 1 is ideal for degradation to go on without accumulation of excess ammonia or organic acids.
- Salinity has a negative impact on the gas yield. However, saline sediments / mud have no significant effect.
- Temperature has a direct bearing on the gas yield and the period of decomposition. Temperatures of 35 to 40^0 C promote mesophilic fermentation and 50 to 60^{0}C promote thermophilic reactions.
- Effect of inhibitory materials – When the volatile acids reach 200 ppm or ammonia reaches 1500 ppm the microbial action slows down. Besides these chemicals, industrial chemicals and certain salts can affect the performance.

Selection of wastes for biogas production

A variety of organic materials can produce biogas. While livestock wastes are the best crop residues, city refuse, aquatic weeds, grass clippings and certain industrial wastes may be used effectively. Common wastes and their composition are given in Table 1.

The amount of waste produced by pigs and cattle was assessed in a livestock farm at Shasha in Ibadan. There were 43 pigs and 7 cows and the waste production was monitored for 10 days by weighing the amount every day. The pig waste amounted to 772.8 Kg/day (652.5 litres) and the cattle waste 744.8 Kg (688.5 litres). The pig waste showed 19% carbon, 3.27% nitrogen, and 0.785% phosphorus. The cattle waste showed 20.6% carbon1.27% nitrogen, and 0.306% phosphorus. These wastes were used for biogas generation in the drum digester.

Experiments on Digester Design and Biogas Production

Laboratory scale experiments.

Interest in biogas generation and utilization goes back to 1984 when *Pistia stratiotes* L. was used to produce biogas. Varying amounts of the aquatic weed (1, 2 and 4 Kg were taken respectively, in 20 litre capacity Winchester glass bottles improvised for feed input and gas trapping. The Pistia showed 7 % dry matter and has organic matter 69.9 % and nitrogen 2.4%. The experiment was carried out for 60 days and the mean gas yield was (cc per day) 322.4, 371.5 and 721, respectively. These preliminary experiments led to scaling of the plants using various wastes.

A drum digester.

The digester was designed to operate within a mesophilic temperature range of 28 to 40^{0}C. The ambient temperatures during the study were around 32^{0}C. A used oil drum of about 200 litre capacity was used for this purpose as the main digester. The height was 88 cm and diameter 52.5 cm. Another 170 litre smaller diameter drum was inverted and used inside the tank to hold the gas. A 69.2 cm long and 9.0 cm diameter galvanized pipe served as the inlet pipe for feed input. Another 15 cm long and 6 cm diameter piece of galvanized pipe acted as the sludge outlet pipe to discharge the effluent. A 12.5 cm PVC pipe with a valve was connected for controlling the rate of gas flow. A 18 cm long and 2.5 cm diameter pipe provided a gas vent. A hose pipe of 1.5m was used to connect the gas to the stove. The slurry holding capacity was 170 litres. The drum was coated with anti-corrosive paint and connections were made with araldite. Foam, plastic film or rags were used to make it leak proof and to maintain the temperature where appropriate. The unit used in the experiments is given in Fig.1.

The digester was loaded with 40Kg of pig and cattle waste made into slurry with 80 litres of water (1:2 ratio), for the collection of data. One type of waste was used at a time. The generation of gas is given in Fig. 2. The results indicate that 0.6517 m^3 of biogas was produced from 40 Kg of fresh pig waste at a detention period of 31 days. The cattle waste (20 Kg) produced 0.393 m^3 of gas at a 16 day detention period. A mean generation rate of 25.6 litres for cattle and 21 litres for pigs was obtained from the three experiments.

A PVC family digester

Having optimized the conditions for generation of gas from cattle waste and pig waste, it was found necessary to design a suitable digester for a family. The objective was to build a clean system where an adequate quantity of gas can be generated for use in an individual household. Most of the designs looked messy when they started functioning. A few models, however were tried in the field by UNDP in Kano (Figs. 3 and 4). Except for the digester using the floating drum (Fig. 3), others were not found popular. A visit to the site revealed that they were not put to use by the beneficiaries. The plastic tube fixed digester looks very delicate and maintenance in semi-literate or illiterate communities may not be sustainable.

The design. A fixed dome design was tried at the University of Ibadan. A digester wiht a capacity of 1000 litres was chosen. A detention time of 50 to 60 days was considered in view of experiences around the world. In this design, the digester may be filled to ¾ capacity while the remaining ¼ space is kept for storing the gas generated. A daily loading rate of 15 litres is planned.

The tank chosen is a cylindrical shape black original Gee Pee (PVC) tank of 1.05 m diameter and 1.25 m high. The choice of black was to enhance maintenance of temperature during the operation. Modifications were carried out on the tank. A PVC pipe of 10 cm diameter was fixed on either side to serve as feed inlet and spent slurry outlet. To maintain strict anaerobic conditions, the opening of the tank is completely sealed with a high power glue. The factory cooperated in supplying the modified version of the tank. Stirring is not practised as the benefit is still inconclusive from the available literature (Montheith and Stephenson, 1981). The feed used was cow dung which was made into slurry by mixing water in a 1:1 ratio, and a volume of 15 litres was fed in every day.

Gas storage. For storing the gas generated, researchers used a variety of devices such as an inverted drum in a container filled with water or slurry or a tube of plastic film. However such devices have inherent problems such as leaks and the possibility of puncturing. In this study, a rubber tube measuring 21 X 600 cm, usually used for truck tyres, was modified and used. Two valves were fixed, one for receiving the gas and the other for the outlet (Fg. 6).

The burner. Biogas use demands a special type of burner. A burner was designed using locally available materials. A 10 cm diameter perforated flat plate was cut to shape, welded to a circular flat bar at one end, then to a flat plate at the other end. In the centre of the plate, a hole was drilled where a ¼ inch galvanized pipe was welded to it. An elbowjoint was used to change the direction of the pipe. At a convenient distance along the pipe length, a ¼ inch gate valve was installed. The burner has the shape of a shower rose. The whole unit is fitted into a locally produced frame used for firewood stoves (Fig.7).

Gas yield. Determination of gas yield is rather difficult. A manometer or the weight of the storage container is normally used to calculate this. The time taken for burning would be a better way of assessing the quantity. The results obtained over a period of eight days were computed and given in Table 2. The results indicate that a day's loading was able to cook for 2.54 hours. Efforts are being made to increase to 6 hours storage.

Way Forward

Biogas is essentially a rural technology. However, it has the ability to be adapted for urban and peri-urban areas. Classical plants utilized human excreta and animal waste. The future lies in utilizing urban waste, particularly food waste. Another aspect of biogas technology which was not adequately considered in developing countries is tapping from city refuse. One of the reasons is that many of these countries do not have properly designed sanitary landfills from where the gas can tapped and converted into electricity. There are examples where relatively cheap electricity is generated from biogas. On the Canada border the electricity generated from urban wastes is exported to the neighbouring United States for a fee. The yield from biogas generation is crucial in propagating this technology. Controlling the feedstock and improving the digestion system are also crucial. The applications of biogas are enormous (Mital, 1996):

- As a lighting fuel – lamps are designed to produce 100 candle power and consume 0.11 to 0.15 m^3 biogas per hour.
- For pumping water – a single cylinder, 4 stroke SI engine with 3000 rpm speed, 3hp, centrifugal type, 8 m suction with a water delivery rate of 35,000 litres/hour at 10m head consumes 2.5 m^3 gas per hour; 60Kg/h cow dung is used during the operation.
- Biogas consumption for various domestic needs are (litres/hour): cooking (5 cm burner) 325.65; lighting (1 mantle lamp) 70.79; refrigerator (25cmX45x30) 70.79; incubator (45cmx45x45) 56.6; boiling water (per 3.785 litres) 283.2; running IC engine (per BHP) 453 to 509.7; running table fan 99.11; running heater 155.74
- Various small scale industrial needs may be met (litres/hour): button making machine consumes 135.9, plastic moulding machine141.6; a small toy making machine 155.7.
- Used as a vehicle fuel – 1 litre of petrol or diesel can be replaced by 0.7 5m^3 of biogas; in 1942 Mogden Sewage Works in UK supplied biogas for the first time for use in cars.
- For power generation – 1 KW electricity can be generated from 0.75 m^3 of gas. Decentralized electricity generation is more sustainable.
- For agricultural applications - crop drying, irrigation, tractor running

For quick adaptation by the common man, the technology should be made simple, affordable and the taboos attached to waste as a source of disease should be eliminated from the minds of the communities. One of the best ways is to set up demonstration plants and let the communities see and decide for themselves. Education goes a long way towards convincing people.

Government on its part should make a national policy on the conservation of energy and initiate waste-to-energy policies on a small scale, involving the community. Biogas technology should be integrated into waste management strategy as an appropriate measure. There should be more research and development on energy issues in various tertiary institutions and the local technologies developed should be disseminated through the media.

Table 1. Various Organic Wastes, Their Composition and Biogas Yields (Source: Mital, 1996)

Waste Material	Nitrogen % dry basis	C:N Ratio	Biogas Yield m^3/Kg dry matter
Cattle waste	0.29	25	0.31-0.33
Poultry droppings	6.3	7.3	0.46-0.54
Sheep/Goat wastes	0.55	29	0.37-0.61
Pig wastes	0.60	13	0.49-1.02
Horse wastes	0.42	25	0.561
Urine (Human)	15-18	0.8	0.2-0.3
Blood	10-14	3	-
Slaughter house waste	7-10	2	-
Night soil	0.85	29	0.38
Wheat straw	0.3	128	0.432
Rice straw	0.63	67	0.0056
Corn stalks	0.75	53	0.0054
Bean stalks	1.3	32	-
Groundnut stalk / leaves	0.59	19	-
Saw dust (aged)	0.10	200-500	-
Refuse (Municipal)	2.2	25	-
Water hyacinth	2.48	28	0.0203
Water lettuce	2.4	29	0.61*

*expressed as m^3/Kg volatile solids/day; Water hyacinth contains 82% moisture, 18% total solids and 82.5% volatile solids based on dry basis

Table 2. Volume of Feed Input and the Gas Yield in the Family Biogas Digester

Day	Feed Input m^3 (Litres)	Gas Yield (Cooking time, hours)
1	0.37 (373.4)	2
2	0.35 (347.7)	2.30
3	0.37 (371.1)	2.40
4	0.27 (266.5)	2.27
5	0.33 (0.327)	3.23
6	0.33 (0.331)	3.40
7	0.34 (0.336)	3.26
8	0.27 (0.270)	1.4
Mean	0.329±0.037	2.54±0.65

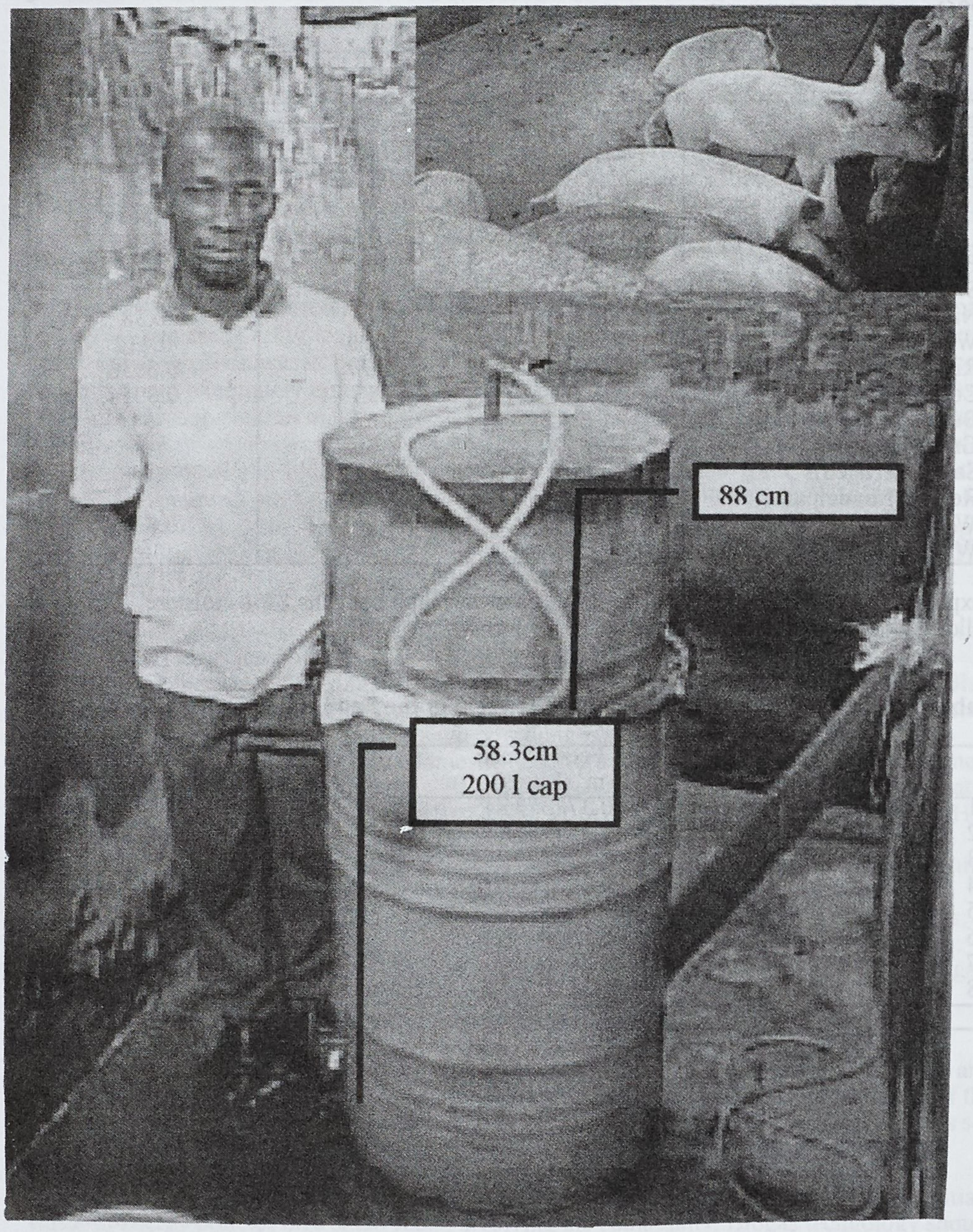


Fig. 1. A biogas plant designed with used oil drum by the authors to treat piggery waste at a livestock rearing unit at Shasha, Ibadan

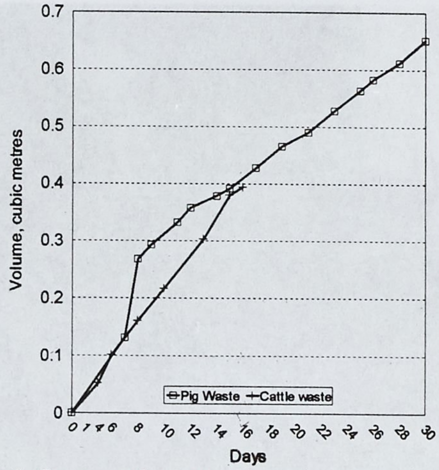


Fig.2. Gas generation pattern from pig and cattle waste

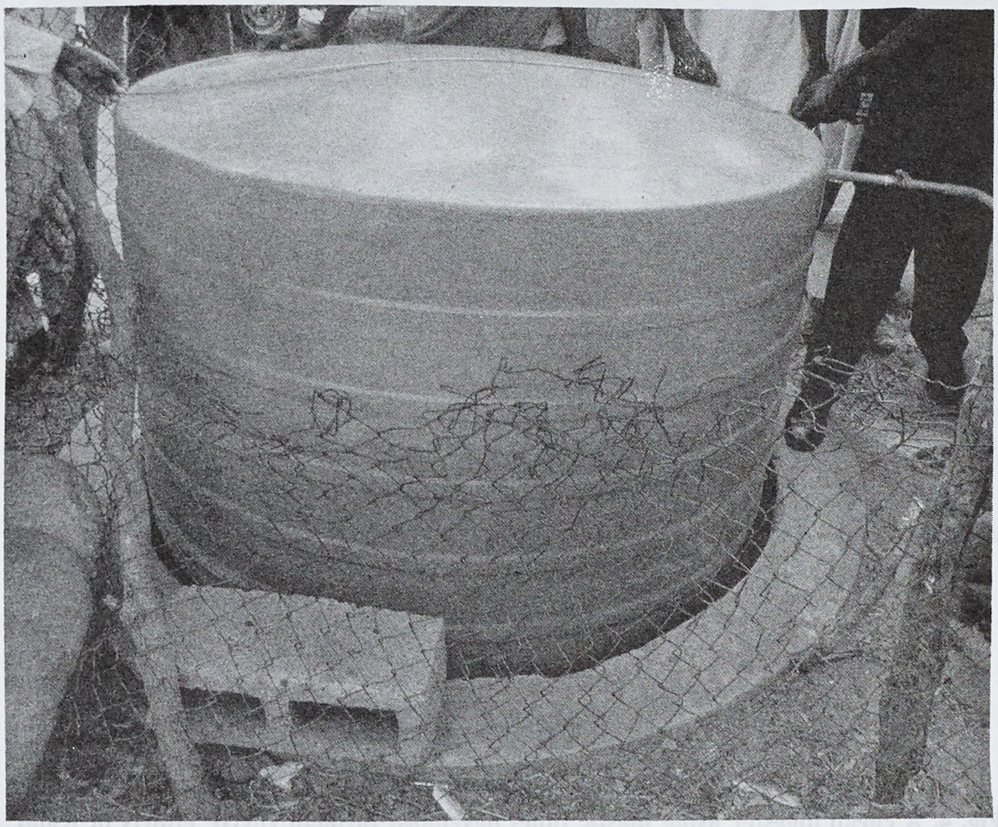
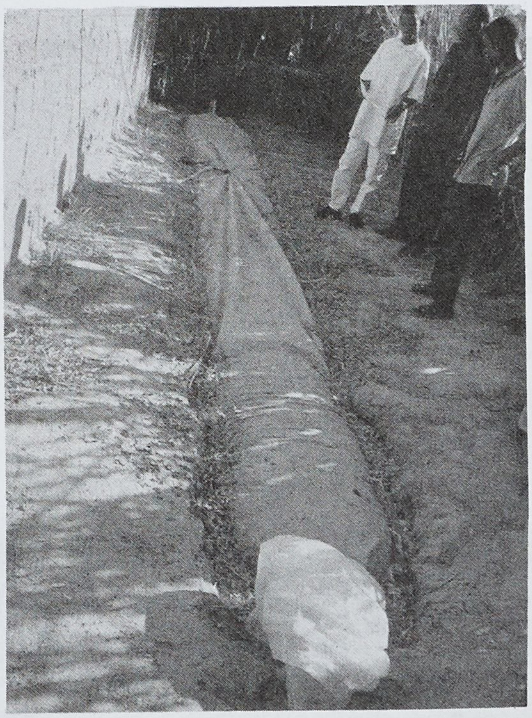


Fig. 3. A floating dome biogas plant installed in Kano for a community by a UNDP Consultant (2001)



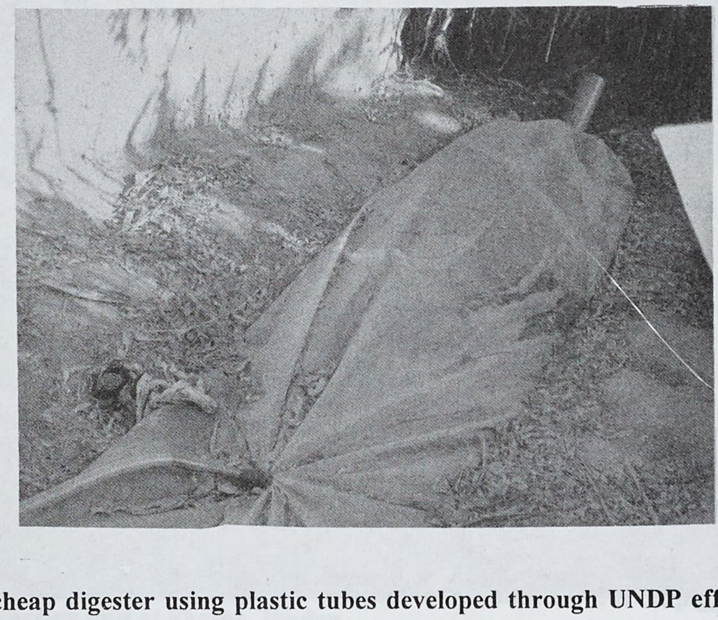


Fig. 4. A cheap digester using plastic tubes developed through UNDP efforts in Kano (2001)

Fig. 5. A $1m^3$ capacity family biogas plant designed by the authors for a typical Nigerian family with 10 people

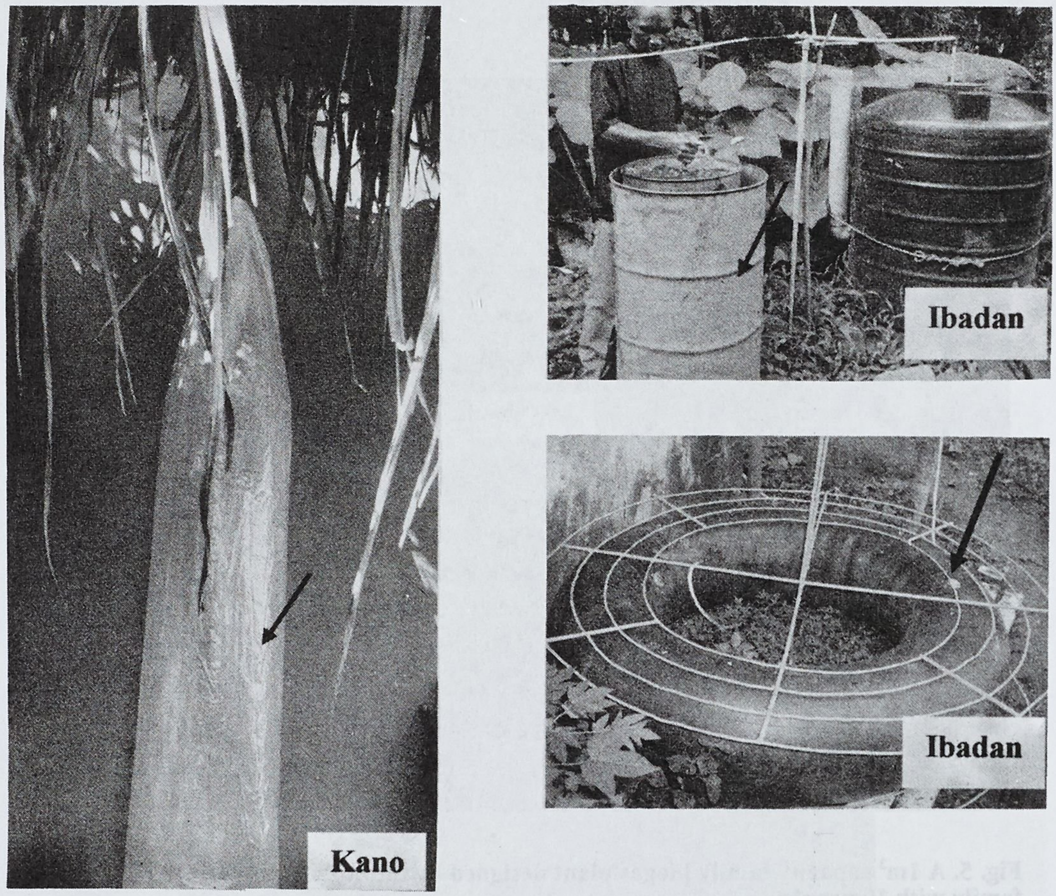


Fig. 6. Gas storage devices

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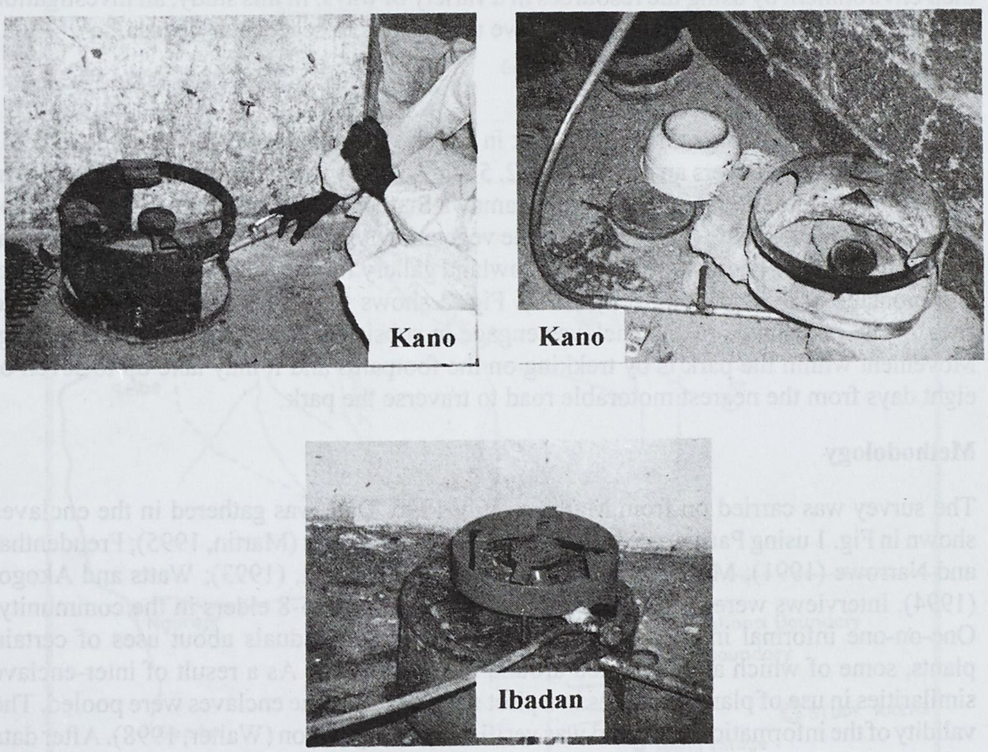

Fig. 7. Various stoves used for cooking