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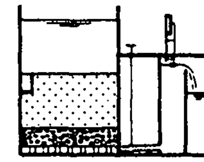
Research and Demonstration Project on Slow Sand Filtration



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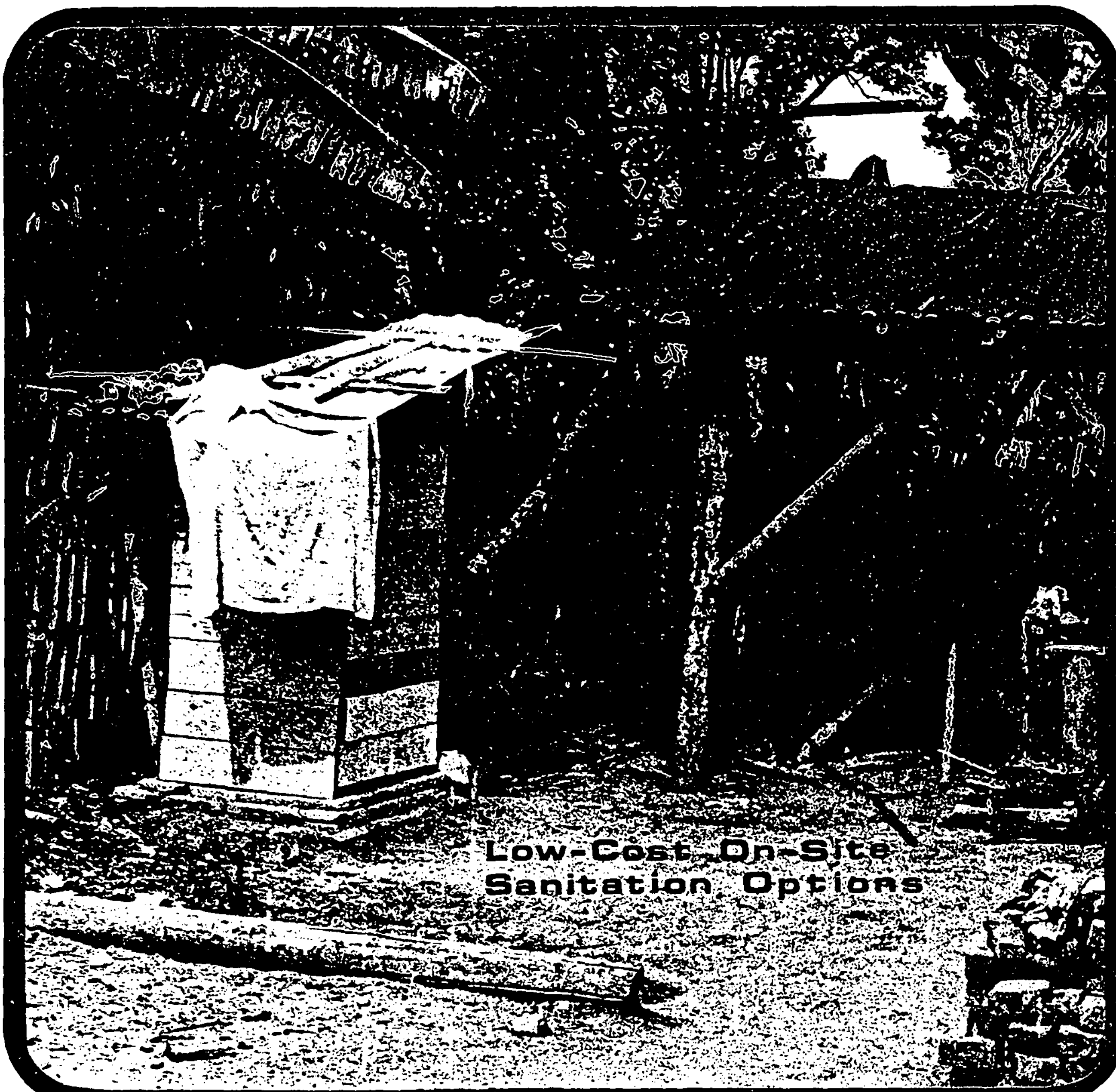

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No. 21

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Cover Photo: Yard in Colombia. Right: Baking oven. Left: Pour-Flush Latr

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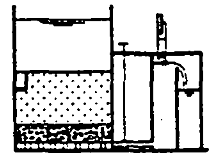

LOW-COST, ON-SITE SANITATION OPTIONS

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To prepare this manual extensive use has been made of the recent World Bank Series on Appropriate Technology for Water Supply and Sanitation, "Sanitation without water" by Winblad and Kilama, published by the Swedish International Development Authority and the "Chinese Biogas Manual" published by Intermediate Technology Publications Ltd.
However, the opinions expressed in this monograph are those of its authors and do not necessarily reflect the views of the authors of the above-mentioned publications.

Adapted from:
World Bank series: Diagrams 2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13
Sanitation without Water: Diagram 3
Biogas Manual: Diagrams 18, A.1.

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PREFACE

Provision of safe water alone has only limited impact on the improvement of health. More is needed to break the transmission cycle of excreta related diseases and prevent the reinfection of the environment and especially man.
Breaking the transmission cycle may effectively be realised by providing adequate, affordable and culturally acceptable excreta disposal facilities.

However while the economic benefits and the convenience of water supply systems are usually clear to the future consumers they may view sanitary disposal of wastes, particularly excreta, as an expensive luxury which apart from status serves little or no purpose. For generations people may have been defecating in the bush or near streams and thought this an acceptable (and cheap) way of disposing of their faeces. Unknowingly however the continuous transmission of disease-carrying organisms was thus sustained.
Health education therefore will initially have to show and convince the people of the health benefits that may accrue from sanitation facilities for themselves and their families. Once the facilities are built continued health education programmes will further need to ensure the proper use and upkeep of the facilities.

Though as explained, there is more to sanitation than technology alone, this monograph limits itself mainly to a discussion of the technical aspects of the provision of sanitary disposal facilities.

The manual has been prepared to serve as essential background material for use in the international seminars which are organized in the context of the Slow Sand Filtration Project. In this project promotion of Slow Sand Filtration through research and demonstration is the main objective in Thailand, India, Kenya, Sudan, Ghana, Jamaica, Colombia and recently Cameroon. However, in the demonstration phase great attention was also given to involvement and participation of the community in the development and implementation of the water supply projects. Health education and, as far as possible and appropriate, sanitation programmes were executed simultaneously to ensure optimum health benefits for the population.

As IRC is planning to expand its activities in this area, comments on this version of the on-site sanitation monograph are highly appreciated. Records of sound field experiences will enable IRC to update and revise the monograph and this, in turn, will be beneficial to all those working in the field of sanitation.

1. Introduction

The percentage of the rural population with adequate sanitation facilities increased from 11% in 1970 to 15% in 1975 and declined to 13% in 1980. During the same period the percentage of the rural population with reasonable access to safe water rose from 14% in 1970 to 29% in 1980. Yet if the objective of improving the community's health is to be realized, water supply provision needs to be complemented with effective excreta and wastewater disposal facilities and its proper use supported by a health education programme.

To improve this situation will require a sustained long-term effort, gigantic in terms of personnel and financial resources. The scale of the waste disposal problems faced by the developing countries, in many respects, is of unprecedented proportions.

Rural sanitation programmes have been notably unsuccessful in most parts of the Third World. Often failure of the programmes can be ascribed to the inappropriateness of the proposed sanitary improvements in the sense that they are (too) expensive or not sufficiently adapted to fit in the people's social and cultural setting.

Too often also a sanitation programme was not sufficiently supported by knowledge of the people's perception of their sanitary environment, nor was this knowledge used as a start for a health education programme and a discussion of feasible improvements on the prevailing sanitary situation. These are certainly reasons why mass propaganda or education campaigns have not brought the expected response. Or for that matter large scale latrine programmes in which squatting slabs were given free or subsidized.

In the context of this paper it has not been possible to exhaustively deal with the complex socio-cultural problems of effectively integrating sanitary facilities in a rural or peri-urban setting. In the following chapters however, relevant examples and observations have been included in the discussion of the various sanitation options. More specific literature is indicated in the bibliography.

1.1. Water Supply, Sanitation and Public Health

An improvement in the quality of drinking water alone may not reduce the incidence of gastro-enteric diseases significantly as these diseases are often spread also by a lack of hygiene. The diarrhoea causing organisms are not merely transmitted by water-borne routes but also by a mother who does not wash her hands properly, by contaminated and improperly prepared food, by dirty pots and containers. This is sometimes unavoidable when the nearest water source is far from the house and the water must be laboriously carried or when a standpost near the house provides only an intermittent supply of water. A convenient and adequate supply of water is a prerequisite for improved personal and domestic cleanliness. But it would be a mistake to assume that there is a direct positive relationship between the availability of water and a better personal and domestic hygiene.

The availability of water will not ensure the correct use. Mothers who do not practice good domestic hygiene will not automatically change that part of their behavior that is infecting and reinfecting their infants and small children with diarrhoeal diseases, simply because of easy access to water. Further, the potential health benefits of a more accessible and adequate clean water supply frequently fail to be realized because infections and enteric diseases continue to be transmitted by other routes which remain unaffected.

Sanitation must therefore be improved concurrently with the upgrading of the water supply. The hygenic disposal of wastes is of major importance to check the spread of the excreted infectious and parasitic organisms. Equally important is the correct continuous and universal use of these facilities as well as improved personal and domestic hygiene. The provision of adequate watersupply and sanitation facilities will therefore only lead to an improvement in public health when a health education is carried out simultaneously.

1.2. Participatory Health Education

The health education programme will need to be planned in consultation with the community. Initially it should focus on creating an awareness among the people of their sanitary environment by discussing with them the relationships between disease, water and sanitation. With that awareness established the people themselves will be in the best position to recognize those aspects of their behavior as well as the existing facilities which are an environmental risk.

The required changes in practices can then be discussed, together with the ways in which health education will be carried out, in a water or health committee or, in the smaller settlements, in open assembly.
It is important that an atmoshpere of dialogue is created in which the difficulties and constraints facing community members (especially the poor) in changing their practices are openly discussed, and ways found in which the changes can be facilitated.

In the discussions the feasible sanitary improvements should be identified and a selection of acceptable and affordable water supply and sanitation options made. The health education programme should subsequently be directed at realizing the correct hygienic use of the selected options. Once the facilites are built continued health education programmes will further need to ensure the proper use and upkeep of the facilities.

2. SANITATION OPTIONS

2.1 Introduction

The primary objective of an excreta disposal program should be the improvement of health and to provide as many people as possible with appropriate sanitation facilities. In the past, some of the primary obstacles to the provision of sanitation facilities, particularly in the rural areas, have been the lack of funds and of information on alternative low-cost appropriate technologies. Often sanitation programs included expensive high technology options, thereby limiting the possibility of using these to higher income groups as they usually have regular water supply through yard/or houseconnections. Little attention was paid to low cost sanitation facilities aimed at the sharing of health benefits with the majority of the population.

This monograph has been limited to a choice of low-cost on-site excreta disposal, and treatment and reuse alternatives excluding options such as the septic tank, which are usually beyond the financial capacities of the rural population. This is also likely to be true for the aquaprivy. Because to maintain the waterseal an expensive watertight tank needs to be constructed. A significant quantity of water is furthermore required to top up the water level above the waterseal. If this is not done fly-breeding and bad smells will occur. This may be avoided in a sullage-aquaprivy in which domestic wastewater is also flushed in order to help maintain the water seal. However increased wastewater quantities also require a larger tank thus making the system even more expensive. In the context of this monograph aquaprivies and their improved versions are therefore not considered in the range of low-cost sanitation options. Apart from the financial aspect is is not likely anyway that aquaprivies are appropriate in a rural setting because it is safe to assume that village water supply service levels only allow for communal standposts and private yard connections. Regular topping up of the water level in the aquaprivy can with such levels of service not always be assured. The daily quantity of water used for domestic purposes will be small and not much sullage will be generated. Proper drainage and possibly soak-aways will be sufficient to ensure hygienic sullage disposal. With a little bit of attention by the householders this is not likely to pose great problems in rural areas. Alternatively, waste water may also be utilised to irrigate home gardens, as long as stagnant water is avoided and vegetables are not consumed raw. A further discussion of sullage disposal systems is therefore not considered necessary in this monograph.

A deliberate choice is made for individual household systems as opposed to communal sanitation facilities. Experience in all parts of the world has indicated that public conveniences are no substitute for individual household solutions. The principal disadvantages of communal facilities are:

(1) the lack of cleanliness and maintenance, as it appears to belong to no one individually and so there is very little commitment by individual users to keep it clean and operating properly;
(2) the lack of privacy;
(3) the distance from the individual households, a problem for children and for users at night during wet or cold weather and illness.

Sanitation improvement will only be effected if the facilities are used for defecation at all times by all members of the community including young children. It is essential therefore that sanitation facilities be constructed near the homes as well as near the fields where many local agricultural communities spend most of their working day.

Reuse

If in the past, human wastes were regarded as something dangerous and to be permanently disposed of, in the light of rising energy costs and depletion of local sources of fuel, many are beginning to view excreta as a useful and valuable natural resource. Human and animal wastes are potentially valuable resources which will become more valuable as time goes on and the price of chemical fertilizers and oil continue to rise. In the long run, excreta used to make biogas or composted fertilizer may play a key role in reducing additional energy and nutrient needs in areas where human and animal excreta comprise one of the very few resources, thus helping to restore the ecological balance of the region.

Treated excreta can provide an important source of nutrients to help increase the productivity of fish farming. Fish, in turn, are getting more attention as a high protein source of food in the developing world. Not only is the treatment of wastes beneficial from an agricultural and economic perspective, but it has great importance from the public health point of view as well. Both the process of composting and biogas digestion destroy the majority of the causative agents of faecal-borne diseases.

In the following brief descriptions will be given of the Ventilated Improved (Double) Pit Latrine, the Pour-Flush latrine and two systems for excreta re-use: the Double-Batch Composting latrine and the Bio-gas digestor.

Selection and Design of Latrine

The final choice of which latrine option is most environmentally and technically sound and socially acceptable will depend on a number of factors such as:

1. Soil Conditions

- The stability of the soil will influence the construction of pit latrines. Pits dug in loose and unconsolidated soils (loam or sandy soils) will have to be lined to avoid cave-in or collapse. Soil containing fissures, cracks and holes will increase the possibility of groundwater pollution.
- To be able to use on-site disposal, rock should be at least 1-2 meters below the surface.
- The pit should preferably not penetrate the ground water table to prevent ground water pollution. If the ground water table is high, the construction of an unlined pit becomes difficult, and the pit may collapse in the wet season. There is also an increased danger of mosquitoes breeding in so-called wet pits.

2. Socio-cultural Factors

Religious or cultural factors affect hygiene practices and thus the technology. For example the use of bulky materials for anal cleansing necessitates the use of a pit latrine. The attitude towards excreta will influence the potential for re-use. A good participatory programme will facilitate the choice and acceptance of a particular sanitation disposal system. Design and appearance will also play a role in the adoption of the facility (e.g. a squatting plate or raised seat). Location or use of shared facilities may not be acceptable to both sexes and all age groups.

3. Cost

Cost-effective construction can be realised because the latrine can be made using locally available material and skills. Small scale village industries may be promoted for the fabrication of squatting slabs, ventilation pipes etc. A high-quality compost is produced which has an excellent potential for conditioning the soil and raising crop-yields.

4. Climate

Temperature range, rainfall and vulnerability to flooding all influence the application and siting of a particular type of latrine.

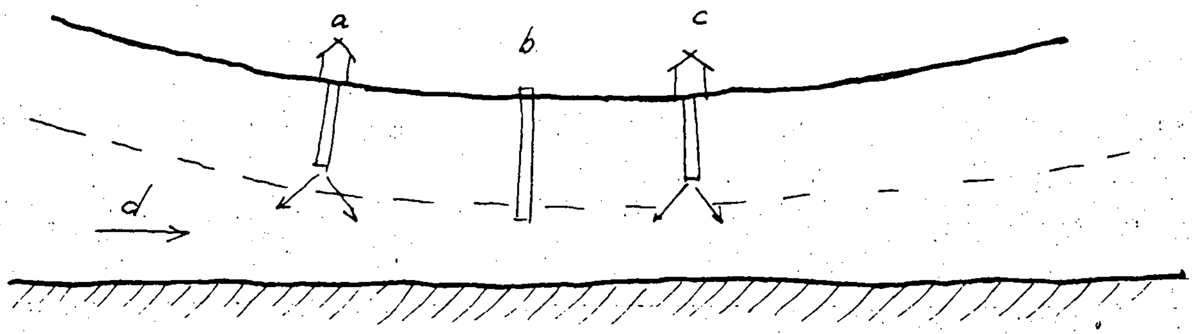
Location of Latrine

The choice of latrine type can be influenced by the water supply system in the vicinity of the proposed latrine location. If the latrine is to be built near a well the following factors must be considered: the type of latrine (open bottom or sealed/water-tight) the ground water table, the slope of the ground and the subsoil conditions

A latrine with a water-tight receptacle from which there is no filtration does not pollute the groundwater. With filtration the risk of groundwater pollution is virtually nil if the bottom of the receptacle is more than 1.5 m above the ground water table and the soil is homogeneous. If the bottom of the pit is close to or reaches down into the ground water, the latrine must be located downhill from the well. The well will then be safe because the contamination does not move against the direction of flow of the groundwater. Where uphill locations cannot be avoided, a minimum distance of 30 meters, but preferably 50 m, will prevent bacterial pollution of the well.

In the sandy soil, a latrine may be located as close to 7.5 m from a properly constructed well, if it is impossible to place it at a greater distance. In areas containing fissured rock or limestone formations, filtration through the underground may not always directly take place and seepage from the latrine can thus be carried long distances. In such conditions it is essential that the latrine is placed downhill from the well.

Diagram 1. Siting of a pit-latrine.



a = bad site for latrine

b = shallow well

c = suitable site for latrine

d = direction of groundwater flow

<u>Participation of the community in selecting the sanitation option</u>

As the ultimate users the community members need to be involved to the greatest possible extent in the various stages of the sanitation project. A possible set-up for the participation of individual future users and their representatives is indicated below.

Directly or in the context of a water supply, rural development or primary health care project, the community may become involved in a sanitation improvement activity. Assuming that the community sees the construction of better waste disposal facilities as a first priority, the first action to be undertaken to achieve this end will be the examination of the physical and environmental conditions by the sanitary worker/water engineer/ health worker together with the village (health) committee and the collection of basic data about sanitation-related practices and preferences of the community.

Next a list of all feasible sanitation options needs to be prepared, giving details about:

- technical, economic and social advantages and disadvantages of each option.
- consequences and potential benefits such as economic and agricultural gains from re-use, and energy conservation.
- direct and recurrent cost of each option, contribution required in labour, materials, cash.
- potential for community or household self-reliance especially with regard to operation and maintenance.
- potential for future upgrading.
- organisational possibilities to guide self-help and to set-up and sustain the required participatory health education programme.

All information is presented to and discussed with the community.

Members of the community, for example, the health committee visit pilot projects, where models of the various latrine options are on display or in operation. In addition, meetings can be arranged with members of other communities who have successfully introduced sanitation facilities.

The community or individual householders select the latrine option which is most acceptable and affordable.

A properly located, constructed and maintained latrine will meet all public health requirements for the sanitary disposal of human waste. Criteria for the design of sound sanitation systems are:

a. the top soil should not become contaminated.

b. there should be no contamination of ground water that may be abstracted from springs or wells.

c. there should be no contamination of surface water.

d. excreta should not be accessible to flies or animals.

e. there should be no handling of fresh excreta.

f. there should be no odours.

g. the technology should be such that the latrines can be constructed and maintained by the local community using local materials.

h. the system should have minimum water requirements and

i. should provide for proper use by children.

A summary of some of the reasons latrine programs may fail

Lack of health education

a. communities do not sufficiently understand the relationship between excreta, polluted water and disease, and therefore do not realize the need to use latrines, and adopt a hygienic behaviour.

> In Durban, South Africa, worms were for instance believed to be an essential part of the gastro-intestinal system.

b. the nature of the work of the villagers (farming and herding) encourages defecation in the bush or fields.

> In several rural villages in Egypt, a combined sanitation and mass medical treatment program was carried out in an attempt to control the incidence of various parastic infections. Bore-hole latrines were constructed near the villagers' homes.The program as a whole failed because no sanitation facilities were provided near the fields, where the villagers spent the major part of their day. People defecated in the fields while at work, not understanding sufficiently that many important parasites were thus transmitted in the fields.

c. belief that childrens' feces are harmless.

> The health workers at the Kasangati Health Center near Kampala, Uganda, in carrying out home visits, found that an important factor contributing to the poor level of domestic hygiene was the lack of disposal of children's feces. This was due to an insufficient understanding on the part of the mothers of the relationship of children's feces and disease.

Technical Flaws

d. poorly constructed and maintained latrines are offensive and a health hazard because of their uncleanliness, smells and attraction of flies, mosquitoes, and rodents.

> The construction and use of latrines in Ethiopia was hampered by the belief that bad smells themselves are a cause of disease, hence one should not return to the same smelly place.

e. the faecal material is visible.

f. accidents (pit collapsing) associated with latrines.

g. children are not permitted to use the latrine because of the possibility of their falling in.

h. the user is exposed to contaminated water when the ground water table is high or the pit is open to rain or storm water run-off.

Insufficient knowledge of community's beliefs and practices

i. opposite sexes and/or different age groups do not wish to share the same facilities.

j. The design and choice of a latrine facility may not be adapted to the users' habits, resulting in its possible rejection or misuse.

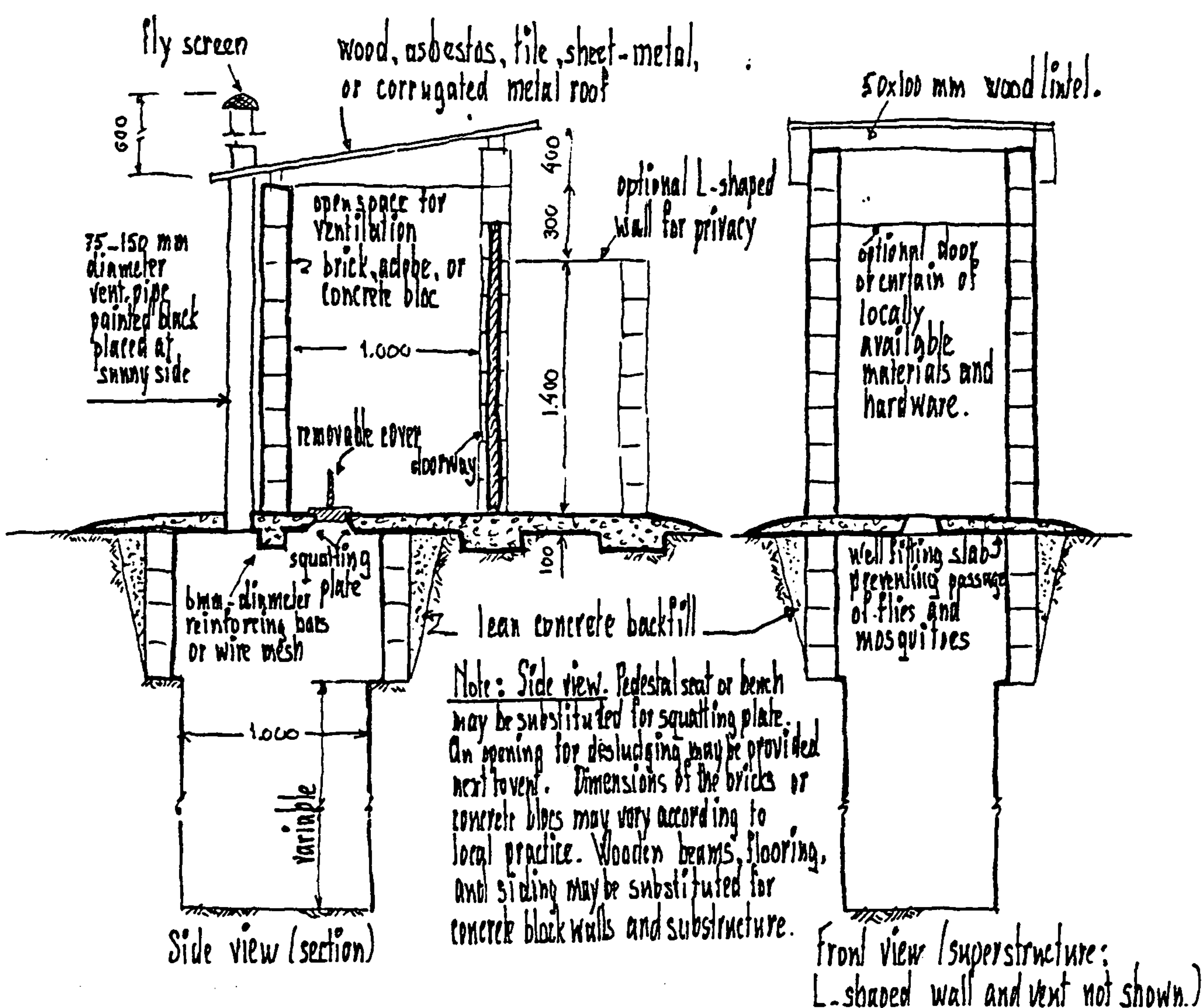
> In a rural area of Zimbabwe pour-flush S-bend latrines which require water for flushing were installed. The intended users, however, had the tradition of using bulky anal cleansing materials which consequently blocked up the S-bend and resulted in malfunctioning of the system.
>
> In another case, pit latrines were introduced without consideration of the community's cultural beliefs. The belief that excreta in a pit latrine could provide a fetisher with the opportunity to cast a spell upon a person was the reason for the community's initial rejection of the latrine, and their preference for defecating in the bush, where their feces would be hidden. Upon learning the reason why the latrine was culturally unacceptable, the planners suggested throwing dirt, refuse, or any organic matter into the latrine after defecating in order to cover the excreta and protect it from the fetisher's spell.
> This may be an example of an entry point where the traditional beliefs allow for the introduction of a composting latrine.

2.2 Dry On-Site Excreta Disposal System

The (VIP) Ventilated Improved Pit Latrine

The Ventilated Improved Pit (VIP) latrine is a simple, but significantly improved design of the traditional pit latrine incorporating a vent pipe with a screen which if properly designed and constructed ensures that the latrine is odour free and also acts to reduce mosquito and fly nuisance.

Diagram 2. Ventilated Improved Pit-Latrine (mm).



This design provides an odour free, periodically emptyable latrine, hygienic and low in cost which is likely to prove very acceptable to householders who have experienced flooding, collapsing, smelly latrines with earth floors which cannot be kept clean and which harbor hookworm larvae. VIP latrines are designed for use without water. Recent World Bank field studies confirmed that among the household systems the pit latrine is the most common and cost-effective technology.

Once the single VIP is filled to within 0.5 m from the slab the slab and superstructure must be removed and the pit sealed and a new pit must be dug. In areas where there are objections to emptying the pit and reusing its contents after composting, a fruit tree can for instance be planted over the sealed pit.

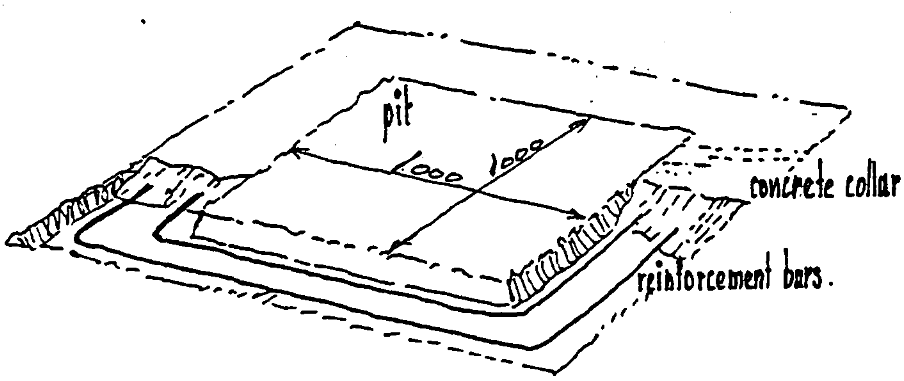
The VIP twin pit is more convenient and possibly less expensive because the alternating use of the twin pits enables it to be a permanent facility remaining in one position, and precludes the necessity of digging another pit. When the first pit becomes full after a year, it is rested and the excreted pathogens die away, leaving a rich humus which can be used as a soil conditioner. During this time the adjacent pit is used. Thus the excreta are never handled until they are at least 12 months old.

Construction

The single VIP pit can either be round with smooth, straight sides, or square in shape. The pit depth ranges from 3-8 meters, although pit depths of 12 meters or more are found where soils are particularly suitable. With VIP latrines, it may be advantageous to use enlarged pits provided the ground conditions are suitable. The pit is approximately 1 square meter in cross-sectional area.

In digging the pit, it has been found helpful to start by providing a collar around the top of the pit. The collar helps in getting the sides straight and preventing the top portion of the pit from falling in. It is best to make a concrete collar by digging a shallow trench, 60-80 mm deep, and at least 0.3 m wide around the marked location of the pit. Fill the trench with 20-30 mm of concrete, place two Ø8 mm iron rods horizontally next to each other and fill up the trench with concrete. After about two days the concrete will have hardened enough to allow digging of the pit to start. The support may also be provided by lumber beams extending well beyond the top of the pit. One layer of bricks is built on top of the collar to make a plinth which will support the superstructure. An alternative method is shown in diagram 2 where the plinth has been constructed below ground level. The superstructure can be made of wood, plywood, re-inforced concrete or ferro-cement. The pit is covered with a durable fixed slab which should tightly fit the rim of the pit to prevent passage of mosquitoes and flies. This slab contains two holes, one for squatting and one for the vent-pipe. The external vent pipe runs up the outside of the superstructure back wall.

Diagram 3. Construction of concrete collar.



The vent pipe should be at least 75 millimeters in diameter (ranging up to 200 millimeters); it should be painted black and located on the sunny side of the latrine superstructure. The air inside the vent pipe will thus heat up and create an updraft with a corresponding downdraft through the squatting plate. Thus any odours coming from the pit are expelled via the vent pipe, leaving the superstructure odour-free.

Latrine Ventilation

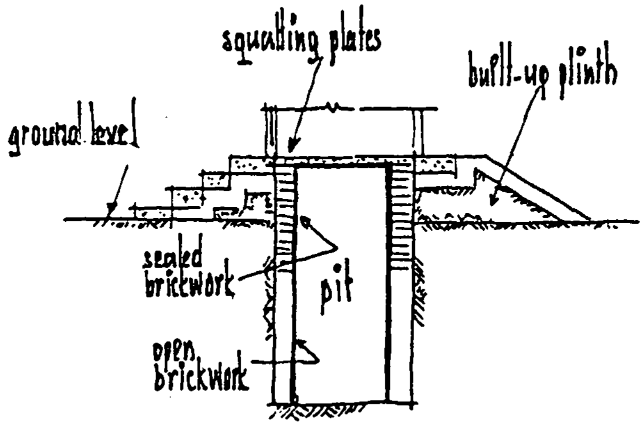
Recent work has indicated that pit ventilation may also have an important role in reducing fly and mosquito breeding. If the vent pipe is large enough to let light into the pit, and if the superstructure is sufficiently dark, the adult flies will try to escape up the vent pipe. The top of the vent pipe is belled outwards to about 30 cm. and the aperture must be covered with a durable netting to prevent the escape of flies and mosquitoes. The netting deteriorates very quickly due to ultraviolet light and rusting. Aluminum wire, fiberglass or stainless steel mesh are recommended. The vent pipe must also be made from corrosion resistant material (asbestos cement, fiberglass, PVC).

Pit Lining

The upper part of the pit should be lined so that it can properly support the squatting plate and superstructure. If this is not done the pit may collapse. This support may vary in depth, reaching down only about 1 m. below ground level in stable soil, or, in unstable soil conditions, it may be necessary to extend the lining down to the bottom of the pit. Care must be taken to ensure that the lining does not prevent filtration from taking place. The pit supporting wall can be made from a variety of materials: open-jointed or sealed brickwork or blockwork, circular concrete pipes of about 1 m. diameter. Local material that can be used to line the pit can be: splint cane or bamboo poles filled with mud, fibre mats, stones, laterite blocks, adobe materials, or rough hewn logs (if termite free).

The pit should be open at the bottom and constructed so as not to extend below the water table so the pit remains dry and ground water contamination is minimized. In areas where the water table is within 1 meter of the ground surface, or where excavation is extremely difficult (in rocky ground) a built-up pit can be used, as shown in diagram 4. The raised plinth should not be more than one meter above ground level and a water-tight lining should extend at least 0.5 meters, and preferably 1 meter below ground level. This lining allows for increased diameter, thereby achieving a reasonable volume even with a reduced depth. All pits should be constructed to prevent surface water from entering the pit. This requires arranging the soil around the latrine to ensure diversion of surface water. Where the pit is partially off-set from the superstructure, it should normally be constructed on the downhill side.

Diagram 4. Raised pit latrine for use in areas of high groundwater level.



Squatting Plate for VIP Latrines

Local preference should determine whether a squatting plate or pedestal seat will be used. In the case of a squatting plate the following four design considerations are important.

(1) The opening should be about 400 mm. long to prevent soiling of the squatting plate, and at most 200 mm. wide, to prevent children from falling into the pit. A "keyhole" shape is suitable.

(2) Foot rests should be provided as an integral part of the squatting plate. They should be properly located to facilitate defecation into the pit and not onto the squatting plate. This is particularly helpful when it is still dark. (One design of the footrest which has proved attractive to users in the Philippines was shaping the footrests in the design of a jet plane).

(3) The free distance from the back wall of the superstructure to the opening in the squatting plate should be in the range of 100-200 mm., if it is less there is insufficient space, and if it is more there is the danger that the rear part of the squatting plate will be soiled. The preferred distance is 150 mm.

(4) The squatting plate should have no sharp edges which makes its cleaning difficult and unpleasant.

A variety of materials can be used to make the squatting plate: timber, reinforced concrete, ferrocement and sulfur cement are usually the cheapest. Diagram 5 shows a typical design for a reinforced concrete squatting plate. A construction in ferrocement is advantageous since the squatting plate need then only be 18 to 25 mm. thick, rather than 70 mm. as shown, with consequent savings in material and weight but with equal strength. The mix specification for ferrocement is: 1 part cement, 2 parts medium to coarse sand, and 0.4 parts water; reinforcement is provided by two layers of 12 millimeter opening chicken wire across the slab. An alternative and cheap design is shown in Figure 5a. In the latrine project executed by the National Directorate of Housing

Diagram 5. Reinforced Concrete Squatting Plate (mm).

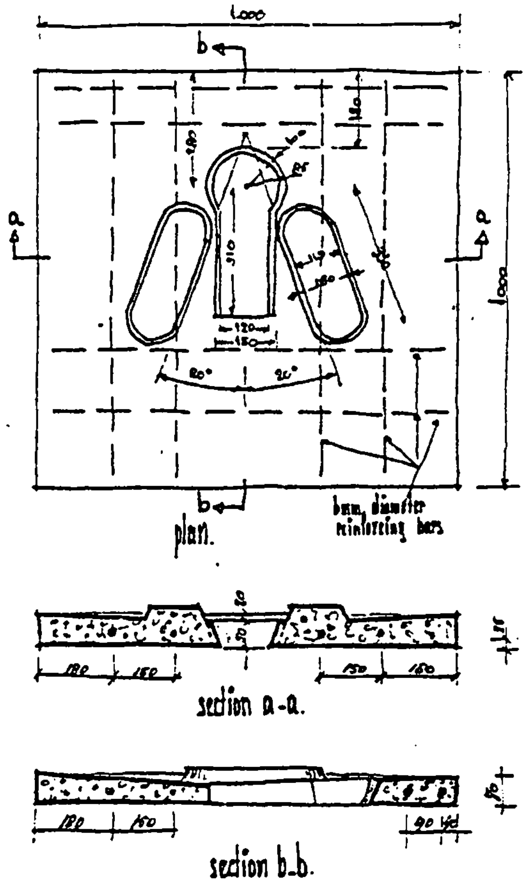
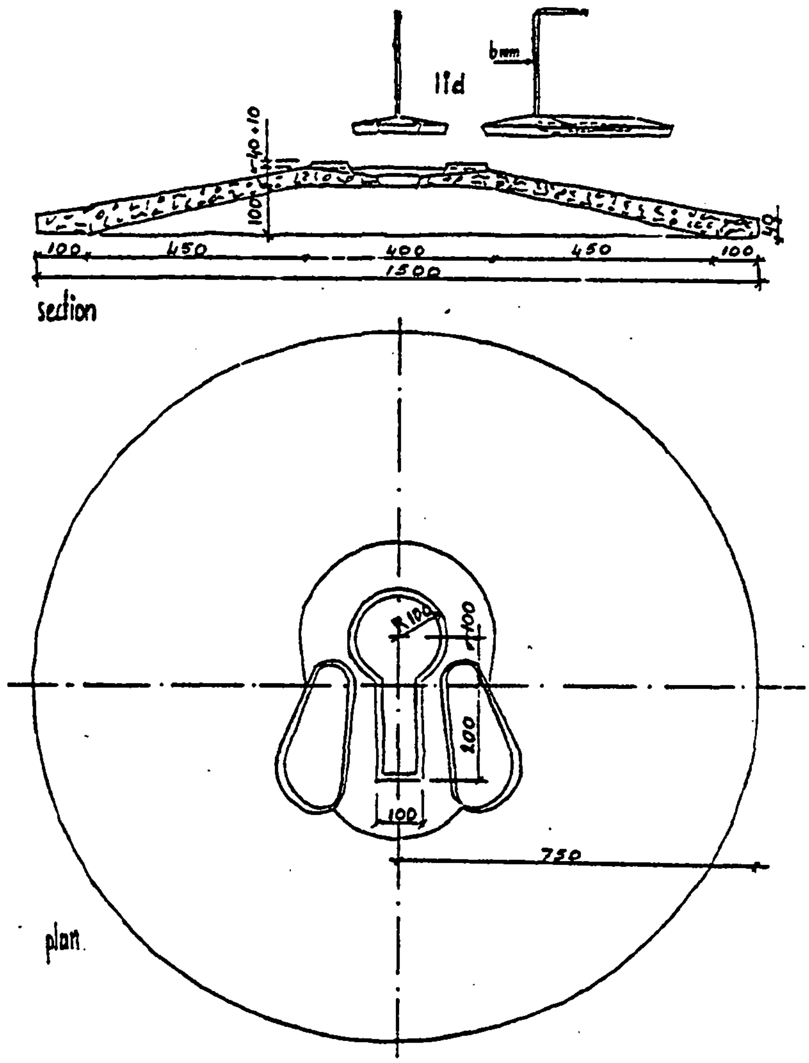


Diagram 5a. Concrete Squatting Plate (mm).

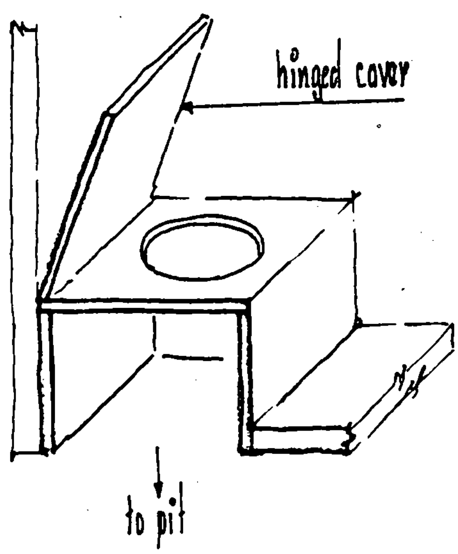


in Mozambique non-reinforced circular slabs with a slightly conical form were tested. After hardening for one week the slabs were test-loaded and proved strong enough to support six persons placed in a straight line accross the slab, while the slab was supported by four wooden wedges. In the Mozambican case these non-reinforced conical slabs turned out to be stronger and a lot easier to produce than ferrocement slabs.
Squatting plates should be cast in an oiled timber mould to avoid damaging mould and cast when the latter is removed.

Pedestal Seats for VIP Latrines

The important design criteria are the seat height and the size of the openings. For adults a 250 mm diameter is suitable. The pedestal riser can be constructed in brick, concrete, blockwood, or wood. To encourage proper use by children a smaller seat (150 mm diameter seat should be provided). This may be a separate seat on the seat cover. A cover should always be provided for both the squatting plate and the pedestal seat to minimize access and escape of flies and mosquitoes through the squatting hole. The cover should have several small holes drilled in it to permit the through draft necessary in these toilets for odour control.

Diagram 6. Pedestal Seat.



The (VIDP) Ventilated Improved Double Pit Latrine

A VIPD latrine differs from a VIP mainly in that it has two alternating pits (see diagram 7). To facilitate emptying and prevent collapse of the partition wall, the pits should not be as deep as that of a VIP. Furthermore the superstructure of te pitlatrine is half displaced relative to the pit to permit access for emptying purposes. Two pits can be provided with a separation wall in the VIP pit or by constructing two separate pits (see diagram 8). Each pit should be designed to have an operating life of at least one year before it is necessary to seal the pit and switch to the second pit. The required capacity of the pit should be 0.06 cubic meters per person yearly. In areas where bulky anal cleansing materials are used such as grass, leaves, corn cobs, mud balls or paper of cement bags, this figure should be increased by 50 percent. The regular VIP squatting plate or pedestal seat is used.

With two pits available, one pit will be used until full and then sealed while the second pit is in use. When the latter is almost full, the first pit will be emptied and put back into use once more. By alternating, the two pits can be used indefinitely. Because of the long retention time (a minimum of one year) of the decomposing excreta in the pit which is not in use, the pathogenic organisms will have been destroyed by the time the pit needs to be emptied. As a consequence, there is no danger of spreading pathogens, and the emptied humus-like material can be used as a soil conditioner or disposed of without fear of contamination.

Further Observations

a. Potential for Upgrading

Both the VIP and VIDP can be easily upgraded to Pour-Flush (PF) toilets by the replacement of the squatting slab with a PF water-seal unit.

Diagram 7. Ventilated Improved Double Pit Latrine (mm).

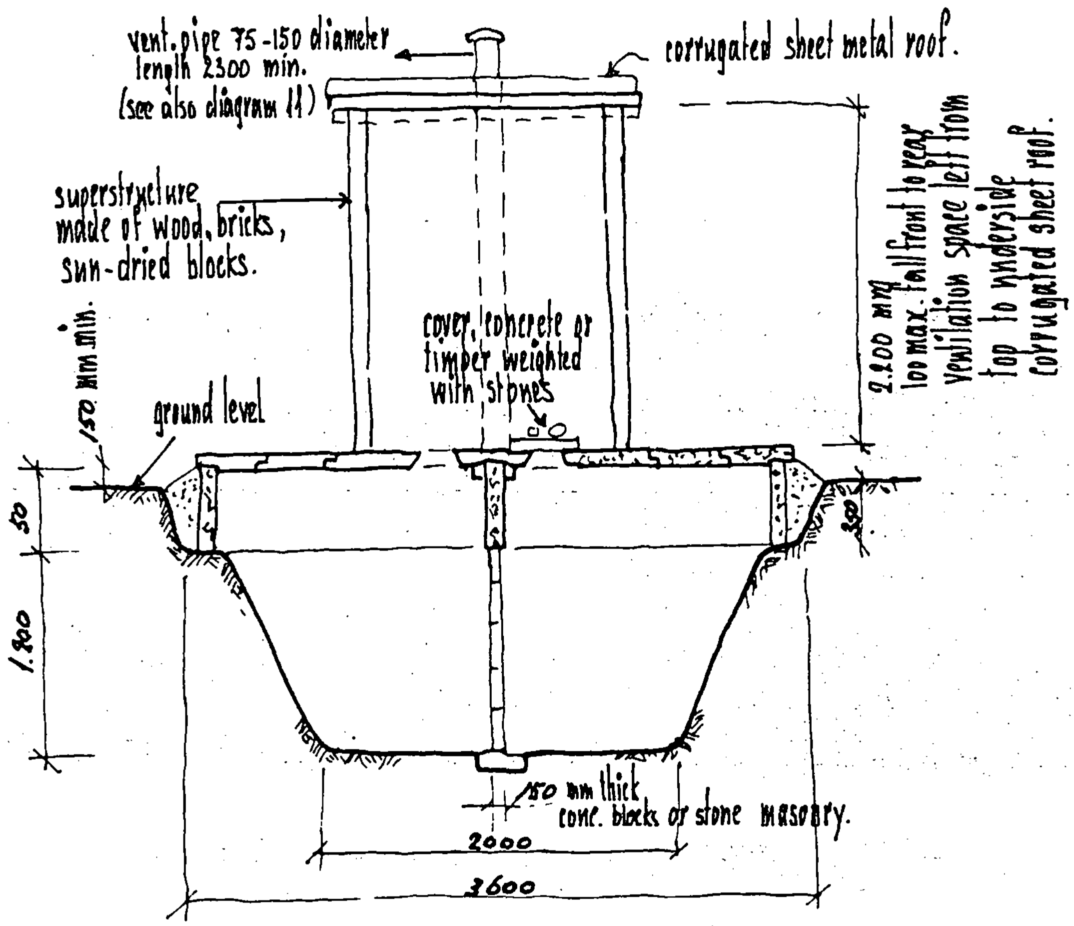
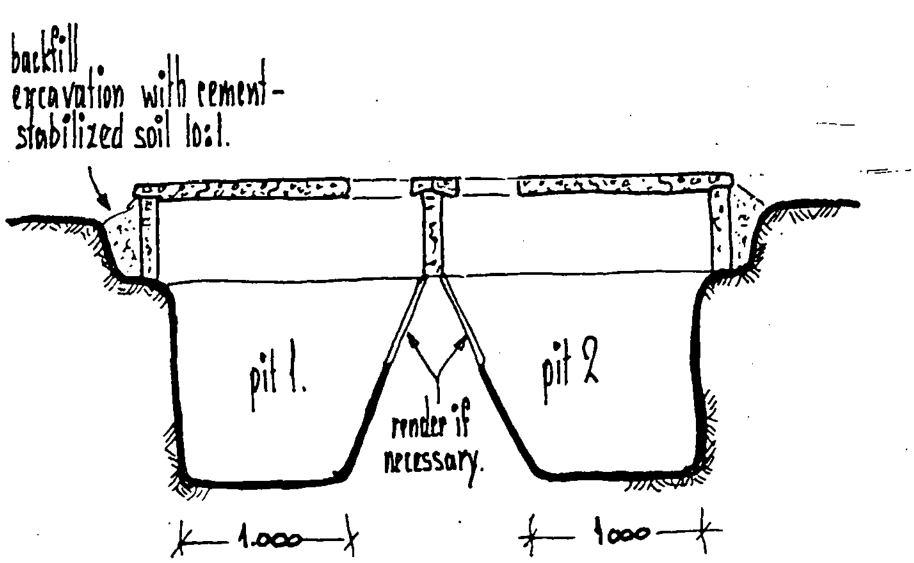


Diagram 8. Ventilated Improved Double Pit Latrine, alternative design (mm).



b. Maintenance Requirements for VIP and VIDP

Pit latrines require good maintenance. Maintenance is however simple and consists principally of keeping the squatting plate, floor and superstructure clean. To prevent mosquito breeding in wet pits a cupful of wood ash, lye, used lubricating oil or kerosene should be added to the pit each week. If the decomposed excreta is to be used as humus, once the pit is filled to within 0.5 m from the slab, a bucket of fresh garden soil should be added to the pit to provide the seed for carrying out rapid digestion. The pit is then sealed.

c. User Education

A user education program is necessary to ensure that latrines are used correctly. Commitment to indeed use and maintain the system properly will be enhanced by discussing excreta related disease transmission with the consumers and clarifying the functioning of the latrines. Early participation of village members in the planning, design and execution of a latrine programme will also increase programme efficiency.

Proper usage is also very important with the VIDP latrine, where one pit must always remain sealed while the other pit is in use. Lack of understanding on the part of the user led in Botswana to the simultaneous use of two pits, one for adults and one for children.

d. Costs

The cost of a VIP or VIDP is composed of the labour required for pit excavation and lining and for the purchase and fabrication of materials for the squatting slab, the vent pipe and the superstructure. In most cases the cost of the superstructure will be the biggest component. Thus any reduction in the costs through the use of inexpensive local materials or self-help labour will significantly reduce total costs of the latrine.

e. Advantages of VIP and VIDP Latrines:

1. very low annual costs
2. ease of construction and maintenance
3. all types of anal cleansing materials may be used
4. absence of odour nuisance and minimal fly and mosquito nuisance
5. minimal water requirements
6. minimal risks to health
7. good potential for upgrading
8. good potential for re-use of emptied humus for gardens
9. a VIDP latrine is a permanent facility.

f. Disadvantages

1. Pollution of groundwater may occur.
2. Once the VIP latrine is full, it must be taken out of service and another unit built.

g. Pertinent Socio-Cultural Aspects

In certain areas, existing customs and beliefs may make the emptying of the VIDP and VIP and re-use of the humus for agricultural purposes infeasible.

h. Vent Pipe

Research is continuing on the most appropriate design of the vent pipe. Experiments are also being carried out to determine how effective black pipes are compared to other pipes. Local wind patterns and the diurnal variation in ambient temperatures affect ventilation efficiency. There are some problems related to ventilation of pit latrines that remain to be solved. In some countries it might not be effective during the wet season when cloud-cover can be high. There may also be reversals in air flow direction at night. However, work is going on and it is probable that simple design modifications can be made to overcome these difficulties (Mara, Feachem, 1980; Wright, pers.comm.).

i. Public Health Aspects

In order to prevent ground water pollution, care must be taken that the pit does not penetrate the ground water table. It is further essential that the retention time of excreted matter in the pit is over 12 months and that the contents be dry to ensure that the emptied humus applied to the soil as a conditioner poses no health hazards to those working on the land, or those handling, preparing or eating the crop after it has been harvested. However, if the sealed pit becomes wet the parasitic ova in the excreta may survive for more than 12 months and the humus may not be safe to handle.

If not kept clean, the pit latrine becomes a focus for continuous disease transmission and may make matters worse than defecation in an open field.

j. Small-Scale Industry

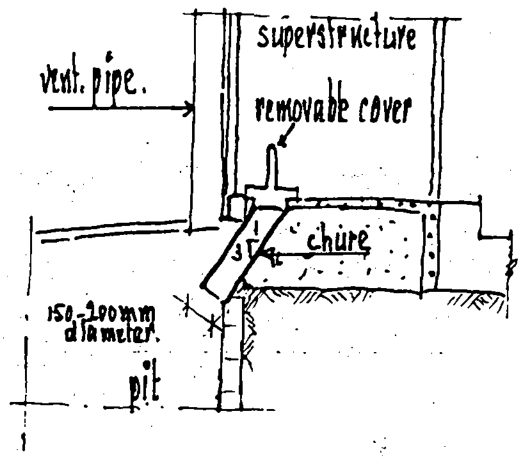
A small scale local industry may be set up in order to fabricate the squatting plate or other components of the latrines making use of locally available materials and skills.

Reid's Odorless Earth Closet (ROEC)

An alternative design for a VIP latrine is the ROEC. In this latrine the pit is completely offset and excreta are introduced into the pit via a chute (Diagram 9). A vent pipe is provided, as in the VIP latrine, to minimize fly and odor nuisance.

A major disadvantage of the ROEC, is that the chute is easily fouled with excreta and thus may provide a site for fly breeding. The chute therefore has to be cleaned regularly with a long-handled broom or brush. Hygiene problems may be created when the cleaning of the chute is not carried out regularly because of lack of broom or stick. And if it is carried out than the broom itself may not always be cleaned after use. In spite of this disadvantage, ROEC's are sometimes preferred to VIP latrines because the pit is completely displaced and the users (particularly children) have no fear of falling into it. Furthermore, it is not possible to see the excreta in the pit.

Diagram 9. Detail Chute Reid's Odorless Earth Closet.



2.3. Wet On-Site Excreta Disposal System

The Pour-Flush Waterseal Latrine (PF)

The Pour-flush latrine has a water seal unit incorporated into the squatting plate. The advantage of this type of latrine is that the water seal prevents the development of odours and the breeding of insects and therefore no venting system is required. Approximately 3 litres of water or sullage are manually poured in to flush the excreta into the pit after each usage. Because of the odour elimination, this type of latrine can be located inside the house, if desired. The PF latrine is an appropriate sanitation technology in rural areas where sufficient water is available for flushing as well as in those societies where water is used for anal cleansing. It is important that the tradition of using water for anal cleansing purposes prevails because the use of bulky cleansing materials such as corn cobs, stones, newspapers etc., will result in the water seal not being flushed; the seal will be blocked, and the sanitation system will be of no avail. The PF model discussed here is a modification of the VIP or VIDP latrine in which the squatting plate is provided with a simple water seal. It is possible to upgrade a VIP or VIDP latrine by replacing the squatting plate with a water seal unit. The PF latrine can be built with either single or twin pits. The twin pit PF design may be preferred because its location is permanent, and therefore, the superstructure remains in place. This provides for a more long-term solution which may be more cost-effective than the single pit PF latrine. Moreover, just as with the VIDP latrine, the twin pit system provides a satisfactory manner of hygenically converting excreta into a rich humus.

Pit Design and Size

The pit is designed in the same way as described for wet VIP latrines, and provided with a concrete slab cover and water seal unit. On calculating the pit's volume, a design capacity of 0,04 cubic meter per person yearly can be used. This is somewhat less than what is necessary for dry VIP latrines, because the digestion of excreta solids proceeds more rapidly in wet pits.

Construction

The pit is lined at the top to make it waterproof. In areas where the soil conditions and the ground water table permit, the bottom of the pit should be left open to allow for the seepage of water and urine. If the water table is high, or ground conditions are infavourable the pit can be elevated in the same way as described for the built-up VIP latrine.

Just as with the VIDP latrine, the superstructure is half-displaced relative to the pit so as to facilitate emptying.

Water Seal and Squatting Plate

The design of the water seal and squatting plate is shown in diagram 10. The water seal has the form of a bowl with an inverted siphon. After the water seal bowl is made, it is cast into the squatting slab so that it forms one unit. It is important to note that the water seal unit must be placed in position to flush forward in order to avoid erosion of the pit wall. The water seal unit can be made from ferro-cement or reinforced plastic with a good mould and some training these units can be made locally. The latrine should be provided with a heavy, well-fitting cover. If the twin pit PF latrine is constructed a water seal unit and a concrete cover are provided, their positions being interchanged as necessary. The water seal unit should be constructed in such a way that it is durable and re-usable. Once the single pit PF latrine is filled, a new pit must be built, thereby necessitating the removal and re-use of the water seal unit. In the case of the twin pit PF latrine it is solely a matter of interchanging the water seal unit and the concrete cover. In order to prevent the water seal unit from cracking during this procedure it is advisable to provide grips or iron rod handles on the sides of the slab to facilitate its removal and transportation. This can be done by placing two 25 Ø 6 iron rods, like handles in the wet cement at the same time that one is casting the slab.

Operation

Once the single pit PF latrine is filled, it must be sealed and taken out of service and a new one built. The water seal unit is removed from the filled up latrine and fitted in place in the newly constructed one. If the contents of the pit are to be emptied and re-used as a humus, then once the pit is filled to within 0.5 m from the slab, the remaining space will be filled up with earth. The pit should then be sealed for twelve months before its contents are emptied and used on the land. In the case of the twin pit PF latrine, the same method is followed and the second pit is used. The concrete slab cover and water seal unit are interchanged in position when necessary.

Diagram 10. Water-seal Squatting Plate for Pour-Flush Toilets Located Immediately above the Pit (mm).

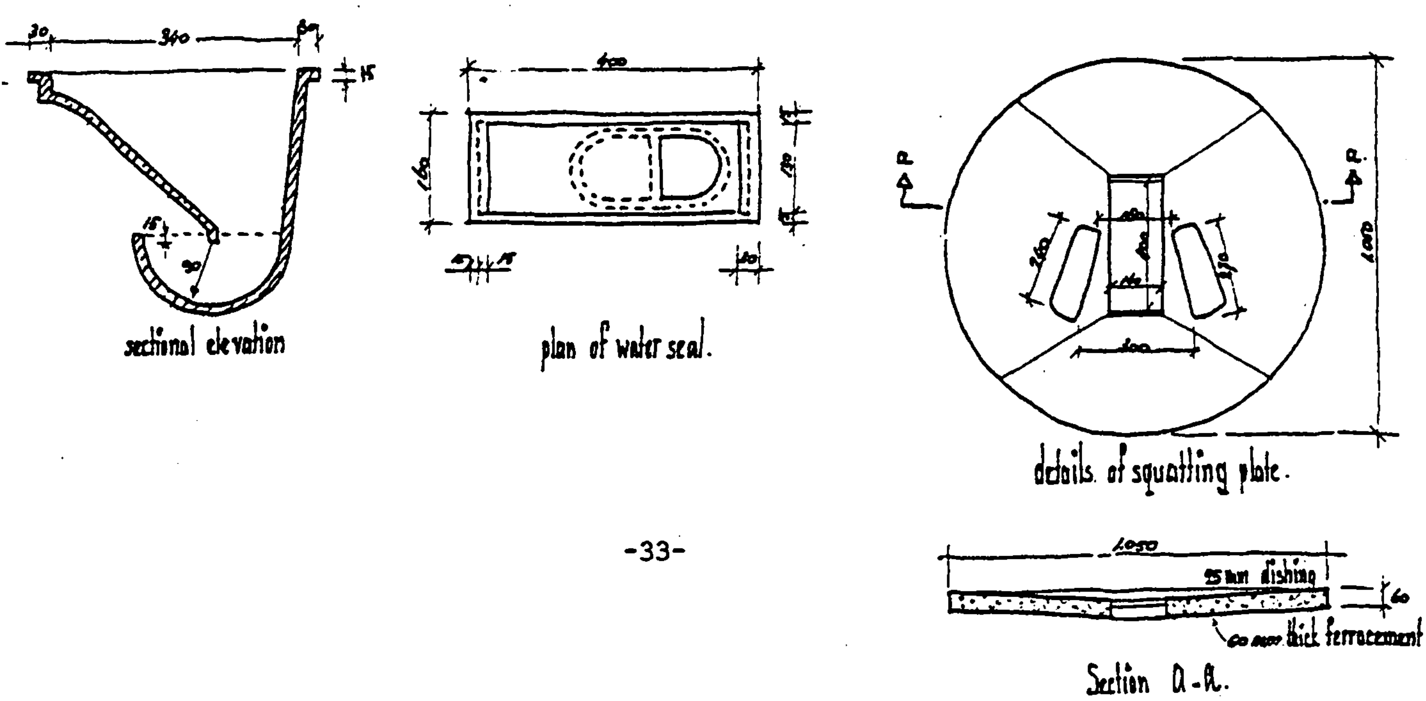
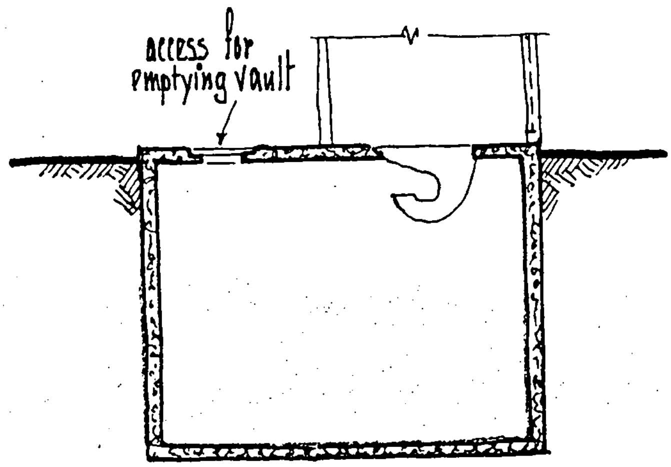


Diagram 11. Discharge Immediately above the pit.



Further Observations

a. Maintenance Requirements

- Sufficient water or sullage for hand flushing must be provided and stored in a container inside the superstructure. One to three liters of water are necessary for each flushing.
- A sufficient amount of water must be flushed into the pour flush bowl to create a water seal after each usage.
- The PF latrine will become clogged and will not function properly if solid anal cleansing material is thrown into the water seal unit.
- The squatting plate and superstructure of the latrine must be kept clean.

b. User Education

A program of user education is necessary in order to ensure that the latrines are used correctly. This is also true for the twin pit PF latrine, where one pit must always remain sealed while the other is in use to ensure proper decomposition of the excreta.

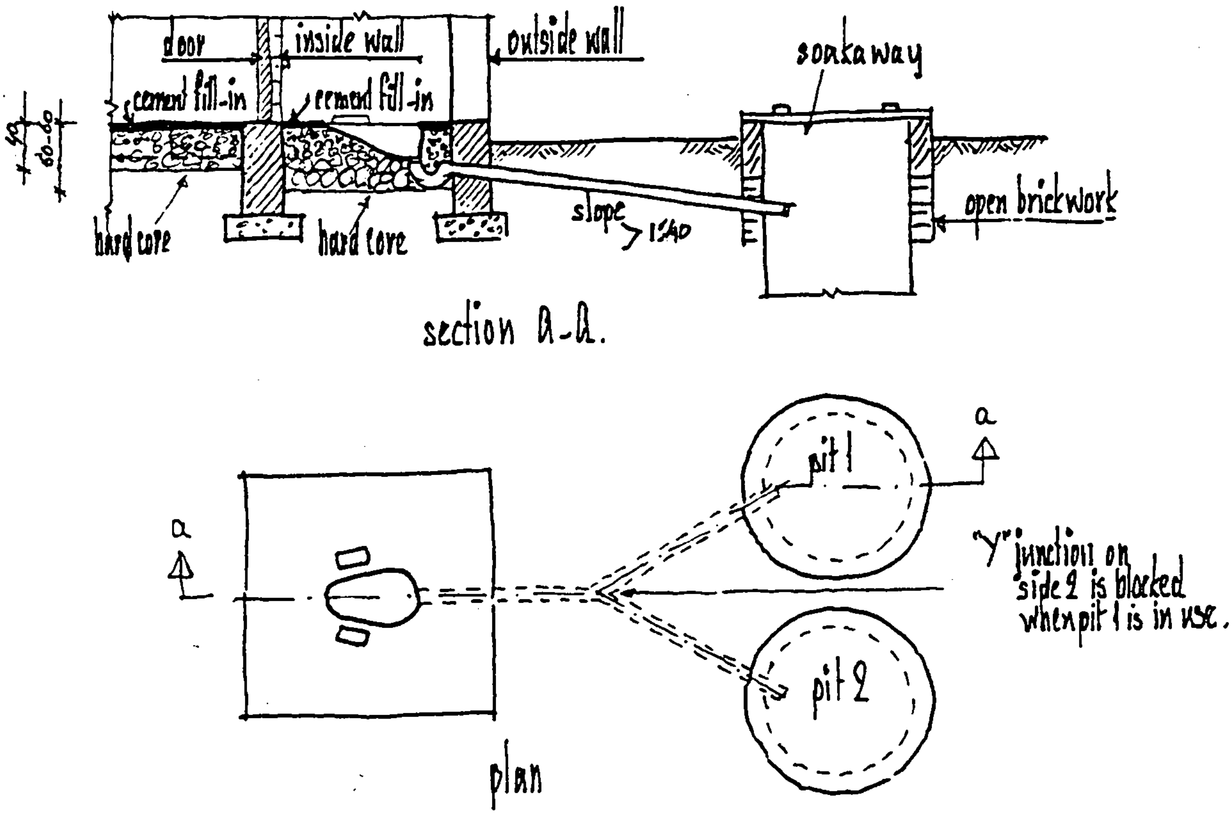
c. <u>Costs</u>

The costs of the PF latrine is similar to that of the VIP or VIDP latrine with the additional expense of the water seal unit. Flushing water requirements may increase the cost somewhat as well.

d. <u>Advantages of PF latrine</u>

1. PF latrine can be constructed inside the house (see diagram 12).
2. No odours or insect breeding (if adequate supply of water used for flushing).
3. The twin pit PF latrine provides a solution which is cost-effective and can be used nearly indefinitely.
4. Minimal risks to health.
5. Low annual costs.
6. Fair prospects to establish small-scale local industry to fabricate water seal units.
7. Good potential for agricultural re-use.

Diagram 12. Offset Pit Design.



e. Disadvantages

1. It can only be used in areas where adequate water is available;
2. A small but nonetheless significant amount of water is required for flushing. The maximum water requirement is 6 liters per person daily.
3. PF systems will become blocked and not function if not sufficient water is used or if solid bulky materials are used for anal cleansing.

f. Pertinent Socio-Cultural Aspects

g. Re-Use Potential

In areas however, where this re-use practice is accepted, the emptied contents will provide a rich humus which can be used as a soil conditioner.

h. Public Health Aspects

If well used and maintained PF toilets are free from fly and mosquito nuisance and thus pose no greater health risk than a cistern flush unit. As long as there is adequate seepage of all liquids and the contents of the pit are dry after a 12 month retention time, the public health risk of the humus produced is minimum. When the contents are still wet an additional period of dry composting is required.

i. Small-Scale Industry

A small-scale village industry may be set up in order to fabricate the water seal unit making use of locally available materials and skills.

3. WASTE REUSE

3.1. Introduction

The reuse of excreta to provide a crop fertilizer, nutrients for fish or algae ponds or a gaseous fuel substitute can provide a positive economic incentive for improving sanitation in the rural areas. The economic benefits from using excreta in these ways are often more tangible to a villager than the benefits to public health. These reuse options may provide, therefore, a stronger motivation for improving the village's environmental sanitation. The techniques discussed in this section - Double Vault Composting (DVC) latrines, biogas digestion, the fertilization of fish and algae ponds -are all applicable at the rural level and within the control of the family.

Socio-Cultural Problems

There are several social and cultural problems associated with excreta re-use for agri- and aquaculture and biogas production. Although in certain communities there may be local cultural constraints against the re-use of human and animal wastes, this rarely is true for the entire society. For instance where a group of people object to re-use, there are other groups who do not and who see it as beneficial. In more and more countries people are aware of the potential benefits for a start to be made with re-using of wastes. With the spread of new ideas, and with practical demonstrations of the benefits, even people who now oppose re-use may slowly change their minds. So this should not be viewed as a closed situation. If there is opposition to a re-use plan in one place, its promotors should try it first in a community where people are in favour of it. Once it succeeds there, opinions in other places may change.

Health Problems

There are health hazards involved in these re-use systems. However, if the techniques are operated hygenically, and the precautionary measures discussed later are taken, the recycling of wastes is certainly an acceptable an sanitary human waste disposal and treatment system.

3.2. Composting Latrines

There are two basic types of composting latrine systems: the continuous system in which an aerobic decomposition process takes place, and the batch system which is anaerobic. Continuous composters are extremely sensitive to the degree of user care; the humus must be removed at the correct rate, supplemental organic matter must be added in the correct quantities, and only a minimum of water can be added. If not, aerobic decomposition will not occur. However, even if all these conditions are met, fresh excreta may occasionally slide into the humus pile and thus render this mixture of humus and fresh waste in fact hygienically not fit for reuse.

Because of these disadvantages, especially the ones relating to the relatively high user knowledge and discipline, the continuous composters are not discussed in this paper.

Double-Vault Composting (DVC) Latrine

DVC latrines are the most common type of batch composting latrines. They have two adjacent vaults, one of which is used until it is about three-fourths full, then covered with grass, filled with earth and sealed. The other vault is then used. The vaults are thus used alternatively.

The ventilation system is the same as that of the VIP latrines. The anaerobic composting process requires approximately one year to make the compost hygienically safe for use as a soil conditioner or fertilizer for fish and algae ponds.

DVC latrines are very versatile for they can be used under difficult soil and groundwater conditions. Where the groundwater table is high or the soil is impermeable or unsuitable, the double-vault latrine is recommended. The vault can be built above the ground (for a sealed unit) or just a few centimetres below ground (for an unsealed unit).

Advantages of DVC Latrines for the Rural Areas:

Stimulating Agriculture Production

1. Produces a rich agricultural fertilizer and soil conditioner.
2. Higher yields of fish and algae ponds if enriched with composted humus.

Beneficial to Health and Environment

3. Improved nutrition, an important factor in the prevention of disease can be achieved when the wastes are applied to farm lands or introduced into fish or algae ponds as a natural fertilizer.
4. A sanitary treatment of human wastes. A properly maintained batch composting system with the right temperature/retention time produces a pathogen-free and odourless compost. The humus is thus safe for handling.
5. Reduces breeding of disease-carrying insects.
6. Applicable in flood-prone areas.
7. No pollution of ground water.

Prerequisites that must be met before considering constructing DVC Latrines:

1. Sufficient quantities of organic waste matter such as ashes, sawdust, woodchips, grass and vegetable wastes must be available.

2. Sufficient user management. A continuous long-term and vigorous program of user education will be necessary to ensure that DVC latrines are used correctly.
3. Users willing to empty and handle the composted humus.
4. Local agricultural or aquacultural use for humus produced.
5. Locally available construction materials and skills such as those for VIDP latrines.

Construction Materials and Labour Requirements

Construction material and labour requirements are generally comparable to those for the VIDP latrines, provided special care is given to making the vaults waterproof when the local conditions make that necessary.

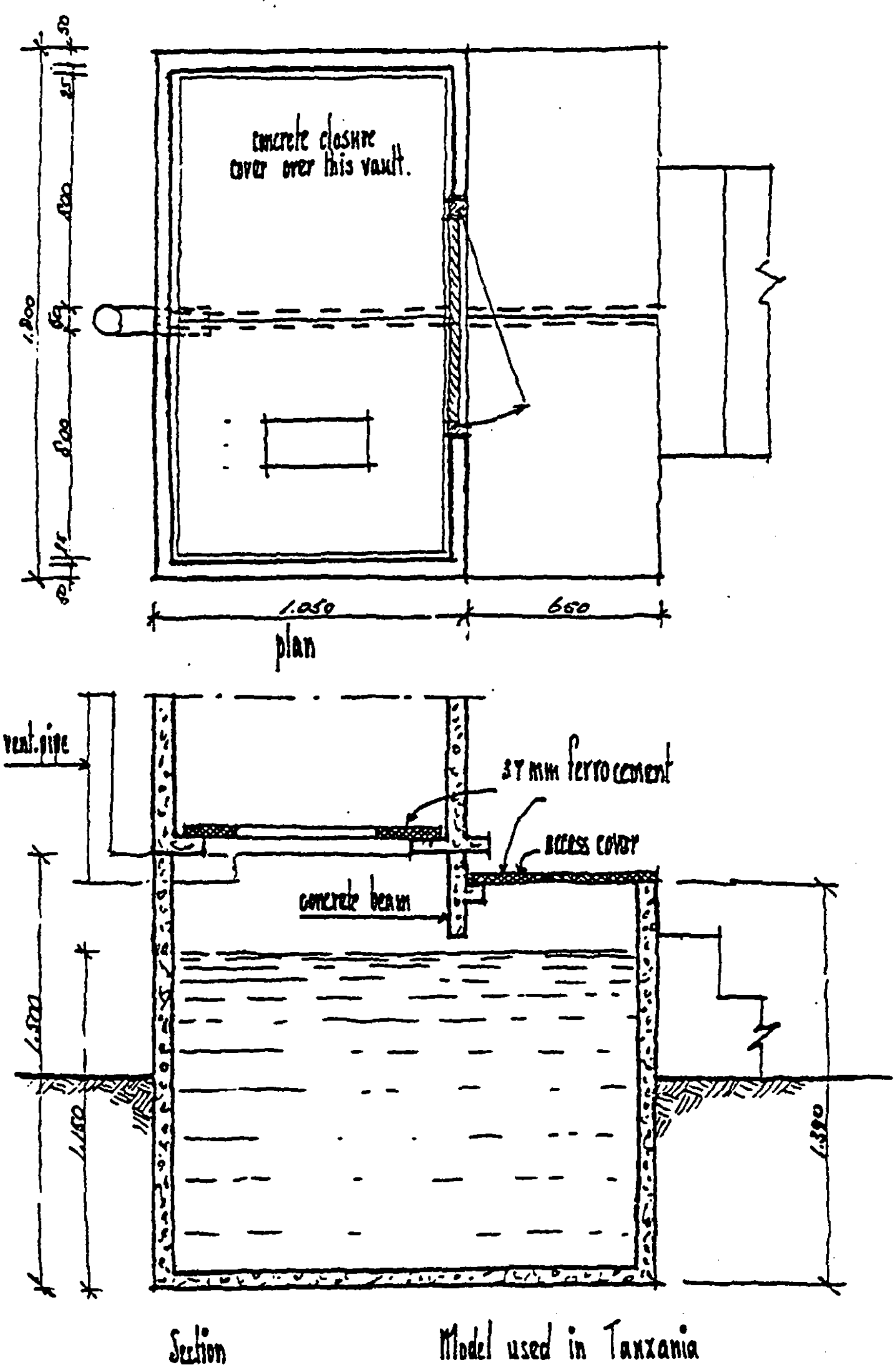
Vault Design and Construction

The squatting plate and superstructure are the same as those for the VIDP latrine. The superstructure is permanent and fixed in place. One squatting plate and a concrete slab or other type of heavy cover are provided within a single superstructure, their positions being interchanged as necessary. DVC latrines should be ventilated and include the vent pipe as in the VIP latrine.

DVC latrines are shallow and are designed to serve households. Two adjacent vaults are constructed with a common wall between them. As the alternating cycle of each vault is one year, the design capacity of each vault should be 0.3 cu. meter per person yearly. The volume of the vault can then be calculated by mul tiplying the number of family members using the latrine, with 0.3 and taking into consideration that the vault is taken out of service when it is filled to within 0.3 or 0.4 m of the squatting plate.

Double-vault latrines may be lined and sealed at the bottom or left open. In areas where there is a low groundwater table the base of the vault consists of earth, permitting infiltration of urine and water. Where there is a high water table or the soil is impermeable the vault must be completely sealed water-tight with a concrete or ferrocement floor. As with VIP latrines, in areas of high groundwater, the vault can be shallower and raised so that a larger part of the vault is above ground.

Diagram 13. Double vault Composting Toilet (mm).



The vault which is not in use should be closed off wit a heavy lid. The heavy lid should prevent any further use of this vault until the compost has been removed. It can be made of concrete, ferrocement or planks weighted with stones. Diagram 13, shows how the humus can be removed from the upper opening of the vault. To facilitate emptying, the vault is partially offset relative to the squatting plate.

Operating Instructions

The construction of the DVC latrine is only the first step. Proper use, careful upkeep and adequate disposal of the contents are even more important.

Starting Up

Before the latrine is used for the first time the vault should be filled with loosely packed organic residue: grass, weeds, leaves, straw, husks, sawdust, yard sweepings-whatever is available. This serves to absorb liquid, provides carbon for the decomposition, increases the variety of micro-organisms and prevents the pile from becoming too compact.

Utensils and Materials

Inside the latrine shelter, there should be a container full of ashes, husks, sawdust, vegetable waste, dry earth, or a mixture of such materials. An empty tin or coconut shell should be kept at hand to facilitate sprinkling of the dry material.

Daily Use

Sprinkle ashes, husks, sawdust or powdered earth after each defecation. Put into the vault daily all floor and yard sweepings as well as kitchen leftovers. Several times a week put grass clippings, weeds, straw or leaves in the vault. Do not throw glass, tins, or plastic into the latrine. Avoid also slowly degradable materials such as corncobs, sugar canes, mango kernels and wooden sticks. Save up ashes and put them in the container mentioned previously for later use in the latrine. The ashes deodorize excreta, make the faecal matter less attractive to flies and absorb moisture. Husks should be saved and used for sprinkling if there are not enough ashes for this purpose.

Moisture Content

The correct moisture content in the composting latrine is very important. To produce good composted humus, the optimum moisture content in the vault should be between 40 and 60 percent. When the base of the vault is open, urine and water percolate out through the bottom, so excess liquid drains away. However in a sealed vault, the moisture control depends on the correct addition of the absorbent materials mentioned above. Care must be taken to add only the absolute minimum of water, especially when water is used for anal cleansing.

Carbon-Nitrogen Ratio

Microbes feed on organic matter containing, among other things, carbon and nitrogen. They use carbon for energy and nitrogen for body building. The carbon/nitrogen balance in a compost or soil is called the C/N ratio. The microbes require much more carbon than nitrogen: the optimum C/N ratio for composting is thus within the range 15/1 and 30/1 in the initial mixture.

Excreta and especially urine are rich in nitrogen. The C/N ratio of human faeces is around 8/1 and of urine 0.8/1. Green grass clippings and vegetable trimmings have a C/N ratio of about 15/1 while straw and sawdust are very low in nitrogen, with a ratio for straw of about 150/1 and for sawdust up to 500/1.

The more the C/N ratio differs from the optimum range of from 15/1 to 30/1, the slower the decomposition proceeds. To achieve quick decomposition in a latrine it is therefore necessary to add high carbon materials like grass, garden litter, sawdust, and organic household and kitchen residue. Excluding urine from the latrine would have a similar effect.

Sealing and Changing Vaults

When the vault being used is three-quarters full or filled to within 0.5 m from the slab, it is time to switch over to the other vault. The pile should be covered with grass and topped with earth. Finally the vault must be properly sealed with the heavy lid cover. Prepare the second vault as described under Starting Up earlier in this section.

Emptying and Removing Compost

When the second vault is nearly full, after approximately one year, the compost from the first one can be removed. Leave some of the ripened compost to give the new pile a good start. The compost should be fairly dry, soil like and odourfree. It will be no more dangerous to handle than the soil in the garden. The compost can be used to fertilize croplands or fish or algae ponds.

User Education

A continued long-term and vigorous program of user education will be necessary to ensure that DVC latrines are used correctly. A high degree of user care, and motivation is required for satisfactory operation.

Socio-Cultural Aspects

As mentioned earlier in some communities there are local cultural constraints against the reuse of human excreta. Composting latrines are only suitable in areas where there is a tradition of reusing excreta in agriculture or aquaculture, or where the community is open and receptive to this innovation.

Costs

Expected ependitures for material and construction will no doubt influence one's selection but cost estimates have not been included. This is because building cost expressed in monetary terms can be very much misleading. The real cost depends on who is building (the owner himself, local artisans or a building contractor), how many units are to be produced (repetition makes for economy in formwork and skills), and on the extent to which local material can be used.

Health Aspects

Vault ventilation minimizes odour and fly nuisance, and if the squatting plate is kept clean, DVC latrines do not pose health risks. After composting for one year, the pathogens will be destroyed and the humus can be safely handled and used on the land or added to fish or algae ponds.

3.3. Biogas Digestor

A Biogas digestor installation aims to simultaneously improve rural health, supply energy and recycle resources. The anaerobic fermentation or digestion of animal manure, human excreta and vegetable wastes generate the so-called biogas. By fermenting the materials in an airtight, watertight digestor pit, methane gas can be produced and collected for use as fuel for cooking, lighting and engines. The digestion process leaves a liquid slurry which can be returned to the land as a high quality fertilizer or used as a nutrient feed for algae or fish ponds. Furthermore, digesting the wastes in a closed container kills many of the pathogens responsible for faecal borne diseases and as a waste disposal system helps to improve the level of environmental sanitation. There are four principal tasks for biogas:

- solve the fuel shortage by developing a renewable source of energy.
- raise the efficiency of organic fertilizer.
- increase the level of rural sanitation.
- treating human and animal wastes and controlling faecalborne diseases.

Advantages of Biogas Installations for the Rural Areas

Solving the Fuel Problem

1. Provides a fuel substitute which can be used for cooking and lighting and power generation. One cubic meter of biogas is the equivalent of 5 kgs of firewood.
2. Decreases the demand for firewood, spares the forest and therefore furthers afforestation efforts.
3. Reduces fuel costs.
4. The vast amount of labour that is used to gather firewood can be put into agricultural productivity.

Stimulating Agricultural Production

5. The recycling of human, animal and plant wastes provides a high quality fertilizer and soil conditioner which can improve the soil quality and raise crop productivity.

Improving Environmental Sanitation

6. Processing human and animal faeces in a digestor reduces fly-breeding and eliminates the majority of feacal-borne disease-carriers during fermentation, thus breaking the transmission cycles of many excreta related diseases.

Applications of Biogas

Biogas can be used as a high quality fuel for cooking and lighting. One cubic meter can keep one biogas lamp of an equivalent of a 60 Watt electric light burning for six to seven hours. One cubic meter can also cook 3 meals for a family of five to six persons and lastly, it can keep 1 hp internal combustion engine working for 2 hours or it can generate 1.25 Kwh of electricity. However, in order to obtain optimal results and the maximum amount of energy when using biogas as a fuel, it is best to use cooking or lighting appliances which allow for complete combustion of the biogas.

Requirements for Biogas Production

Fermentation Process

The fermentation of the organic raw waste materials takes place by the action of bacteria in the absence of oxygen. Various bacteria work upon the raw waste materials and convert them into methane and carbon dioxide. The efficiency of biogas production will depend on a variety of factors:

1. Air and Watertight Enclosure

It is crucial that the biogas pit be air- and watertight in order to produce methane. Only in the absence of oxygen will the decompostion of organic materials result in the production of methane. If the biogas pit is not completely sealed to ensure the anaerobic conditions, the digestor will not function normally nor be able to retain the biogas stored there. This is the most important single factor in the successful production of biogas.

2. Suitable Temperature

The temperature in the pit will greatly affect the production of biogas. The optimum temperature for fermentation is 25°C - 35°C. When the temperature falls the process of digestion is retarded, and below 10°C it is reduced so much that the digestor produces very little gas. A sudden change in temperature will also affect production, therefore one must ensure relative temperature stability.

3. Mixing Materials for Fermentation

Human excreta and animal manure, crop stalks and crop residues such as corncobs, corn, rice and peanut vine stalks, cocoa pods, husks, chaff, straw, and green matter are all good raw material for producing biogas. These fermentation materials provide the necessary nutrients, nitrogen and carbon for the bacteria. Human and animal excreta and urine are all nitrogen-rich materials. Plant and vegetable waste are the carbon-rich materials and promote biogas production, whereas the nitrogen-rich materials provide nutrients which promote the multiplication of anaerobic bacteria. A specific ratio of carbon to nitrogen must be maintained, between 20:1 and 25:1. In order to ensure a correct ratio there must be a suitable mixing of human and animal excrements with vegetable residues. See table 1 for typical carbon/nitrogen ratios of various materials.

Table 1. Appropriate Carbon/Nitrogen Ratios of Some Common Fermentation Materials *).

Material	C/N Ratio
Plant Wastes	
Dry straw	85 : 1
Dry stalks	60-70 : 1
Fallen leaves	40 : 1
Potato tops	25 : 1
Dry grass clippings	20 : 1
Fresh grass clippings	12 : 1
hay, alfalfa	17 : 1
Animal Wastes	
Fresh sheep manure	22-29 : 1
Fresh horse manure	25 : 1
Fresh cow/ox manure	25 : 1
Fresh pig manure	15-20 : 1
Fresh chicken manure	7 : 1
Blood	3 : 1
Urine	0.8 : 1
Night soil	6-10 : 1

*) The C/N ratio of a material may vary from place to place.

3a. Gas yield

The amount of gas produced varies widely with the raw material. For example, pig manure produces more gas per unit of weight than cow manure. Yet poultry manure produces considerably more gas than both. Vegetable matter from young plants produces more gas than from older plants. Moreover dry vegetable matter generates more gas than green vegetable matter.

3b. Proportion of Raw Materials

If plant waste is added to the mixture care should be taken to treat it first before feeding it into digestor pit. In order to increase the rate of fermentation of plant waste and raise the gas output, plant matter should first be cut up in short pieces, piled in layers, and allowed to compost from 7-10 days before introducing the material into the pit. The quantities and nature of raw materials vary widely from country to country. A suitable mixture should be devised to suit the local conditions, so that an efficient use of locally available materials is made.
Practice has shown that digesting only one single kind of material yields less biogas. A mixture of raw materials gives better results. The following proportions may be suitable:
30% anumal manure, 20% agricultural waste, 50% water.
10% human excreta, 20% animal manure and 20% agricultural plant wastes, 50% water.

3c. Loading Rate

The quantity of gas produced in a digestor per day or during a certain period of time depends on the amount of waste material loaded into the pit. The loading rate is the rate of addition of solid waste material (kg) per cubic meter of digestor capacity. If this loading rate is changed there is a possibility that the balance inside the digestor will be affected. Hence, the rate should be kept as constant as possible. The loading rate has also another significance. For a given capacity of the digestor if the loading rate is increased, the period of detention is correspondingly decreased, the period of fermentation is curtailed.

When material is added and effluent withdrawn at a constant rate, the digestion process occurs continuously. It is also possible to operate the digestor plant in a different way - that is by loading the digestor with waste, letting the matter ferment, and when gas production ceases, emptying the digestor. This is known as a batch process.

4. Water Content

The production of biogas is inefficient if the fermentation materials are too diluted or too concentrated. The water content should normally be around 90% of the weight of the total contents. With too much water the rate of production per unit volume in the pit will fall, preventing optimum use of the pit. If the water content is too low, acetic acids will accumulate, inhibiting the fermentation process and hence gasproduction, while also a rather thick scum will form on the surface. The water content should differ according to the difference in raw materials for fermentation. If the materials are excreta, urine and manure, the water should be added in ratio of 1:1, if the material to be fermented includes crop stalks, it is better to add a bit more water as the water content of stalks is difficult to estimate.

5. Maintaining a suitable pH

The gas production is optimum between a pH of 7 and 8; a litmus paper can be used to determine the pH. If the pH drops appreciably below this the gas production may altogether stop. If the fermentation liquid becomes too acidic, alkaline materials such as lime or ashes can be added to neutralize it.

Different Designs of Biogas Digestors

Digestors can be broadly divided into either continuous flow or batch. Continuous digestion involves the continuous feeding of raw waste material with the removal of the equivalent volume of digested waste (slurry). The continuous production of gas is maintained by daily additions and removals of material. The process is usually started with the addition of a sample of partly digested waste to provide sufficient micro-organisms for the digestion to proceed.

In a batch process, the raw material to be digested is loaded with some partly composted material into the digestor at the start of the process. The digestor is then sealed and the contents left to ferment. After the gas production has ceased, the digested liquid slurry and sludge may be removed and the tank reloaded with fresh material. With a batch system, it is desirable to have at least two digestors, so that one (or more) are in operation to ensure a fairly constant supply of gas. Batch-fed plants can be constructed where daily supplies of raw materials are difficult to obtain. Furthermore batch digestors are particularly suitable to ferment coarse vegetable wastes as corn stalks or cobs and sugar cane husk, which cannot flow smoothly through a continuously fed digestor. One advantage of a batch operation is that daily attention is not as crucial as with continuous operation where the maintenance of steady operating condition are very important. Careful and disciplined management, however, are necessary in operating both the batch and continuous type of digestors in order to maintain the biogas production at a level that makes their construction and operation economically worthwhile.

Small-size Continuous Digestors

The two most common designs are variations of the Chinese and Indian designs. The Indian plant consists of two separate elements: a brick or cement fermentation tank and a movable airtight steel drum gas collector which is fitted over the tank to hold the gas under pressure.

Diagram 14.
Indian Biogas Plant.

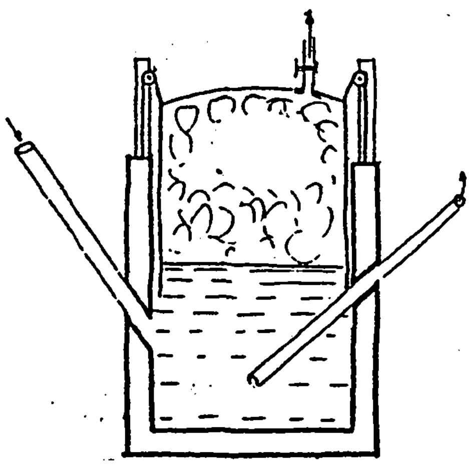
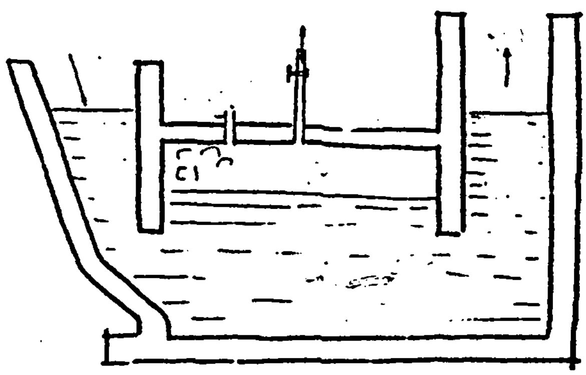


Diagram 15.
Chinese Biogas Plant.



Studies have shown that there are several problems related to this steel gas holder design:

- the metallic gas holder corrodes and requires an annual protective re-painting.
- difficulty in removing heavy gas holder for repairing and maintenance.
- as the digestor is above ground there are problems in maintaining a steady temperature.

The distinctive feature of the Chinese design is that the fermentation tank and gas collector are combined into one unit. The cover of the tank is itself made to function as the gasholder and the whole unit is built underground. This type has several advantages over the Indian design:

- In many countries, steel is scarce and an expensive commodity, particularly in rural areas.

- As there are no moving parts wear-and-tear and maintenance are very low.
- The underground design ensures a steady mean temperature.

Another possibility is the horizontal displacement unit, an above-ground unit consisting of two separate elements: the cylindrical steel drum fermentation tank and the steel drum gas collector. In areas where below-ground pits are infeasible, and steel drums and local welding skills are available this type of digestor may be preferred.

Diagram 16.
Horizontal Displacement Type.

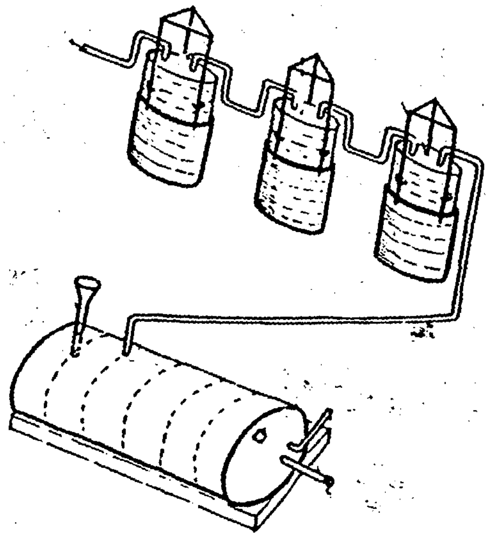
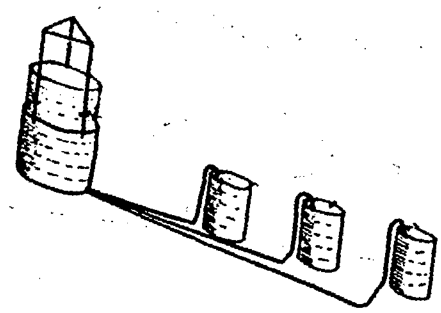


Diagram 17.
Batch Digestor.



Batch Digestor

The vertical steel drum plant is perhaps one of the simplest in construction. The plant consists of a steel drum functioning as the digestor and a steel drum gas collector.

The purpose of this monograph is to provide examples of small size household digestor units that are suited to local conditions, using locally available materials and skills, simple to operate and as cheap as possible. For these reasons we have included in our discussion two examples of continuous digestors - the Chinese rectangular digestor pit and the steel drum horizontal displacement unit as well as a batch digestor - the vertical steel drum unit.

Certain pre-requisites that must be met before considering constructing a biogas plant:

- be certain of careful and disciplined future management.
- sufficient supply of water.
- sufficient supply of raw waste materials.
- available construction materials and skills.

The economic performance of biogas systems is dependent on a number of local factors like climatic conditions, local terrain, village setting, social practice, availability of water and other inputs and the ease of using gas and effluent effectively.

Factors Affecting Choice of Digestor Design

- type of raw waste materials locally available.
- frequency of supply of raw waste materials for fermentation.
- type of local construction materials and skills available: cement, concrete, stones, masonry skills or steel drums and welding skills.

Digestor Site Location

The location of the pit is influenced by the following factors:

1. It should be close to where the gas will be used, because gas tubing is expensive.
2. If possible, it should be close to the supply of animal manure to avoid unnecessary carrying.
3. If the effluent is to be composted before application to the soil, a composting site should be located nearby.
4. It should be 10 to 15 metres (depending on soil type) from any well or other water source, so as to prevent water

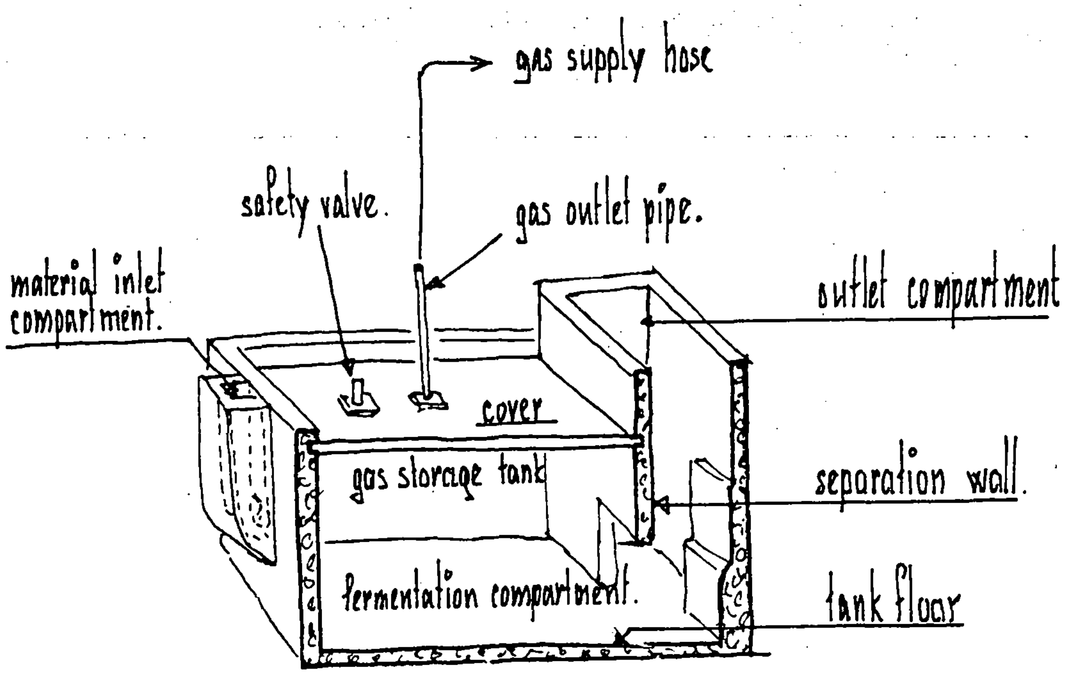
contamination. However, the pit should not be so far away from a water source that bringing the water needed for mixing is a major difficulty.

5. It should be in a sunny site to keep it warm.
6. It should be away from prevailing cold winds.

Chinese Model Rectangular Biogas Pit-Continued Process

The techniques involved in constructing the rectangular pit are fairly simple and easy to learn. This type of underground pit is suitable for regions where the soil is firm and unlikely to cave in. This family-size digestor of 10 m^3 capacity can produce approximately 5 m^3 of gas. As the operation is a continuous process, a sufficient quantity of raw materials must be available to feed the pit daily.

Diagram 18. Chinese Biogas Digestor.



Cross-section of Rectangular Biogas Plant

Basic Components:

The Material Inlet Compartment

This is where the materials to be fermented enter into the fermentation compartment. This inlet should be large enough to allow easy introduction of materials. It is built as a slanting trough, inclining enough to ensure the natural flow of these materials into the fermentation compartment. A heavy concrete lid cover should be provided to cover opening of inlet compartment.

The Outlet Compartment

At the other end of the fermentation compartment is the outlet compartment where the effluent slurry or fertilizer will be taken out after fermentation. Its size will depend on the volume of the pit. There should be an adequate distance between the inlet and outlet to prevent freshly incoming materials from flowing directly into the outlet.. A heavy concrete lid cover should be provided, to cover the opening of the outlet compartment.

The Fermentation Compartment and Gas Storage Tank

These two sections are actually one unit. They connect the inlet and outlet and form the area where the gas is produced and stored. The middle and lower sections are the fermentation compartment, the upper is the gas storage tank, with the cover above it. The organic materials ferment in the fermentation compartment and biogas is produced and rises to the upper section into the gas storage tank.

The Separation Wall

In the rectangular pit this separation wall creates a gas storage tank. The wall is extending downwards from the top of the tank to about half of the total height of the pit.

If the free opening between the bottom of the pit and the separation wall is too narrow, residues accumulate at the bottom of the pit and may cause blockages in the inlet and outlet compartments. If the separation wall ends too high, it diminishes the gas storage capacity of the tank. If one extracts a little too much effluent slurry and the liquid contents fall below the separation wall, this will cause gas to escape from the tank.

The Gas Pressure

The pressure of the biogas inside the gas storage tank is kept constant by the automatic adjustment of the liquid pressure.

The Gas Outlet Pipe

The gas outlet pipe is set into the gas tank cover. It can be made of steel, hard plastic, PVC, or clay. At the bottom it opens into the gas storage tank, level with the bottom of the cover. At the upper end it may be connected to a plastic, PVC or rubber tubing leading the gas to the kitchen or to where it will be used.

Choosing a suitable Foundation for the Pit

The choice of a suitable base is a key determinant in the final quality of the pit. Before construction a study should be made of the soil conditions and ground water level. In order to ensure that the pit will last the soil should be suitably firm and the ground water table low. Whenever possible, pits should be built a fair distance away from woods, trees and bamboo groves, so that the roots will not come into the pit or cause cracks. It is also possible to cut off roots at various points where necessary and to spread some lime over the surface to stop the root growing in that direction and into the pit.

Volume of the Pit

The size of the pit will depend on how much gas will be needed and how it will be used. The calculation of the pit's volume is normally based on 0.5-1.0 m^3 per person to provide sufficient gas for cooking. A digestor of 10 cu. meters can generate about 5 m^3 biogas daily, depending on the quantity of waste material available and the management of the digestor.

Steel Drum Biogas Digestors

Two types of steel drum digestors are discussed: the vertical batch-fed and the horizontal continuous-fed. These digestors are airtight and watertight units constructed above ground. Therefore they are particularly suitable in areas where an underground pit is difficult to excavate or not recommended because of:

- unstable soil;
- high water table and danger of water contamination; and
- rocky ground.

The prerequisites for building these types of digestors are:

- availability of steel drums for a fair price
- local welding and soldering skills.

Waste Material Mixture

The frequency of the availability of raw material is a deciding factor in selecting the type of digestor.
In rural areas where a local supply of adequate raw waste materials is available daily or every few days the horizontal continuous digestor may be preferred. However, where daily supplies of waste materials are difficult to obtain, the batch-fed vertical digestor is recommended. Batch-fed digestors are charged with waste and left to ferment. After about 2-3 weeks gas production begins and continues for approximately three months. When gas production ceases, the digestors are opened and emptied. The effluent-slurry can be immediately disposed of on croplands.

Both these digestors can be fed with a mixture made of:

- animal manure and water
- animal manure, agricultural vegetable waste and water; or
- agricultural vegetable waste and water.

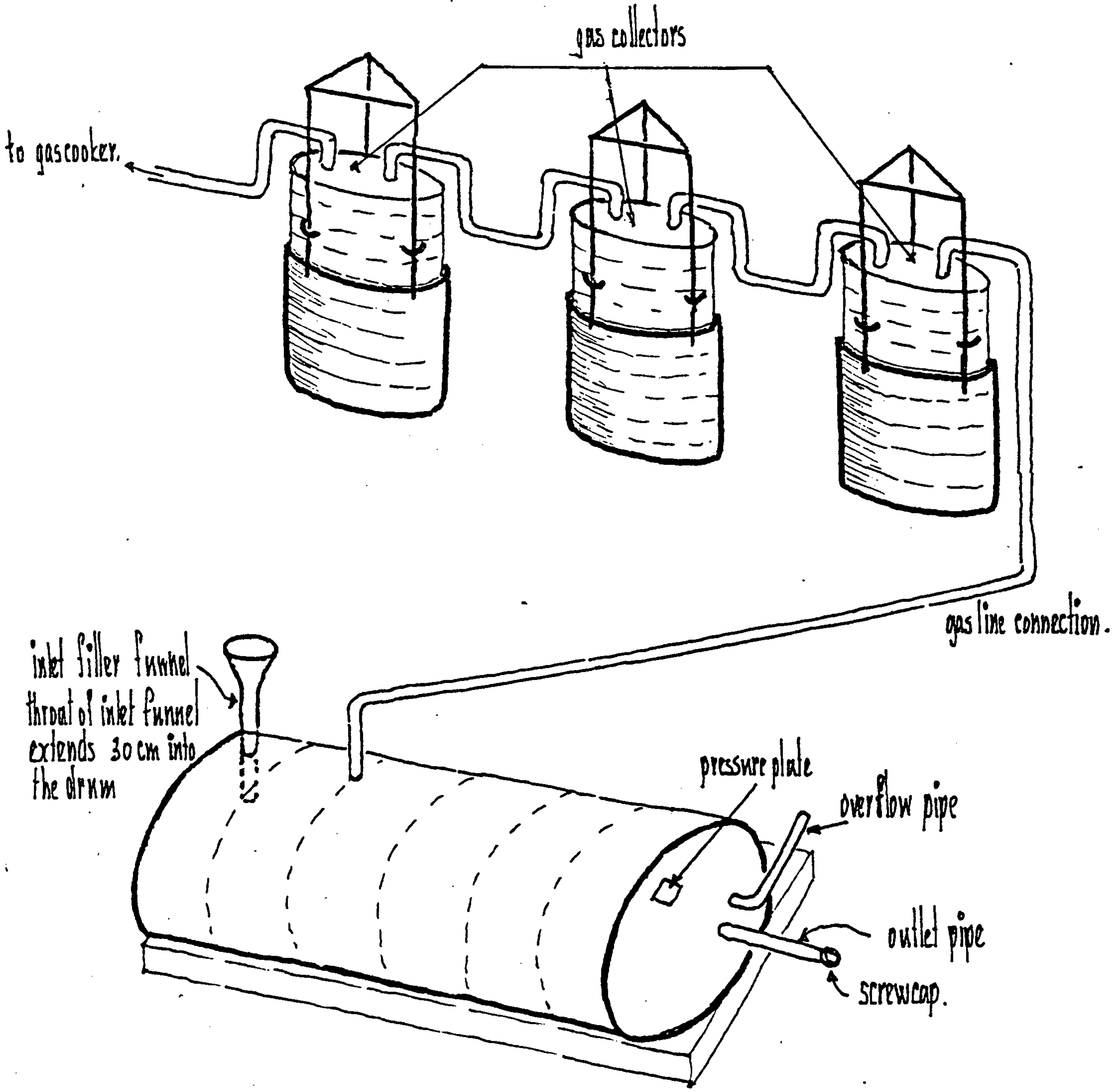
(In addition, the continuous horizontal digestor, just as the Chinese-type digestor, can be directly connected to an aqua-privy and automatically fed with human excreta, if it is socially acceptable and physically practical. See diagram 19).
For reasons explained earlier the aqua privy was not discussed in detail, however in the context of a biogas installation, the aquaprivy is the most appropriate type of latrine for direct connection to a biogas digestor.

As mentioned before, if vegetable waste is added to the mixture, care should be taken to chop up the pieces finely, and compost them for 7-10 days before adding them to a mixture.

The Continuous Horizontal Steel Drum Digestor

This digestor was designed by the Development Technology Center of the Bandung Asian Institute of Technology in West Java (Indonesia). The digestor compartment and the gas collectors are separate units, connected by plastic tubing. Three 200 liter drums are welded together to form a continuous horizontal digestor chamber. The digestor was fed with a slurry one part chicken manure with rice chaff and two parts water. A full description is given in Annex 2.

Diagram 19. Horizontal Displacement Type, AIT, Bandung.



Operation

The digestion chamber is set sloping downwards from the inlet end to outlet end, so that the inlet end is higher than the outlet end, with a drop of 15-20 cm.

The chamber is filled with slurry of one part manure (chicken with rice chaff) and two parts water. A manure-water mixture of 1:2 ratio, instead of the more usual 1:1 is used, because the former provides a more smoothly flowing mixture. The manure and water are mixed thoroughly first and then left to stand for a couple of minutes. Hard materials then sink to the bottom - such as gravel, sand and sheel grit - and are not poured into the digestor. The filled chamber is left standing for two weeks while the bacteria, which are naturally present in all manures, begin the initial breakdown of organic polymers before biogas can be produced. The first gas collected will not burn because it contains too much carbon dioxide, but by the end of the second week methane usually predominates. Thereafter the digestor is charged each day with a sustrate mixture (one part of manure:two parts water) equal to one thirtieth of the volume of the digestion chamber. For a three drum chamber this means 18 l. of slurry per day.

Emptying and Removal of Scum and Residue

Many types of vertical and horizontal displacement have to be emptied from time to time to remove the scum that builds up on the surface of the digesting slurry, and the indigestible residue sludge that settles on the bottom of the chamber. The inert residue may take up valuable space in the digestion compartment and the scum can seriously interfere with the gas collection process. However, this type of digestor discussed may require less frequent emptying because of two reasons.

- This horizontal steel drum design is arranged so as to eliminate air space in the chamber so that there is no interface for the scum to form.

- Moreover, the residue in the chamber has been kept to a minimum because:
  - As far as possible, indigestible solids are not to be poured into the unit;
  - The overflow pipe is large enough to allow some inert material to be swept out in the effluent each time new slurry is poured in;
  - There are no baffle plates to catch inert material;
  - A 1:2 manure water mixture is used, facilitating a smooth flow.

Maintenance

Periodically, as the situation demands, the exteriors of the digestor and gas collectors should be re-painted with bitumax paint to prevent corrosion. If a mat of scum does build up and inert residue collects at the bottom of the digestor, interfering with the gas collection process, then the digestor should be emptied and cleaned.

Re-use of Effluent Slurry as Fertilizer

- Used directly taken from collection pit placed under outlet pipe;
- Stocked in another covered pit ready for use;
- Liquid effluent slurry can first be dried quickly by absorbing it in paddy husk, saw dust and such waste materials and further dried in the sun and stored for use when required;
- Placed in compost pit and composted.

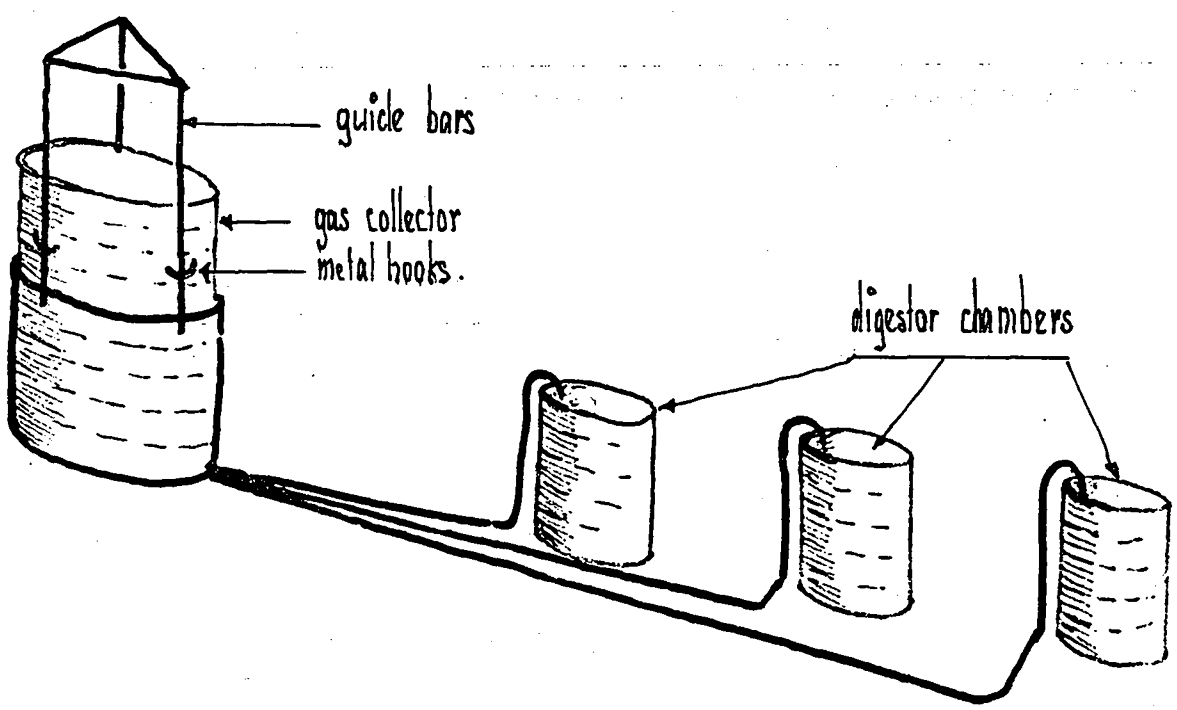
The Batch-Fed Vertical Steel Drum Digestor

This model was designed by the Rural Industries Innovation Center in Botswana* and is currently being constructed in Botswana. A mixture of cow manure and water is recommended, although any animal manure could be used. A brief description of its construction will be provided below.

The unit consits of one or more sealed steel drums functioning as the digestion compartment connected by piping (tubing) to a gas collector storage tank. In order to ensure a steady gas production it is desirable to have two or more drum digestion compartments operating in a series connected to the gas collector.

The gas collector is made of a one 30 gallon drum upturned in a 45 gallon drum full of water with 1 cm steel bars used to guide the rise and fall of the collector.

Diagram 20. Batch-Fed Drum Digestor.



The steel drum should be filled up with fresh cow manure a little less than half way. Add the same amount of water and stir the mixture thoroughly to break up any lumps. Seal the drum tightly, using a mallet to gently tap the lock ring into place, and tighten the clamp. It can take from two to twelve weeks before gas will be produced. During this time gases high in carbon dioxide content will be produced which do not burn. These should be released, but take care not to let air into the drum as this will lower the production of biogas.
When the gas coming out of the drum begins to burn, it is time to connect the drum to the gas collector with polythene tubing. The large outer tank is already filled with water and all gas in the inner tank is released.
The gas collector can now be connected to a gas cooker or lamp with polythene tubing. Biogas will continue to be produced for another 6-10 weeks. After that it is necessary to empty the drum and start again. Leave, however, about 5 cm depth of the old effluent in the bottom of the drum to act as seed to start up the next batch. Using a small amount of the old effluent as seed helps speed up the gas production process. The remainder of the effluent can be immediately disposed of on the cropland as fertilizer or stored and composted.
Because of the time delay from loading the drum until it begins to produce gas, it is better to have 3 or more drums connected to the main gas collector (see diagram 20).

The drums are loaded one month apart, so that at any one time 2 drums are producing gas while the 3rd drum is reloaded.

Public Health Aspects of Biogas Digestors

Although the anaerobic digestion of human and animal wastes provides a health benefit beyond that of any other treatment likely to be used in rural areas, some viable parastic and disease-carrying organisms may survive in the effluent slurry and and sludge used as fertilizer or fish nutrient. This is especially true if human excreta is used as part of the waste fed to the digestors. If only animal manure and crop wastes are used, the pathogen removal will be much higher and the health hazards considerably reduced. For this reason, if human excreta is used, additional precautionary measures are necessary to reduce the health hazards involved in re-using the effluent/sludge for agricultural or aquacultural purposes.

Conditions for Pathogen Destruction

The destruction of pathogens and disease-carrying organisms is dependent upon the temperature in the pit and the retention time.

When human and animal wastes are kept without oxygen for a length of time between 30 to 40 days at 35° C or above, the digestion process kills off many pathogens and disease-carrying organisms. However, certain hardier parasitic ova and disease carrying organisms such as Salmonella, hookworm, round worm and schistosome cercariae may require a retention time of over 40 days to ensure pathogen destruction.

Batch processing with longer retention times may have greater pathogen destruction that the continuous process, in which the effluent slurry is removed daily.

Precautionary Measures

1. In order to eliminate any health hazard of directly handling human excreta as part of the waste fed to the digestors, it is recommended to connect the aqua-privy latrine directly to the continuous-process household biogas digestor. Because of the problems involved in batch processes with transportation and storage of the human excreta, it is not advised to use human feces as part of the feed for batch digestors.
2. When human excreta are digested, composting of effluent and sludge before application to the land will further reduce any health hazards.

3. If the effluent/sludge is used to enrich fish ponds, thorough cooking of the fish before eating will destroy excreted pathogens.
4. As mentioned earlier, it is important in constructing the fermentation tank that the inlet and outlet compartments are not directly opposite each other. This is to ensure that freshly added waste material and settled sediment at the bottom of the pit, which contains many parasitic ova, do not flow directly into the outlet compartment.

3.4. Aquacultural Reuse

Fish and algae are getting more attention as high-protein, nutritional sources of food in the developing world. The most common method of fertilizing these fish and algae ponds is to add treated human and animal wastes or plant wastes as nutrient feed.

Fishfarming

The wastes-fertilized fish pond demonstrates the reuse cycle. The consumer produces wastes, which are treated, by either composting or biogas digestion and introduced to the fish pond. The wastes provide the main source of nutrients for plankton growth in the pond. The by-products from this process are the primary nutrients for the algae, which in turn are the basic food for the fish, which in turn are the food for the consumer.

Contrary to what might be expected fish farm workers indicate that fish cultivated with well-treated domestic wastes are equal or even superior in taste or smell to non waste-fed fish. Fish such as gourami, catfish, mullet, tilapia, snakeskin gourami, tawes, and Chinese, Indian and common carp grow rapidly in such enriched fish ponds. It is important to point out that the productivity of fish ponds enriched with organic wastes has been found to be higher than that of ponds fertilized with inorganic matter. Rather than growing only one species of fish, polyculture is to be preferred. A good polyculture uses the natural fish sources in a pond better. If the polyculture is mixed correctly, each of the species eats a different food in the pond. For example, one type of fish feeds on large algae, one kind on small algae, some on zooplankton, some in the bottom layers and some near the surface.

Algal Production

Algae need nutrients for growth. Human, animal and vegetable wastes introduced into oxidation ponds provide nutrients necessary for optimal conditions for algae production. One of the main reasons for the interest in algae is the fact that they usually consist of about 50% protein. The harvested algae can be fed to fish or to animals. The importance of algae as an animal feed substitute, (thus liberating grains for human consumption) could be beneficial for rural areas.

Moreover the quality of the water discharged from algae ponds is considerably improved and can play an important role in agriculture for irrigation. The harvesting of algae requires three steps: initial concentration, dewatering and final drying). Sun drying of algae is very important in pathogen removal of the algae. If the algae are dried to less than 5% water, pathogen removal will be complete. If not. pathogens will survive to a degree depending upon the time of drying, the final moisture content achieved and the sunlight intensity. If the moisture content of the harvested algae is above 10% even parasitic ova may survive.

Adding Organic Wastes (Fertilizers) to Fish and Algae Ponds

The various organic fertilizers that can be used as nutrient feed for fish or algae ponds are:

1. Composted animal manure.
2. Composted vegetable matter and household refuse, i.e chopped up yams, cassava, sweet potatoes, banana leaves, guinea or

napier grass, grass cuttings, rice husks, and household refuse.

3. Composted human excreta emptied from VIP or DVC latrines.
4. Digested effluent slurry from biogas plants.

There are several ways of adding the composted organic waste. It is possible to mix together whatever composted wastes are available and add water; thereafter adding the liquid mixture to the fish or algae pond. The composted matter can also be placed in a burlap bag hung from a stake in the water. This way, the nutrients from the manure will be released slowly into the water without the matter clogging up the pond bottom. If this cannot be done, then pile the composted matter in the corners of the pond. Do not add too much animal or human manure. Decaying matter uses up the oxygen in the pond, particularly in hot, humid climates. The digested effluent slurry can be added as it is into the fish or algae pond. However, sometimes it is better to first store it, sun dry or compost it.

Health Implications of Excreta-enriched Fish and Algae Ponds

The contamination of the fish or algae depends on whether the pretreated animal or human wastes fed to the ponds still contain concentrations of pathogens and parasitic ovum.

If the animal and human excreta are composted for 12 months or longer, the composted manure used as a nutrient feed poses a minimal health risk.
However, as mentioned earlier, the destruction of pathogens in the biogas process depends on the temperature and retention time. If this is less than 30 days at 35° C pathogens may survive in the effluent slurry. In this case, it is advisable to store, compost or sun dry the effluent slurry before introducing it into the fish or algae ponds. Biogas digestion does destroy oriental liver fluke (clinorchis), but salmonellea, schistosome cercariae and other disease-carrying organisms may survive the digestion process.

The possible health problems in aquaculture are:

- the passive transference of human or animal pathogens by the fish or algae contaminated in the pond.
- the transmission of certain parasites whose lifecycles include fish as an intermediate host.
- transmission of schistosomiasis through the snail host*.

Control Measures include:

1. sun drying the harvested algae before consumption.
2. allowing fish to reside in clean water for two weeks for depuration before harvesting them for consumption.
3. Promoting good hygiene in all stages of fish and algae handling and processing.
4. Thorough cooking of fish before consumption.
5. Clearing vegetation from pond banks to discourage the breeding of the snail hosts of schistosomes.

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* R.G. Feachem et al; Health Aspects of Excreta and Wastewater Management Part I, The World Bank, October 1978, pp. 71.

ANNEX I

Chinese Rectangular Biogas Digestor

Preparation of Materials for Construction

Before starting work, one would calculate the volume of the pit, the rough quantities of materials needed for construction, and these should be made ready.

Choice of Construction Materials for Pit

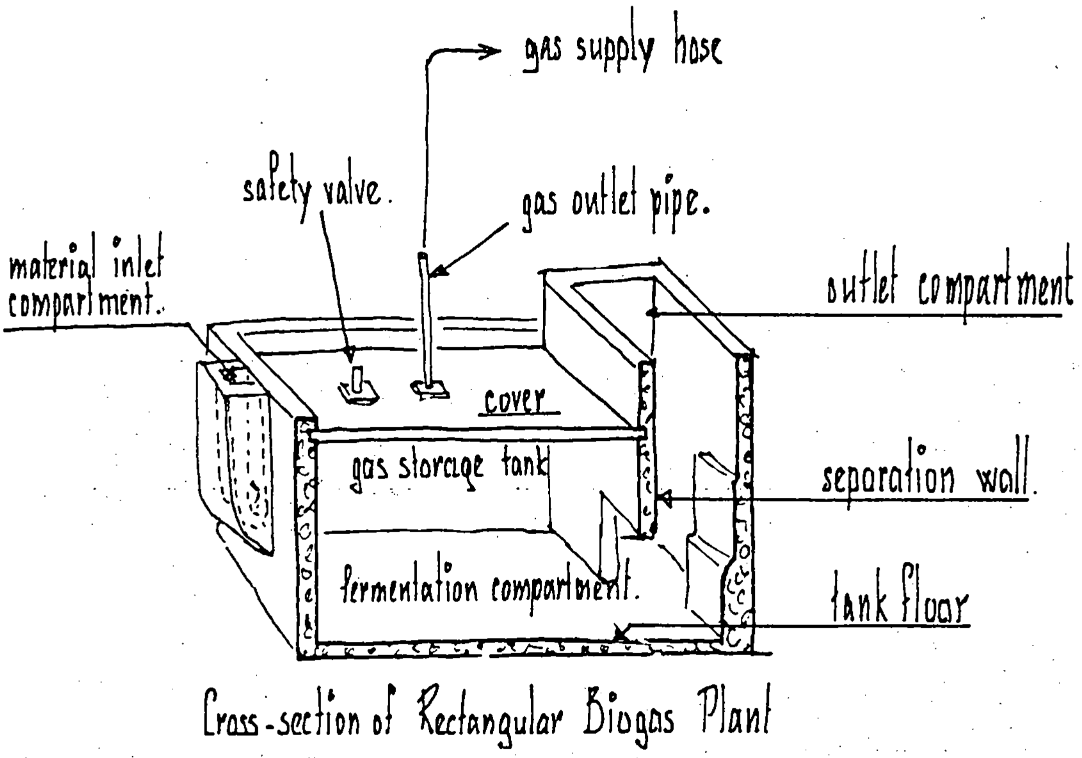
Do what is appropriate under local conditions. The pit should be built using local materials and building methods. Cement is an important building material, and where possible in the course of pit construction one should save it and use locally available materials. The pit can be made of a variety of materials:

- dry or liquid triple concrete in areas where sand, stone and lime are easily available;
- long pieces of cut stone;
- round stone;
- Triple cement bricks; and
- bricks and cement mortar.

Rectangular Pit made of Dry Triple Concrete

This is a type of pit adopted in places where sand stone and lime are all readily available. The advantages of this type of pit are that it is easy to make at a low cost and the techniques required in the building are fairly easy simple and easy to learn. See Diagram A.1.

Diagram A.1. Rectangular Biogas Plant.



Construction Instructions

Construction Materials

To build a digestor pit with a capacity of 10 cu. m.:

- 1250 to 1500 kg of lime;
- 2 m³ sand and;
- 6 m³ large or small stones.

Digging the Pit

The depth of the pit depending on the soil characteristics and ground water table level, is normally about 2 m. and between 1.2-1.8 m. wide. Where the soil is sandy, or the soil is loosely packed, an adequate slope must be provided, when digging so that the pit tapers as it goes down, to prevent collapsing of the walls. If the water table is high and water infiltrates into pit, either the length of the pit should be increased to allow for a compensatory decrease in depth, or another site should be chosen.

Mixing Triple Concrete

The key is to control the water content and the sand content. It must contain 14% water and 63 to 75% sand. In order to improve the strength of the triple concrete, a suitable amount of cinders may be added to improve the workability of the concrete. For common triple concrete mixture, the ratios of lime, sand, sandy clay is by volume 1:3:3. There should be no twigs or bits of grass in the concrete, the lime should be thoroughly shifted, and the clay completely fine. Any hard pieces of lime should be removed, or they may absorb water and cause imperfections in the structure. A pit of 10 cu. m. capacity will require roughly 8 cu. m. of triple concrete. When the lime, sand, stones and clay have been mixed in proper proportions they should be stirred in their dry state and mixed thoroughly; then add water and mix thouroughly again. Add enough water to achieve a consistency where lumps can be formed which will break up when dropped from a height of one metre on to the ground. If the triple concrete has too high a water content, after it has been applied, it will contract as it dries and leave cracks; the result will be a failure to achieve watertightness and airtightness.

Wall Erection

The bottom must first be pounded very firm so that it will withstand the weight of the wall and the cover piece without sinking. Before lining the wall, draw a line on the bottom to mark the desired thickness of the lining from the outer wall, and along this line put in some wooden stakes. Link these horizontally with some cross-pieces, put planks up against these stakes and the space left between the planks and the outer wall should be 15-20 cm. To form the new wall, the triple concrete should be put in between the planks and the outer wall in layers and pounded very firmly, so that it will set into a single piece. It should also press firmly against the outer wall in order to be able to withstand pressure from within. When a layer of the wall has been completed, move the planks up. The horizontal cross pieces should be moved up as well and propped firmly against the stakes. Carry on building the wall, making sure that what has already been done is even, flat and not sloping.

When building the wall, special attention should be paid to corners and places where different pieces of triple concrete join.

At these places the moisture content on either side should be uniform and interlocking must be firm. Where two horizontal layers of concrete join, place a line of pebbles, approximately the size of a fist, along the centre of the lower layer, and the upper layer should press down upon this, to further strengthen the wall. The height of the wall should reach to about 30-50 cm. below ground level to make it easier to replace the cover board or connect to a latrine. Where the water level is high and the planned effective capacity cannot be achieved, the wall may be made somewhat higher, and may even protrude above ground level.

Building the Separating Wall and Outlet Compartment

Between the fermentation compartment and the outlet there is a partition wall made of triple concrete and approximately 14 cm thick (see diagram A.1). The two ends of this partition wall should be set into the walls of the sides; only this way can it sustain the internal pressure from the pit. In the lower half of this partition wall and to one side there should be an opening to the outlet compartment. The opening should normallybe half way up the wall lining of the pit. It should be 70 to 80 cm across to enable someone to go inside the pit to clean it out occasionally. As a liquid pressure tank is not included, the upper portion of the outlet compartment should come up higher than cover to the pit, and it should be able to accommodate 1-1.5 m^3 of liquid, so as to prevent overflowing.

Inlet Compartment

The top of the opening of the inlet should be about 50-60 mm. This should be a diagonal opening sloping into the central portion of the fermentation compartment. The inlet compartment should not be in line with the door of the fermentation tank but to one side to prevent fresh excreta from flowing directly into the outlet compartment while being fed in. The top opening of the inlet compartment can be connected to a latrine, if desired. The inlet compartment can be lined with triple concrete, stones or it can be made with clay pipe. The construction of the inlet compartment and the wall of the fermentation tank must be done simultaneously, making sure that all the joints are properly made and no leakage is possible.

Tank Floor

After completing the concrete walls, a layer of triple concrete about 15 cm thick should be placed on the base of the tank, compacted properly, and another layer of diluted concrete laid down. If water percolates through the base of the tank, first a layer of pebbles should be spread and then cement slurry (or diluted concrete) poured into the gaps between the pebbles and then finally a layer of concrete should be poured on top (cement, sand, gravel, 1:2:4). The floor of the tank must be constructed in such a way that it will not sink, that water will percolate through it, and that it will protect the foundation of the wall.

Coating the Inside of the Pit

Coating the inside of the pit is a crucial factor in ensuring watertightness and airtightness and great care should be taken with this work. Normally, there are two steps:

1. After the wall has been lined with triple concrete, apply a coat of coarse sand mixed with lime (ratio 1:1:5) 0.3 cm thick. When this has dried slightly, slap it or pound it firmly with a large mallet or a large flat surface. When the arch support has been removed, there may be some flaking away. If this happens, smooth over these areas and coat them over again. At the corners numerous coats should be applied, making the corners rounded.
2. Next, coat the inside with adhesive cement. Adhesive cement is made from cement, lime and sand (volume ratio 1:1:3). While cement and sand mixture alone, though firm, cracks when dry, adding some lime will increase the density and help make it

watertight and airtight. Adhesive cement is normally applied in two coats, each 0.2 cm thick. Each coat should be smoothed over with a trovel three or four times. To further increase the wall's resistance to seepage, it is best to coat the areas lining the gas tank with a further three or four coats of a cement and water mix. This should be applied before the adhesive cement has completely dried - it will increase the airtightness.

Building the Cover

This will determine the success of the pit. In plains areas one can make this out of quadruple concrete (cement, lime, pebbles and sand) or it could be made of cemented pebbles or prefabricated boards of cement. Covers made of quadruple concrete and pebbles are fairly cheap and effective. Where conditions permit, this type should be adopted. The methods of construction are as follows.

A simple arch support: The several wooden poles 12-15 cm in diameter and place them paralell on top of the fermentation compartment. Make them into an arch by placing bricks along two ends to support the poles. The height of the arch should be 20-30 cm. Over these parallel poles place some reed mats and tie them down with string. Then the arch is ready to be built. A similar simple arch support can be made from adobe bricks or pieces of wood, so long as the shapes resemble those described.

Arch made of quadruple concrete: Mix lime, cement, coarse sand and loose stones or pebbles 3 cm in diameter (ration 0.5:2.2:4 by volume). First mix the dry lime, cement and sand evenly, mix in the stones or pebbles then and add the water slowly. When thoroughly mixed pour this concrete on top of the arch support to a thickness of 20 cm or so, then immediately rake it over with an iron rake and shovel, so that it lies firmly on the support. The stones or pebbles must be closely packed and the liquid mix spread evenly. When the concrete is slightly dry, cover this cemented arch over with damp reed mats. The mats should be kept damp by spraying with water for seven days.

Cover piece made of prefabricated concrete boards: Prefabricated concrete boards should be made from a mix of cement and sand and stones (ratio 1:2:4 by volume). Each piece will require around 25 kg of concrete. Before making the cement slabs you need to make wooden frames; they should be 60 cm wide, 50 cm thick, and be 30 cm greater than the width of the fermentation compartment. The frames should be made trapezoidal in cross-section - the measurements on top should be 1 cm larger than the measurements below. One may also dig a similar shape in level ground and use this cavity instead of the wooden frames.

Inside the wooden frames place some lengths of split bamboo as reinforcement. The separation between the pieces of bamboo should be 15-20 cm, they should be bound tightly with iron wire. Spread some very heavy brown wrapping paper with soap suds and put this on very flat ground. Lay the wooden frames on top of this and prop the bamboo reinforcement up with pebbles so that they lie in the centre of the wooden frame. Then pour in the well-mixed concrete to a thickness of 12-15 cm. This should be thoroughly prodded to make it solid and prevent it cracking. When these prefabricated slabs have been made, cover them with damp reed mats and leave for seven days; take the frame off only when the concrete is completely set. In placing the prefabricated cover over the fermentation compartment, first clean the top of the wall lining the fermentation compartment and remove any grass roots. Coat it with a layer of cement sand mixture (ratio 1:2 by volume).

Put a couple of wooden sticks on top of the walls at either side of the fermentation compartment. Lower the prefabricated board down on top of these sticks, adjust until in position, and then remove the sticks. In this way one can avoid any severe vibrations or impact which could cause cracks in the concrete walls. Place the prefabricated slabs so that the wider, smooth side faces down into the fermentation compartment. Where the slabs meet the walls of the compartment, contact should be smooth and without cracks. The paper on top of the slabs should then be wiped clean leaving no clay or earth sticking to it. Pour a mixture of cement and sand (ratio 1:2) into the

V-shaped cracks between slabs an fill them up completely. One may also make a simple arch support, according to the pre-described method; use cement, sand and stones for the concrete to form a one piece cover.

Stone Cover: Flat, long, and wedge-shaped stones about 20 cm in diameter should be selected and washed. They should be placed upward on the arch support from the side walls working toward the centre, using small pebbles or stones to fill the gaps, and then cement mortar or concrete slurry (lime, cement, and fine sand in the ratio of 1:1:2) should be poured into the gaps. (Cement mortar can be used to fill the gaps between pebbles while laying them). If smooth stones are not available, slate or bricks can also be used to build the arch, but if bricks are used, they must first be immersed in water.

After one of the above four methods have been used to build the cover for the fermentation compartment, a further layer of triple liquid concrete should be used to cover the whole construction, to a thickness of 7-8 cm. This should be pounded and slapped repeatedly so as to make it very firm and increase the quality and weight of the cover.

In the cover itself two holes must be left. One for the safety and another hole for the gas outlet pipe of approximately 3 cm diameter.

Removing the Arch Support

Only after the pit cover has set and contracted can the arch support be removed from inside the pit. Once the supporting bricks at either end have been removed, the arch support will become loose and wobbly. Therefore, one must take special care while removing it to prevent accidents.

The Gas Outlet Pipe

After the arch support is removed, the gas pipe can be fitted into a 3 cm hole in the cover. Either steel or PVC pipe can be used as the gas outlet pipe. It should be about 1 cm in diameter and 1 m long as it should extend above the earth packed over the cover. Before fitting the gas pipe into the hole, wash the hole clean and also file off any rust, if the pipe is of steel. Set the pipe in the hole so the bottom end is level with the bottom side of the cover. On the upper side wedge the pipe tight. Fill in the crack around the end with a thick cement motar curb 10 cm high and 20 cm in diameter to prevent any gas from leaking.

The Gas Supply Hose

The gas supply hose which carries the biogas from the digestor to the cooking burner in the kitchen or other place of gas utilization is usually made of polythene plastic or rubber. In China even lengths of bamboo tubes are used. The internal diameter of the hose should be approximately 1 cm. However, if the distance from the digestor to the cooking appliance is greater than 15 m than larger diameter hose is necessary, for example 2.5 cm. This is because the thinner hose will kink up in the hot sun and stop the flow of gas, creating pressure build-up. And so the large diameter hose will permit the gas to flow and the pressure to be maintained over greater distances. The hose is fitted into the gas outlet pipe. The connection must be airtight. If lengths of bamboo tubes are used to make the supply hose, lengths of bamboo tube are first coated with pig's blood plaster. Pieces of rubber hose are then used to connect the lengths of bamboo tube together to form the gas supply hose.

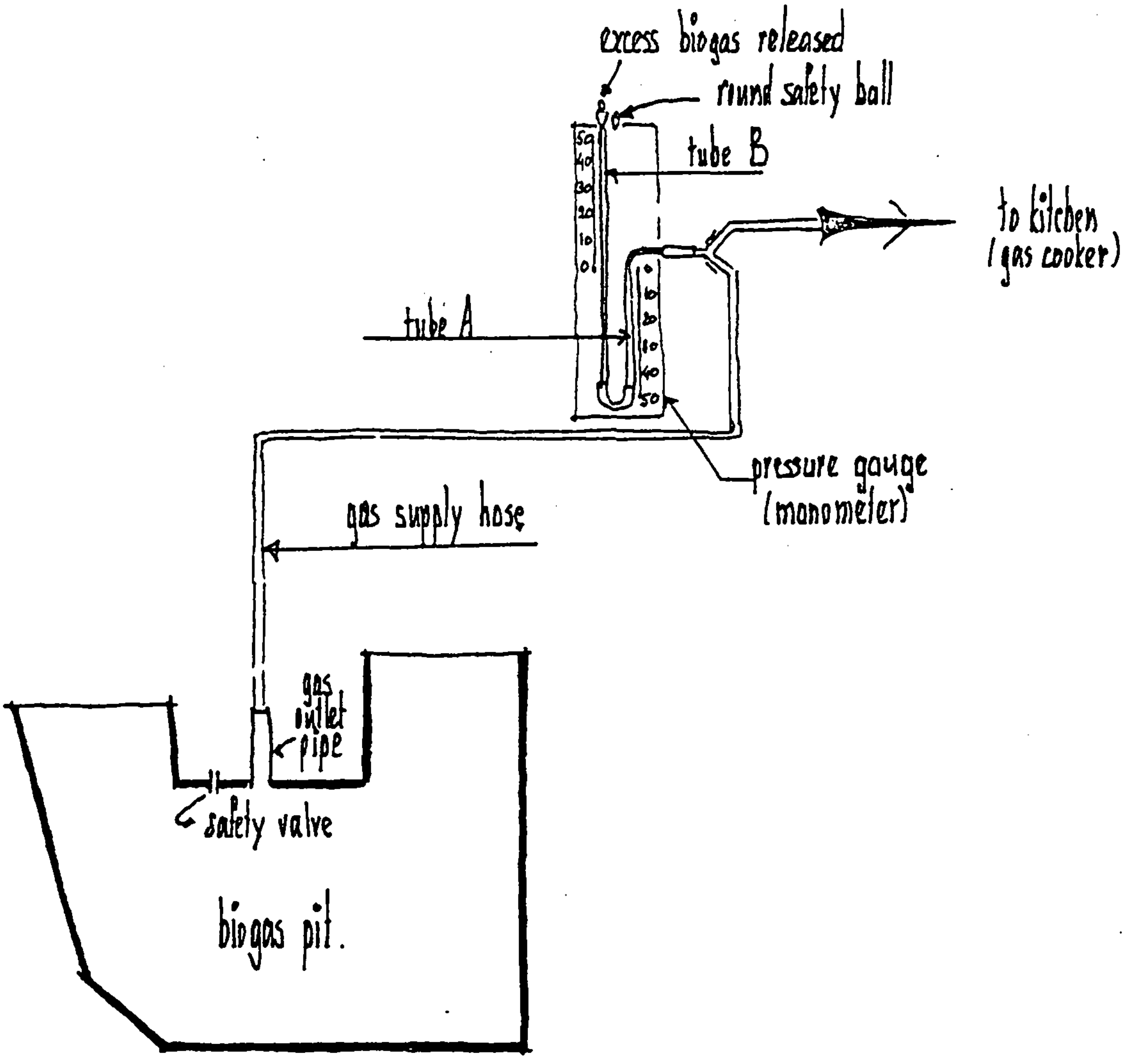
The Safety Valve

The function of the safety valve is basically that of a removable cover. It is normally sealed tight, and only opened when large quantities of material are fed into the pit, so as to avoid unnecessarily large pressures building up which could damage the walls of the pit. Take a long, tapering stick, 15-20 cm long and wrap it in long cloths, like a bandage, so that it can be used as a plug. Spread some rather glutinous clay or other substance around it and then insert it with some force into the hole. Build a little mound in the shape of a ring made of clay or someting very glutinous, fill it with water to make sure that it remains airtight and to ensure that the clay does not dry crack. During the filling of the pit, the safety valve is removed. After the filling is completed, the safety valve is resealed with clay.

The Pressure Gauge (Manometer)

The pressure gauge (also known as the manometer) is a device used to measure the gas pressure within the biogas pit. It is easy to make, and is composed of two glass tubes and a hose in a U-shaped tube filled with coloured water. One tube is connected to the gas outlet pipe via a U-shaped tube, and the other tube is open to the atmosphere. The pressure gauge has three functions: first, to determine whether there is any gas leaking in the biogas pit; second, to estimate the amount of biogas that is stored in the gas storage tank by reading the differences in levels of the water columns in the pressure gauge; and third, to protect the tank from cracking. The pressure gauge, therefore, controls the pressure and indicates all pressure changes inside the pit. When the pressure within the pit is too high the water in the U-shaped tube will flow up into the safety ball and allow excess biogas to escape through the safety valve, thus automatically reducing the pressure within the pit. And when the pressure within the pit has been reduced to a tolerable level, the water will again flow into the U-shaped tube and thereby maintain the gas pressure within the safe zone, avoiding damage to the pit from excess pressure within. In order to assemble the pressure gauge, take two glass tubes 1-1.5 m in length with an internal diameter of 1 cm. Attach the tubes to a board as shown in diagram . Joint the bottom ends of the tubes with a length of rubber hose or plastic tube and by the side of each tube draw graduations in centimeter units, as indicated in the diagram. At the top of tube B, fix a round safety ball, of more than 200 ml capacity. Fill it with coloured water (to facilitate observation) up to the level of the zero mark. Attach a "Y"-tube to tube A, as shown in the diagram. The "Y"-tube is normally made of glass, but can also be made of plastic or

Diagram A.2. Position of Pressure Gauge in Gas Supply Hose.



metal. Now it is possibible to observe the change in the water column in this U-shaped tube, and from this one can measure the pressure inside the pit. For every 10 cm difference in water levels on either side there is a corresponding change in pressure of a hundredth of an atmosphere. To give an example, if the level in tube A drops by 20 cm and the water level in tube B rises by 20 cm, then the difference in the level in the water column will be 40 cm, this would be called an internal pit pressure of 40 cm water.

Examination of the Biogas Plant for Water and Gas Leaks

A very strict examination must be carried out of the biogas plant following its construction. The biogas plant cannot be used until it has been proven waterproof and gastight. The gas storage efficiency increases with effective enclosure as any minute holes in the gas storage tank will destroy the storage capacity and the pressurization. If water leaks from the fermentation tank, or from the intake or outlet chambers, the fecal liquid will seep out causing soil and groundwater contamination, and the gas production will be reduced. Therefore, prior to introducing organic materials into the plant, a thorough examination should be made to see where water and gas leaks occur, and if so, the leaks must be located and repaired. There should be frequent checks and maintenance when the pit is in use, as well. Action should be taken as soon as possible if problems occur. Some common methods of checking for water and gas leaks are the following:

i. By Examination of the Pit Walls

The first method of checking is by direct observation. Once the pit is completed go inside the pit to check for holes and cracks. A finger or small stick can be used to tap all over the wall to listen for any hollow sound indicating unfilled space in the wall, which will have to be opened and repaired.

ii. By Filling the Pit with Water

Fill the pit completely with water up to the cover. Wait until the walls absorb the water and become saturated. When the water level has settled, mark the level. If the level remains the same and has not dropped after a day, then the pit is water tight. However, if the level has dropped this indicates the pit is not water tight, and the cracks and leaks must be located and repaired.

iii. By Using the Pressure Gauge to Check for Water Tightness and air-tightness

Before attaching the pressure gauge, first open the valve of the gas outlet pipe and then fill the pit up with water until the water reaches half-way up in the inlet and outlet compartments. Wait for three to five hours until the pit walls have become saturated with water. Then mark the water level. After a day, check to see if there is any change. If there is a significant drop in water level, this means that the walls or pit bottom leak. When the water level stops dropping, make a mark on the wall: the leakage is then taking place somewhere between the initial level and the lower, final level. Once the leaks have been mended, and the bottom and sides are watertight, connect the pressure gauge to the gas outlet pipe and start adding water. This is done in order to increase the air pressure inside. When a noticeable differential has been reached on the pressure gauge, stop adding water. Wait for 24 hours. After 24 hours check the water column to see if it has dropped or not. Under normal circumstances it should drop about 1-3 cm, although sometimes the drop in pressure is less. This indicates that the pit is airtight. If the drop in the water column is much greater than this, the pit is not airtight and the leak must be located and repaired. In carrying out ths pressure test, it is advisable not to build up pressures greater than 100 cm difference in water level, so as to avoid damaging the pit. Other parts of the pit should also be carefully observed when this pressure test is being carried out. The cover and the curb at the bottom of the gas pipe should be checked to see if any air bubbles develop. The water levels in both the inlet and outlet compartments should rise as a result of the increased pressure in the gas storage tank. This will enable one to check the water leaks in the upper parts of both compartments.

Examination of the Joint Between the Tank Cover and the Side Walls

The earth surrounding the cover-wall seam should be removed and the space filled with clean water. When the positive pressure method is being used, someone should check along the join for any evidence of bubbles of escaping gas.

Examination of the Gas Outlet and Gas Pipe

The conventional method involves submerging these items in water and forcing air from a gas cylinder through them. If bubbles form on the walls of the tubes there is a leak.

Repairing Water and Gas Leaks in the Biogas Plant

Gas leaks occur most commonly where the tank walls meet the cover, and where the gas pipe is connected to the tank's cover. Water leaks usually occur in the intake and outlet chambers and in the floor of the tank. There are five ways that poor wall construction can cause water and gas leaks: (1) incompletely burned limestone that gets built into the concrete wall can "bloom"; (2) the concrete may not be properly compacted; (3) air may get caught between layers of the cement mortar as a result of careless rendering; (4) the various joints may not be well fitted; and (5) the plant may settle as a result of a poorly made wall or an unsuitable foundation. Normally it is easy to deal with gas and water leaks. For instance, if gas leaks around the curb of the gas pipe, the size of the cement curb should be increased; if air spaces are found in the wall then the wall should be widened and deepened and filled with cement mortar. However, several special situations are outlined below.

Unlocated Leaks

The upper portion of the fermentation tank and its cover should be washed and brushed and rendered again with cement mortar and the area should be brushed several times with cement slurry.

Gas leaks that appear once the Plant is in use

After organic material has been put into the plant and a small gas leak is found, the leak can be repaired on the outside surface of the tank to avoid having to empty out the fecal liquid. Before the leak is repaired the tube transporting gas from the gas pipe to the safety valve should first be removed so that the internal pressure of the tank equals atmospheric pressure, then cement mortar or concrete can be used to patch the leaking area, and after the cement or concrete has dried, the tube can be reconnected to the gas pipe. With this sort of repair, a small amount of biogas can still be produced. A proper repair job can only be done when the tank is desludged and the inside of the tank can be thoroughly rendered with cement mortar.

Water Leaks

Groundwater will filter into the tank and the fecal liquid will seep out if there is any crack in the wall or in the floor of the tank. If the floor leaks, it can be reinforced by pouring pebbles and concrete or cement on top; if water leaks through the wall, the crack should be found and patched several times with cement mortar. Sodium silicate may be mixed with cement for patching. The sodium silicate solution and cement will congeal within 2-3 min. To seal the entire area a suitable amount of water should be added to the sodium silicate solution before use.

ANNEX 2

Operation and Management of Chinese Rectangular Biogas Digestor

Careful and disciplined and management are necessary to operate a biogas plant and maintain its production at a level that makes its construction and operation economically worthwhile. In the operation and maintenance of the digestor, the following points should be noted:

1. Digestor Temperature

   Methane gas can be produced within a fairly wide range of temperatures depending on the prevailing conditions. The optimum temperature for fermentation is between 25°-30° C, at these temperature ranges one cubic meter of pit volume produces 0.15-0.20 meters of gas per day; whereas above 30° C the same volume may produce 0.3 cubic meters per day. As methane-producing bacteria are very sensitive to sudden temperature changes, it is very important that the temperature within the digestor remains stable. Covering the inlet and outlet compartments will assist in keeping maintaining the digestor temperature. Also the fact that the digestor is buried underground will help to insulate the pit. However, in certain geographic regions of high altitudes, the outside air temperature may drop during the night thereby affecting the temperature within the pit. If it is observed that there is a significant decrease in gas production, it is possible to further insulate the digestor by surrounding the cover of the pit with composted material. This can be done by piling up in layers on top of the digestor, the cut stalks, crop residue and green matter etc. that must be composted before they are added to the feed mixture.

2. Mixing Material for Fermentation

   The general nature of the feed material, the amount and the rate at which the feed material is being added to the digestor are all important factors for fermentation.

Nature of Raw Materials

The quantities and nature of raw materials used for biogas generation vary widely from country to country and within particular countries. A suitable mixture of locally available waste materials (animal manure and/or human excreta and crop residues) must be devised that will contain the necessary carbon/nitrogen ratio (20-25:1) for the efficient production of biogas. There are a variety of materials that may be used. Although a table of C/N ratios has been provided in Table 1, page 49, these are only approximate values. The same material may have a different ration under different local conditions. For example the nitrogen content of an animal's manure is very much dependent upon its feed. For this reason it is advised that the operator experiment until a combination is found that makes the most efficient use of locally available materials and provides the necessary C/N ratio. The following proportion of materials may be used as an indication:

1. Animal manure 50% and crop residues 20%, water 50%.

   And in the event human excreta is used,

2. Human excreta 10%. Animal manure 20% and crop residues 20%, Water 50%.

3. Water Content of Feed Mixture

In preparing the feed mixture one should mix 50% solids and 50% water. The total water content of the fermentation mixture is usually 90% because the wastes also contain large proportions of water. When it is difficult to estimate the water content of the fermentation material, it is safer to make the mixture too diluted rather than too concentrated.

4. Piling and Composting the Crop Residue and Vegetable Matter

The crop and vegetable wastes should be piled and composted before being fed into the pit so as to speed up the fermentation process and raise the output of gas. In order to pile and compost, cut the material into short pieces and pile them up in layers, each layer about 50 cm thick. It is best to sprinkle some ashes over each layer. The material should be piled and composted about 7 to 10 days before added to the fermentation material. In order to have a sufficient quantity of composted vegetable matter to add to the feed for the first filling to start up the digestor, it is advisable to begin composting the material ten days before the first filling. Thereafter the composting should continue on a regular basis so as to ensure a continual supply for replenishing the feed mixture.

5. Proper pH Value for Fermentation

The pH factor is also important in the proper management of the biogas pit. The pH value of the fermentation liquid (slurry) in the pit should be neutral or weak alkali 7-8.5. The output and quality of the gas (the amount of methane content) will be affected, if the pH value is too high or too low. Therefore, it is necessary to frequently check and observe the pH value of the slurry during the time of feeding materials and during the process of fermentation. When the pH value is correct, the gas will produce a bluish flame when burning. If the gas produces a red or yellow flame, this means the fermentation liquid is over-acidic. In this case one should remove some of the old material from the pit and replenish it with a compensating amount of new material, or add some lime or ash to adjust the acidity and restore normal gas production.

6. Stirring Fermentation Liquid in Pit

In small-size family digestors it is usually not necessary to stir the pit contents. The convection currents resulting from the addition of fresh materials into the inlet compartment and the removal of used slurry from the outlet compartment cause sufficient mixing within the pit. Therefore no stirring device is necessary.

Operating Instructions

The Amount of Feed Material to be Added to the Organic Loading Rate

The quantity of gas produced in a biogas plant per day depends on the amount waste material fed into the digestor per unit volume of the digestor capacity. In other words the amount of waste materials that should be fed into the digestor depends upon the size of the household and the amount of gas that will be needed daily to be used for cooking.

Basic Data

Gas Production

One cubic meter of slurry, or one cubic meter of pit volume can produce approximtely 0.15-0.20 m^3 of gas per day at a digestor temperature of 25-30° C.

Above 30° C, the same volume of slurry can produce approximately 0.3-0.5 m^3 of gas per day.

Gas Consumption

The amount of gas required daily depends on the size of the household and the cooking requirements. A single burner cooking appliance will use approximately 0.25 m^3 of gas per hour. A double burner will use approximately 1.25 m^3 of gas per hour. In China and Pakistan, where this type of biogas plant has been built and used by rural households, it was found that approximately 0.5 m^3 per person was required for daily cooking needs. A family of 8 would require then, 4 m^3 of gas daily if biogas were to satisfy all the cooking fuel needs. In Nepal, a family using a digestor was able to produce enough biogas to satisfy 60% of their cooking fuel needs.

Loading Rate

In China, small, individual family size digestors ranging from 5-10 m^3 in size are used to produce fuel for cooking and lighting. From their practical experience, it was found that a mixture of roughly 50 kg of manure and/or human excreta, composted vegetable wastes and water, are required for every cubic meter of gas needed per day. Of this mixture approximately 20% should be organic solids and up to 80% can be water. If a family then needed 4 cu. meters of gas per day, 200 kgs of a fresh slurry mixture would be added to the pit on a daily basis. The mixture would contain 40 kg of organic wastes (manure and composted vegetable wastes) and 160 kg of water.

It is important to point out these loading rate amounts are only approximations and it will be necessary for the operator to experiment until an efficient quantity and loading rate adapted to local circumstances are found. Once the digestor is filled for the first time and the fermentation process begins, one must keep supplying fresh waste materials into the digestor in order to maintain a constant supply of gas. The daily maintenance of the digestor will be to add in fresh materials constantly and regularly, and take out equal amounts of used slurry. The digestor can be operated on a daily "fill and empty" cycle or at cycles of every 3 days or every week. A daily "fill and empty" operation cycle is advisable, in order to maintain a balanced fermentation process inside the pit. A small amount of material is added and taken out every day.

But even with less material to digest, the biogas produced will satisfy a large part of the family's cooking fuel needs and a considerable reduction of households energy needs can still be achieved.

The First Filling-Starting Up the Digestor

The first filling should be plentiful. It is best to blend the fermentation materials together with water into a liquid slurry, before pouring the mixture into the inlet compartment of the digestor. The animal manure, or a mixture of animal manures is put into a mixing pit together with the cut up, composted crop and vegetable matter. The solid wastes should make up 50% of the mixture and an equal amount of water should be added. The water, manure and vegetable matter should be well mixed to eliminate lumps, as they too, decrease gas production. Before pouring the liquid slurry into the digestor, disconnenct the gas hose from the gas outlet pipe and open up the safety valve. This is done in order to avoid any pressure build-up in the pit. Pour this liquid slurry in through the inlet compartment. If human excreta is used, and the biogas pit is linked to a latrine, it is possible to combine a mixture of 40% manure and pile-rotted vegetable matter and 50% water, as the human excreta will make up 10% of the organic wastes in the pit.

Creating a Water Seal

After the liquid mixture is poured into the pit, fill up the remaining space in the digestor completely with ordinary water. This is done in order to create a water seal whereby all air will be expelled from the pit. Be sure to fill the pit slowly with water so as to avoid a sudden rise in pressure inside the pit. For this could cause cracks to form. When the filling is complete, reseal the safety valve with clay. Once the water seal has been created, and the air expelled, some of the water should be removed. Empty approximately 20-30, 50 liter buckets of water to allow room for the accumulation and storage of the gas produced. At this time, reconnect the gas hose to the gas outlet pipe, so that the gas produced will be channeled off, away from the digestor.

Letting off the First Impure Gas

During the first few days the gas stored will be very impure and should be let off a few times, usually after a few days the pit will begin to produce a methane gas that can be used for cooking. The gas should burn with a bluish flame, when lit. With some pits, in the early stages of gas production, though the quantity of gas produces is quite large for ten days or even longer periods, the gas cannot be lit. This is because the gas contains little methane and much carbon dioxide and other gases as well as a result of incomplete fermentation and consequently, thus there is too little a production of methane. Another reason can also be that the fermentation material is too acidic, and so the growth of methane-producing bacteria is inhibited.

In this situation, one can just let off gas a few times and after a few days normal production will gradually resume. If however, after a few days the material is still acidic, put in a small amount of lime or ash to adjust the acidity (the pH).

Schedule for Feeding Digestor

About two weeks after initially filling the pit, start adding new material. Some of the initial material has already been broken down in the process of producing gas. In order to maintain a plentiful supply of nutrients for the bacteria to ensure a continual production of gas, fresh material for fermentation, as well as water, must be added, and some of the old material should be replaced. It is important to establish a regular schedule for adding and removing the material. As already mentioned, this can be every day, every few days or once a week. The quantity of material removed should equal the amount added. In adding and removing the material, first remove the fermented slurry from the outer compartment, and then pour in the fresh mixture into the inlet compartment. If there is a temporary lack of material for fermentation, simply put in enough water to maintain the previous water level and the same capacity in the gas tank, in order to retain pressure in the gas tank. When removing material from the pit take care not to do this too quickly as it could create a vacuum which could cause the walls to crack. Be sure, as well, that the level of the liquid is not too low so that the openings of the inlet and outlet compartments are exposed, for this will allow gas to escape. One should be careful when removing the fermented slurry, as it may not be entirely pathogen-free, and this may pose a health risk to the person handling the slurry.

Disposal and Use of Digested Slurry

The digested slurry removed from the pit can either be led by means of a channel directly into a compost pit, or removed manually by bucket and poured into a compost or storage pit. The slurry can also be sundried. All these measures will further reduce any health hazards to those using it as a fertilizer or nutrient feed for fish and algae ponds.

Annual Emptying and Cleaning of Digestor Pit

The pit should be emptied once a year of all the liquid slurry and the sludge which lies at the bottom of the pit. At this time the pit can be examined and all repairs can be carried out. In order to avoid intoxication or suffocation when emptying the pit first open up the safety valve, remove and disconnect the gas hose from the gas outlet pipe, so that all gas is discharged. Fire should not be permitted near the pit. The pit should be left for airing for one day before entering the pit. As the slurry and in particular, the sludge that has settled at the bottom of the pit will contain parastic ova, people are advised against touching the slurry and sludge directly with their hands and feet when emptying and cleaning the pit. Therefore it is advisable to wear protective clothing, boots and gloves when carrying out this operation.

ANNEX 3

Construction of Horizontal Steel Drum Digestor

Materials

Four 30 gallon drums 44 gallon drums
Three 44 gallon drums
Nine 1 cm diameter, 5 cm long copper pipes.
Thick-walled 1 cm diameter polythene or rubber tubing.
Eight 1 cm diameter steel bars.

Construction

Horizontal Digestor Chamber

Three well-washed 44 gallon drums in good condition are used. The top of each drum is removed and also the bottom of one of them (the one in the center). The drums are carefully welded together to form the basic digestor chamber.

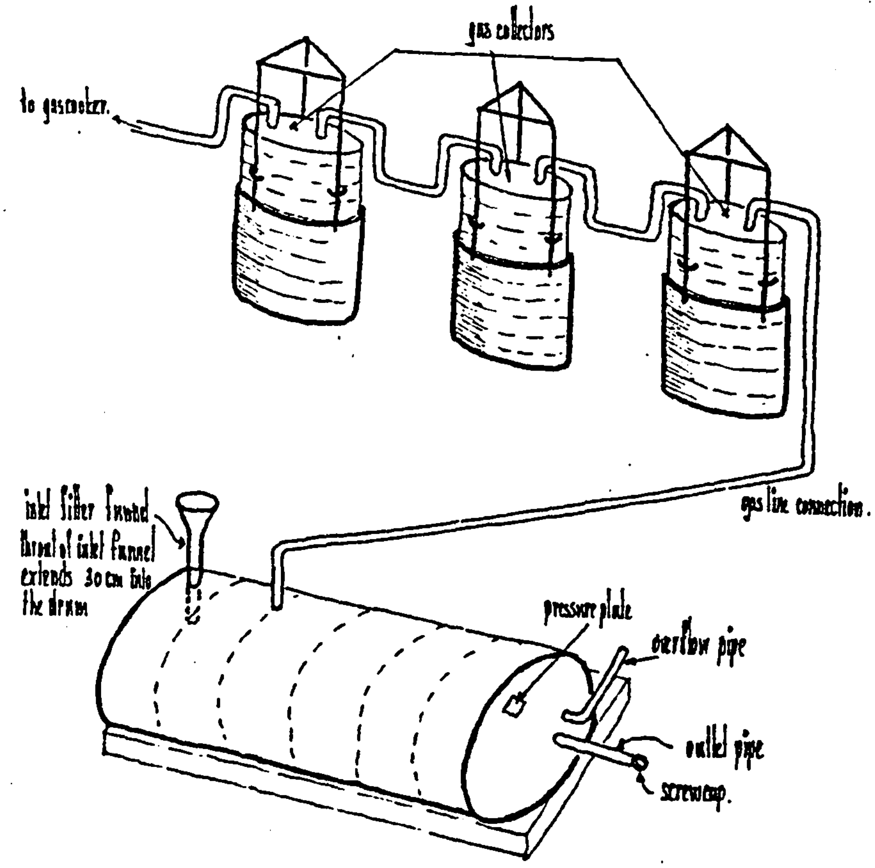
The Inlet Funnel

The inlet funnel should be 30 cm wide at the mouth and 10 cm at the throat. It should be welded in position so that it sits flush on top of the drum and so that the throat of the funnel extends 30 cm into the drum (see diagram A.3).

Gas Outlet Pipe

A 5 cm copper outlet pipe, diameter 1 cm, is welded into position on the drum 30 cm from the inlet funnel. It is important that the gas outflow pipe is large enough in diameter. If the pipe is too narrow, it will become blocked and gas pressure will build up in the chamber, eventually forcing slurry out through the outlet pipe, and biogas will then be lost.

Diagram A.3. Horizontal Steel Drum Digestor



Overflow-Pipe and Outlet Pipe

At the opposite an overflow pipe of minimum 10 cm diameter, and an outlet pipe with a screw cap of 15 cm diameter are welded into position. The overflow should be at least 10 cm higher than the inlet end of the unit. This is done so to eliminate air space in the chamber which permits keeping the digestion chamber as full of slurry as possible in order to maximize gas production.

After completion of the digestor the chamber is then filled with water and carefully examined for leaks.

Coating the Exterior

The exterior of the digestor is coated with a thick protective black bituminous paint. Where digestors are constructed above ground, painting them black will increase the absorption of solar energy to heat the digestor and ensure the necessary temperature for digestion. Moreover painting the exterior of the chamber increases its lifetime.

Gas Collectors

The four gas collecting vessels are made using 30 gallon drums up-turned in 44 gallon drums full of water. Diagram A.3 shows how iron rods are used to guide the rise and fall of the gas collectors. All drums for the gas collector were coated with bituminous paint inside and outside. Each gas collector has two copper inlet/outlet pipes, 5 cm long and of 1 cm diameter, through which the gas can be collected using thick walled one cm internal diameter polythene tubing. If the digestor is near the kitchen or place of gas utilization the internal diameter of the tubing used for all connections between the gas collectors and the digestion compartment can be 1 cm. However, if the distance from the digestor to the place of gas utilization is more than 15 m than larger diameter tubing is necessary, e.g. 2.5 cm. This is because the thinner tubing will kink up in the hot sun and stop the flow of gas, creating pressure build-ups. The larger diameter tubing will permit the gas to flow and the pressure to be maintained over greater distances.

The same tubing is inserted into the gas outlet pipe and the digestion chamber and used to connect the digestor to the nearest gas collector.

ANNEX 4

Safety Precautions in Using Biogas

1. User Education

In order to ensure safety during use of the gas and to prevent accidents it is important to include knowledge about the safe use of gas as well as information about the safe management of the digestor.

2. The Prevention of Poisoning and Suffocation

Although methane is a non-poisonous gas, one can faint if its concentration in the air exceeds 30%, and suffocate to death from lack of oxygen if its concentration exceeds 70%. Furthermore, organic materials in the digestor can produce poisonous gases in the absence of air. Therefore before emptying, cleaning or repairing a digestor one must first entirely discharge all gas from within the gas holder and the digestor chamber and allow sufficient fresh air to enter. Otherwise, there is a danger of poisoning or suffocation. In the case of the Chinese type pit, make sure that the pit is aired for one day before entering the chamber in order to clean it, inspect it or repair it.

3. Avoid Direct Contact with Slurry and Sludge

When emptying the pit of slurry and sludge do not touch it directly with the hand or feet. Wear rubber gloves, boots and protective clothing.

4. The Prevention of Fire and Burns

- Biogas is extremely flammable and will burn violently if it comes in contact with fire. Therefore do not take paraffin oil lamps, a lighted cigarette or anything with a naked flame into the pit or nearby the inlet or outlet compartment. Otherwise a serious accident of burning may occur.

- Make frequent checks for air leaks in the gas hoses and valves. If any gas hose has been broken, or suffered damage through for example, rodent bites or erosion, it must be replaced in order to avoid any gas leakages, otherwise an accident of gas poisoning or fire may occur if the room where the cooking takes place is full of gas.
- Do not place the cooking appliance near any flammable materials. Take special care in houses with thatched roofs.
- The room where the gas burners are located, should always be well ventilated. If there is a strong smell of rotten eggs in the room (the smell of hydrogen sulphide gas), doors and windows should be opened at once to expel the gas. Smoking cigarettes should be strictly prohibited in the room when a rotten egg smell circulates so as to avoid an accident of a fire breaking out.
- After using an appliance, for example the cooking burner, the valve should be shut tight. In the event of fire, one must shut the valve, disconnect the gas outlet hose from the gas outlet pipe, or block it in any way that will cut off the gas supply.
- <u>In using biogas one should light the match first</u>, and then open the <u>gas valve</u>. If the valve is opened and gas is allowed to flow without being lit for any length of time, large amounts of gas will leak out, spread out and rise in the room, and any flame will lead to severe fires.
- Children must be taught not to play with fire close to the inlet and outlet compartments, or, in general, in the vicinity of a biogas digestor so as to avoid burns.

5. <u>Preventing Explosions</u>

In a closed space, where there is a mixture of gas and air, so that the gas content is 15%, explosions can easily occur. Preventive measures which can be taken are:

- When a newly constructed pit has been filled with material for the first time and one is checking to see if methane gas is being produced, the gas should be channeled away via the gas hosing to an appliance, for example the cooking burner, on which tests can be made to see if the flame burns with a bluish colour. It is strongly advised not to test by holding a light to the end of the gas outlet pipe, since the fire could easily be drawn back into the pit, where the sudden explosion of the gases would cause an explosion.

- When digested slurry material has just been removed from the pit, do not use the gas immediately afterwards. If one must use the gas burner, before lighting, carefully check the direction of the gas flow in the mouthpiece, by holding chicken feathers or the down of a bird near the front of the mouthpiece. From the motion of the feather, one can determine the direction of gas flow. If air is being sucked in, then do not light the flame, for the fire may be sucked back into the pit and this may lead to an explosion.
- When filling up the pit with water to test for water-tightness or when filling the pit with material, especially when filling up past the passages in the inlet and outlet partitions, do this slowly, so as to avoid a sudden rise in gas pressure inside the pit which could cause cracks to form. When removing material, from the outlet compartment, take care, as well, not to do this too quickly as it could create a vacuum which could also damage the walls of the pit. When large quantities of material are being added or removed from the pit, detach the hose from the gas outlet pipe and open up the safety valve to avoid the build up of excessive pressure.
- Once a pit has begun full-scale gas production, make frequent use of gas to avoid an exessively large build-up of gas inside the gas storage area. Excessive pressures can damage the pit. It is best to fit a manometer (pressure gauge) to every digestor.

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