

## CHAPTER 8

### METHODS FOR INDIVIDUAL FARMS

Most farmers appreciate the value of animal manure as a fertilizer, and many have found that the composting of organic materials such as night-soil, straw, weeds, leaves, sawdust, and other types of litter is economic as well as important in maintaining the fertility of their soil at a high level. However, very often little attention is given to utilizing the most efficient techniques for effecting sanitary treatment, maximum reclamation of nutrients, and production of good-quality compost.

Composting by correct techniques will : (a) produce a humus which has a C/N ratio satisfactory for application to the soil ; (b) effect maximum conservation of nitrogen, phosphorus, potash, and other nutrients ; (c) destroy weed seeds in the organic litter and pathogenic organisms and parasites in the night-soil ; (d) reduce fly-breeding on the farm ; and (e) provide a means for the sanitary disposal of farm wastes. Composting in stacks and pits is the most satisfactory way of controlling, processing, and storing farm manures and wastes.

#### **Building of Stacks and Pits**

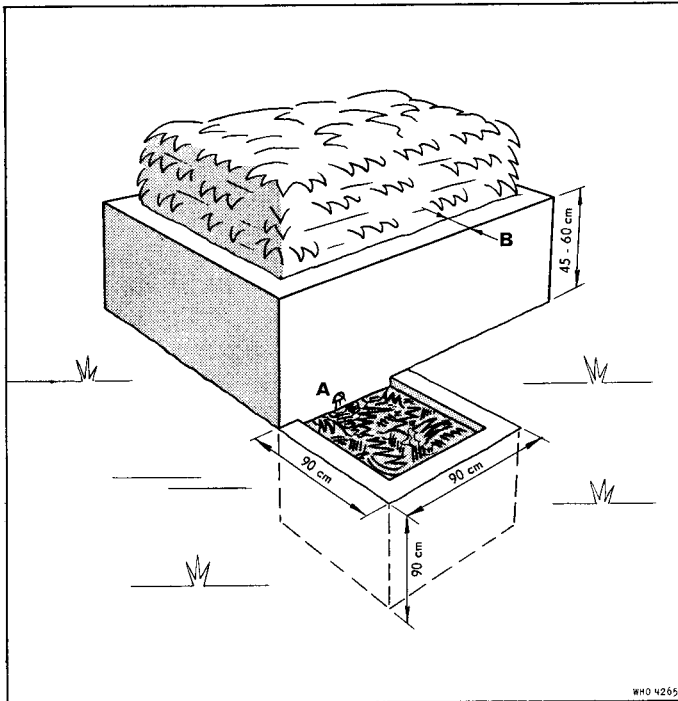
The stabilization of manure and organic litter can be effected in pits or on a slab on the ground surface. It is seldom that a farm has sufficient manure and litter to permit the building, at least once a week, of an individual compost stack which is sufficiently large to maintain high temperatures. Therefore, stacks to which material is added as it becomes available over a period of several weeks must generally be used. Handling and stacking of manure and litter will usually be done by hand labour with pitchforks. However, the use of machinery for conveying the material to the stack and loading the final humus on to carts or trucks may be economical on large stock and dairy farms.

The size and number of pits or stacks to be used depends on the amount of manure and wastes available. Farms with 1-4 animals should provide for only one pit or stack, which should be of sufficient size to contain the manure for a period of approximately 5-6 months in cold climates, and 3-4 months in warm climates. Farms which stable a larger number

of animals will find it more satisfactory to have two or more pits or stacks, so that one can be finishing composting during the period when the other is being filled. One horse or cow which is stabled will produce 10-16 tons of manure per year.

Fig. 35 shows a compost pit which can be built of concrete or masonry. The area should be such as to provide the desired volume when the pile

FIG. 35. MANURE STACK IN PIT WITH DRAINAGE SUMP



A = drain  
B = wall 15 cm thick

of material to be composted is 4-5 feet (1.2-1.5 m) high. The walls of the pit should be about 2 feet (0.6 m) high, and the pit may either be sunk in the ground or placed on the surface. The walls prevent surface drainage from entering the stack and leaching out valuable nutrients, and also permit the retention of any liquid drainage from the manure, which contains large concentrations of dissolved nutrients. An outlet may be placed in the corner of the pit to permit the drainage to flow into a concrete or masonry sump. The walled pit also helps to control fly-breeding and

prevents pieces of manure and litter from being scattered around the ground by chickens.

The sides of the manure piles can be nearly vertical when there is sufficient straw and litter in the manure to allow stacking. The top should be slightly rounded to turn rain-water and prevent seepage through the stack.

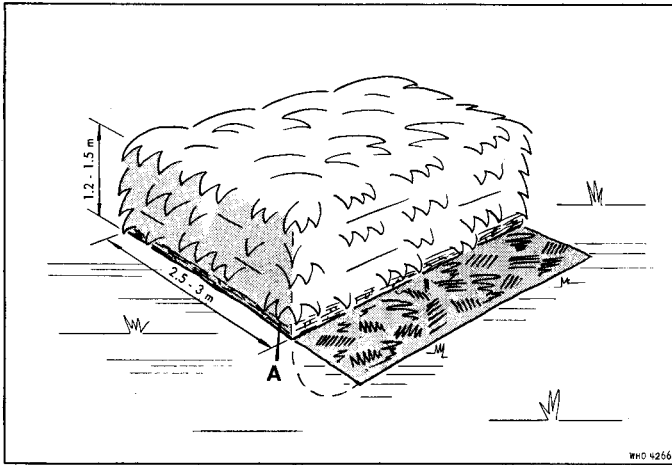
The sump for collecting liquid drainage should have a capacity of about 27 cubic feet (0.8 m<sup>3</sup>) and should preferably be lined with concrete or masonry. Filling with straw or other organic litter with a high cellulose content will serve to absorb the liquid and provide a medium for bacterial utilization of the nitrogen, thus preventing its escape as ammonia to the atmosphere. Layers of soil 2-3 inches (5-8 cm) thick between 9-inch (about 20 cm) layers of straw also help in absorbing the drainage and preventing the escape of nitrogen. The organic litter should be removed from the sump and placed in the compost pile when it has become saturated with the liquid.

The urine from the stable should be drained either to the sump of the compost pit or to a separate sump, constructed, in the same manner as the pit-drainage sump, at an appropriate place to intercept it. If there is insufficient straw and other organic litter available to provide adequate absorption and retention of the liquid drainage from the manure pile and the stable urine, a large liquid-tight sump of 200 gallons (900 litres) capacity, or larger, depending on the number of animals and the rainfall, should be used to collect and contain all the liquid manure. The liquid from the sump should be removed as necessary and sprayed on the land. Since this liquid contains large concentrations of chemical nutrients it should not be wasted. Absorption of the liquid by litter waste is usually more satisfactory from the standpoint of maximum conservation of nutrients and development of soil humus; however, most of the nutrients can be recovered from the liquid by spraying it on the fields.

Fig. 36 illustrates a compost stack for manure. The size of the stack is determined by the amount of organic waste material available and the time the material will remain in the stack, as described above for the compost pit. It is desirable to have a concrete or masonry slab under the stack and a sump for catching the drainage. If the cost of a slab is too great, a reasonably satisfactory base for the stack can be made by packing the ground surface and, if possible, placing on top a layer of packed clay, which will be relatively impervious. The ground should be sloped so that any drainage from the stack can be caught in a small sump, filled with straw or other litter to absorb the nutrients.

If the manure is placed on a concrete or masonry slab, a 6-inch (15 cm) deep channel can be made in the slab around the edges of the manure

FIG. 36. MANURE STACK ON THE GROUND



A = coarse material

stack to trap fly larvae and pupae which move to the outer edges of the stack to escape the high temperature. The inside edge of the channel should be raised about 1 inch (2-3 cm) so that drainage from the stack will flow to the sump and not enter the channel. The channel is kept filled with water in which the larvae are trapped. The channel is not effective as a larvae trap, however, unless it is cleaned and refilled frequently; as this is usually neglected by the farmer, its provision in the slab is of questionable value.

#### **Addition of Litter and Night-soil to Manure Piles**

The placing of a layer of straw, cane stalks, or other coarse cellulose material on the bottom of a compost stack is very important for the retention of nutrients and development of humus. The layer should be at least 12-18 inches (30-45 cm) deep so that it will pack to no less than 3 or 4 inches (7-10 cm) when subjected to the weight of the stack. This porous layer of cellulose material will provide some air for composting and will absorb a considerable amount of the manure drainage. Since this type of cellulose material has a low content of nitrogen and other nutrients and the manure and urine have a high one, it will absorb excess nutrients and decompose into a rich humus. The provision of this layer on the bottom is particularly important when the compost pile is built directly on the ground.

Since most manure and all night-soil contains large amounts of nitrogen, some of which may be lost in composting, any type of organic litter can be added satisfactorily to the manure pile and composted. The resulting humus will be very satisfactory for use as fertilizer, the amount of humus will be increased, and the nitrogen loss will be decreased. A manure pile can be a repository for weeds, live fence or hedge trimmings, and waste organic materials which might otherwise be burned with a resultant loss of nutrients and humus.

Night-soil and weeds can be added to the manure compost stack, but they should be kept 12 inches (30 cm) or more from the sides and covered with manure to a depth of at least 12 inches, so that exposure to high temperatures, with destruction of pathogenic organisms, parasites, and weed seeds, will be ensured and no fly-breeding will take place in the night-soil. Since the nitrogen and moisture contents of night-soil are high, it is desirable to add dry cellulose litter to the night-soil in the trench. This porous material will also provide air spaces, which will facilitate aerobic decomposition and the production of high temperatures.

To minimize fly-breeding, droppings from the sides of the stack or pit should be picked up immediately and placed on the stack. Faeces and garbage are most attractive to flies, whereas organic litter is not very attractive. Hence, placing the manure which contains large amounts of faecal material on the inside of the pile and the manure which contains more straw and litter on the top and sides will help to reduce fly-breeding.

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## CHAPTER 9

# MANURE AND NIGHT-SOIL DIGESTERS FOR METHANE RECOVERY ON FARMS AND IN VILLAGES

### Development and Usefulness

The presence of methane ( $\text{CH}_4$ ) in marsh gas was first observed near the end of the eighteenth century, and during the nineteenth century the evolution of methane from the anaerobic decomposition of organic matter was observed. The first attempt to build a plant to produce methane gas from manure by biological decomposition appears to have been at Bombay, India, in 1900.<sup>54</sup> Since then, knowledge of the process has progressed and extensive use of anaerobic digestion of sewage solids and gas collection has been practised in cities in many parts of the world. From 1930 on, investigations with the object of developing this process for farm use have been made in Algeria,<sup>16, 41</sup> France,<sup>6, 54</sup> Germany,<sup>37, a</sup> India,<sup>2</sup> England,<sup>20, 52</sup> and the USA.<sup>54</sup> Since 1945, many installations for digesting farm manures and wastes and recovering the methane and humus have been set up in Algeria, France, Germany, Italy, India, and other areas. These installations have proved successful, particularly in areas which have a warm or temperate climate.

The use of anaerobic digestion of organic waste materials, such as farm manure, litter, garbage, and night-soil, accompanied by the recovery of methane for fuel, has been an important development in rural sanitation during the past 10 to 15 years. This development is basically an extension of the anaerobic process for sludge digestion used in municipal sewage treatment to small digestion-tank installations on farms. These farm plants comprise one or more small digesters and a gas-holder. Manure and other wastes are placed in a tank which is sealed from atmospheric oxygen, and are permitted to digest anaerobically. The methane gas, which is produced during the anaerobic decomposition of the carbonaceous materials, is collected in the gas-holder for use as fuel for cooking, lighting, refrigeration, and heating, and for other domestic or agricultural purposes, such as providing power for small engines.

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<sup>a</sup> An article in *La Potasse* (November 1941) entitled "Le gaz de fumier en Allemagne" and summarized by Hisserich in *Land, Wald und Garten* (May 1947)

This method provides sanitary treatment of organic wastes, satisfactory control of fly-breeding, efficient and economical recovery of some of the waste carbon as methane for fuel, and retention of the humus matter and nutrients for use as fertilizer.

Most of the farm installations have, so far, utilized only animal manure and organic litter ; however, night-soil can be satisfactorily treated together with the other wastes in these digesters if adequate digestion time is allowed to permit destruction of the pathogenic organisms and parasites. Such a practice has many advantages on farms and in villages where water-carried sewage disposal is not available. The use of the digestion tank can eliminate the dangerous insanitary practices of allowing night-soil to be deposited on fields, and in the immediate environment of homes, without proper treatment. Straw, weed trimmings, or any other type of cellulose material may be digested together with the manure and night-soil for the production of methane.

Digester tanks with gas collection are particularly advantageous in areas which are short of fuel and where animal dung is burned for cooking, thereby wasting the valuable nitrogen and other nutrients needed for fertilizer. The nitrogen, phosphorus, potash, and other nutrients are retained in the tank as humus and liquid while much of the carbon and hydrogen are evolved as methane, for collection and use as fuel. The quality of the humus is similar to that obtained from aerobic composting, and when the liquid is utilized together with the solids for fertilizer, practically all of the fertilizer nutrients are reclaimed.

The evolved gas, which is approximately two-thirds methane and one-third carbon-dioxide, may contain 4500 to 6000 calories per cubic metre, thus providing a convenient source of heat at a low cost. One cubic metre of the gas at 6000 calories is equivalent to the following quantities of other fuels : 1.100 litres of alcohol ; 0.800 litres of petrol ; 0.600 litres of crude oil ; 1.500 m<sup>3</sup> of commonly manufactured city gas ; 1.400 kg of charcoal ; and 2.2 kilowatt-hours of electrical energy.

The gas can be stored in the gas-holder and piped into the house to provide clean fuel for cooking and lighting. It has a slight barn-yard odour by which any leaks can be readily detected, and a very low toxicity since it contains very little carbon monoxide—the toxic constituent of most city gas. It burns with a violet flame without smoke. Since a considerable amount of CO<sub>2</sub> is mixed with the methane, the risk of fire or explosion is somewhat less than it is in the case of city gas. However, every precaution should be taken to avoid obtaining a mixture of methane and air, except when the methane is burned as an open flame. Mixtures of 5%-14% methane in air are explosive when large quantities are ignited.

## Basic Considerations for Planning and Operation of an Installation

There are several basic factors which must be considered in constructing or purchasing a digester installation. These are: (1) climate; (2) single or multiple family installations; (3) amount of wastes available; (4) gas production; (5) number and size of digesters; (6) location of digesters; (7) gas requirements and storage; (8) materials and costs.

### *Climate*

Small digester plants can be used most effectively in temperate climates, where freezing temperatures are infrequent and of short duration. Decomposition and gas production are most rapid at about 35°C, but are satisfactory at temperatures above 15°-20°C. Gas production practically ceases at temperatures below 10°C. The digester can be used satisfactorily in cold climates, provided the tank is properly insulated and heated. The additional heat required can be provided by burning some of the gas produced, by stacking manure and straw around the tank (see page 188), or by placing the tank above the ground so that it is exposed to the sun. When digester gas or an aerobic compost stack is used for heating the tanks, sufficient quantities of organic materials must be available to provide the additional heat as well as enough gas for other purposes.

### *Single or multiple family installations*

Either single or multiple family installations can be provided, the choice depending on whether the single family has sufficient manure and other wastes to operate a unit. A minimum single family installation would normally include a digester tank of about 4-5 m<sup>3</sup> capacity and a gas-holder of at least 2 m<sup>3</sup> capacity. Two or more digesters are desirable so that there will not be an interruption of gas production and so that one tank may be loaded while the other is digesting. A single gas-holder can serve more than one digester unit. If two or more families living in adjacent compounds have not more than one farm animal each, it may be advantageous to combine their wastes in one digester installation from which the gas could be distributed to each dwelling. The plant could be located so as to minimize transportation of wastes as well as to provide latrine facilities for the co-operating families. This arrangement would permit the use of more than one digestion compartment and, hence, more uniform gas production. The cost of the initial installation, per ton of manure decomposed, will be less for multiple family plants than for single plants. However, a multiple family plant serving more than two families, living in adjacent compounds, may require such excessive piping of gas and

transporting of the organic matter as to make individual plants generally more economical.

#### *Amount of wastes available*

As has been indicated, horses and cows produce from 10 to 16 metric tons of manure per year, depending on stabling conditions and amounts of organic litter used for bedding. To this may be added garbage, waste straw, cane stalks, or any other organic litter. Where night-soil is used as a fertilizer, it should be digested with the other organic wastes before application to the land, in order to prevent the spread of faecal-borne diseases. While human excrement does not add much weight to the digester, 30-60 pounds (15-30 kg) per capita per year, it does provide appreciable quantities of the nitrogen and phosphorus necessary for biological digestion and methane production from cellulose and other materials with a high carbon content. The sanitary treatment of night-soil for the reclamation of nutrients is most important. It should be further mentioned that when night-soil and animal manure containing large quantities of nitrogen and phosphorus are digested, large amounts of waste materials such as straw, cane stalks, and sawdust can be added to increase gas production. When night-soil is digested with other wastes, a digestion period of three months or more is desirable in order to ensure adequate destruction of pathogenic organisms and parasites.

Stable manure and mixed organic refuse weighs from less than one-half to as much as one metric ton per cubic metre, depending upon the amount of moisture and the degree of compaction.

#### *Gas production*

In practice, about 50% of the carbon theoretically available for gas production is converted into gas. A metric ton of waste will normally yield about 50-70 m<sup>3</sup> of gas per digestion cycle, depending upon the proportion of organic matter and the carbon content of the waste.

The digestion cycle will be shorter at high temperatures than at low temperatures, and hence the daily yield per ton of material will be greater. Considerably greater digester-capacity is required to produce a fixed amount of gas at a temperature of about 20°C than at a temperature of 30°-35°C. Mignotte<sup>54</sup> gives the following estimates for gas production per ton of manure for different digestion periods at different temperatures :

<i>Temperature</i> (°C)	<i>Gas production</i> (m <sup>3</sup> per day)	<i>Digestion period</i> (months)
15	0.150	12
20	0.300	6
25	0.600	3
30	1.000	2
35	2.000	1

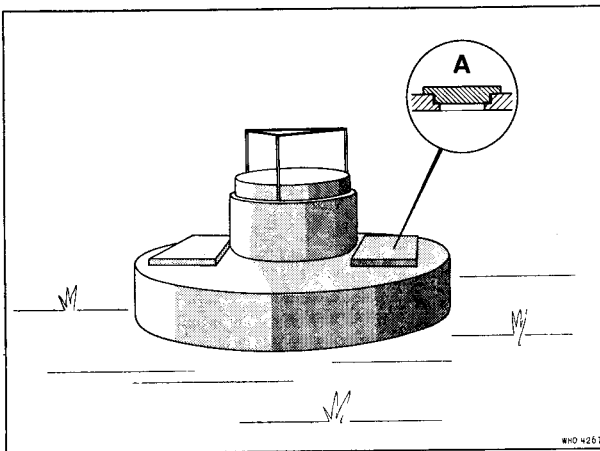
Similar data on gas production and digestion time for sewage sludge at different temperatures may be found in books on sewage treatment. Estimates of gas production can be made from the amount of organic matter in the manure. The amount of gas produced and the rate of digestion at different temperatures are important factors in determining the size of digestion tanks to be used.

### *Number and size of digesters*

The number and size of the individual digestion tanks of a plant will vary with the amount of decomposable material available and the amount of gas desired. A minimum of two, and preferably three, tanks is recommended to maintain more uniform gas production. A digestion compartment of 8 m<sup>3</sup> capacity (2 m × 2 m × 2 m) has been found to be an efficient size. In small installations, where sufficient materials are not available to supply two digesters of this size, smaller digesters could be used, but the saving in cost of construction would be small. For larger installations up to six compartments of about 8-12 m<sup>3</sup> each may be used. It is doubtful whether more than six or possibly eight compartments would be economical, and for very large plants the size of the individual compartments should be increased.

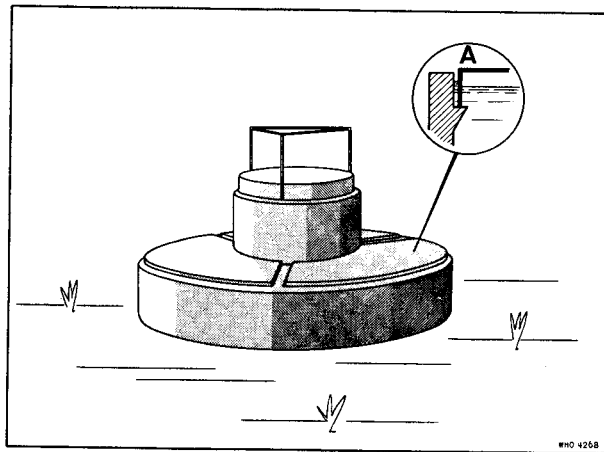
For small installations the tanks may be circular, square, or rectangular. Fig. 37 and 38 illustrate plants in which two or three digester compartments and the gas-holder are incorporated into a circular plan.

FIG. 37. TWO-COMPARTMENT CIRCULAR DIGESTER WITH GAS-HOLDER



A = mud-plaster joint

FIG. 38. THREE-COMPARTMENT CIRCULAR DIGESTER WITH FLOATING COVER AND GAS-HOLDER



A = cross-section of floating cover

The digester may have a concrete cover with mud and cow-dung joints (see Fig. 37), a metal cover with a gasket and clamps, or a floating metal cover (see Fig. 38). Each compartment of the three-compartment digester is approximately a one-third segment in volume, and a circular or triangular gas-holder could be placed in the centre. If circular digestion tanks are used, each will be a separate installation without common walls, and expansion would be accomplished by building a new unit. If square or rectangular tanks are used, the digesters can have common walls and the plant can be expanded by merely adding additional digesters at the ends. The tank arrangement chosen will depend upon the type of construction that will be the most economical under the particular local conditions.

#### *Location of digesters*

The digesters should be located near the source of manure and waste material to avoid excessive handling and transportation. Also it is desirable to place them so as to minimize the amount of gas piping required. It is important to orient a digester so that it will receive the maximum amount of sunlight to help maintain higher digestion temperatures. Greater heating from the sun can be obtained when the tank is placed on top of the ground, but this involves lifting the materials higher when loading. When tanks are used only for manure and litter, it is a common practice

to place them partly below and partly above the ground. This arrangement also permits the placement of compost around the tank for heating. If a latrine is incorporated in the digester, the top might be as much as 0.7 m above the ground without necessitating too many steps.

In more or less tropical areas where a single installation is used for two families with adjacent compounds, the digester can be built under the common wall between the compounds so that half is on one property and half on the other, the wall dividing the plant. Two compartments should be provided, both accessible to each compound. Only one gas-holder will be required ; it may be incorporated into the digester structure or built separately.

#### *Gas requirements and storage*

The gas may be used for domestic purposes, such as cooking, heating water, food refrigeration, and lighting. The following are some approximate quantities of gas for these different uses : domestic cooking, 2 m<sup>3</sup> per day for a family of five or six people ; water heating, 3 m<sup>3</sup> per day for a 100-litre tank or 0.600 m<sup>3</sup> for a tub bath and 0.35 m<sup>3</sup> for a shower bath ; domestic food refrigeration, 2.5-3 m<sup>3</sup> per day for a family of five or six people ; lighting, 0.100-0.150 m<sup>3</sup> per hour per light.

The gas may also be used for purposes such as providing power for engines, milk cooling, and electricity. A two-horsepower stationary engine requires about 0.900 m<sup>3</sup> per hour. For milk cooling on a dairy farm the following approximate quantities of gas are required : 0.800 m<sup>3</sup> for 55 litres ; 1.0 m<sup>3</sup> for 90 litres ; and 1.25 m<sup>3</sup> for 150 litres.

Since the gas is produced continuously, day and night, but is used largely during the daytime, it is necessary to provide storage facilities so that the gas will not be wasted and will be available when needed. The storage capacity should be estimated to meet peak demands. For small installations, storage capacity for about one day's requirement of gas should be provided. This will usually be about half, or less, of the total volume of manure actively undergoing digestion. In tropical or warm areas the storage capacity might be reduced to half the amount required per day, but it is probable that there would be times when gas would be wasted from the digester because the gas-holder was full. At other times, when a considerable amount of gas was being used, the gas-holder might become empty. The volume of the gas-holder should not be less than about 2 m<sup>3</sup>, even for very small installations.

The gas-holder may be circular or square and should be provided with a water seal to prevent escape of gas or admission of air. The weight of the floating cover of the gas-holder provides the gas pressure. The

usual pressure for gas-burning equipment is 5-20 cm (2-8 inches) of water. The bottom and walls of the gas-holder, which must be water-tight, can be made of concrete, but the cover should usually be metal in order not to produce excessive gas pressure. Centre weights on the gas-holder cover may be used to provide the desired pressure for the burning equipment.

Gas may be stored in the digestion tank by using a floating cover as shown in Fig. 47. An additional gas-holder may be used with floating-cover digesters, in which case one gas-holder would serve several individual digesters.

Copper piping is the most satisfactory for gas distribution because it will minimize corrosion problems, but galvanized-iron or black-iron pipes can be used. Valves should be provided for shutting off the gas from the digesters and from the gas-holder. The piping should be arranged so that the gas from the digester can flow directly to the burning fixtures and the gas-holder merely floats on the line producing the pressure, taking up gas when it is produced faster than it is consumed and supplying it when the rate of consumption is greater than the rate of production. A trap should be placed at the low point in the gas line to permit the escape of any water in the line caused by moisture condensation. The trap can be placed in a pit next to the tank or at some other place where the low point of the line can be conveniently located.

If the gas is burned in an engine, removal of the hydrogen sulfide is sometimes desirable to prevent corrosion. This can be accomplished by passing the gas through an absorption tank containing ferric oxide, which will remove very small concentrations of hydrogen sulfide. The oxide can be regenerated by exposure to the air.

### *Materials and costs*

Complete plants, either prefabricated or built of concrete at the site, may be purchased in several countries. The prefabricated plants may use steel or concrete digestion tanks with metal covers and gas-holders. The cost of installation can be reduced by the user's building most of the plant himself. The digestion tanks and gas-holder base can be built of concrete or masonry. If masonry is used, the tanks should be lined with plaster to prevent leakage of gas or liquid.

The gas-holder cover usually has to be purchased since it is most satisfactory when made of metal. It must be gas tight, not easily deformed, and built sufficiently accurately to avoid binding in the guides as it adjusts to varying volumes. The piping valves and burners must also be purchased. Unless the user is skilled in pipe fitting, the pipes should be installed by an experienced craftsman.

The initial cost may seem rather high, particularly if the user does not do a great deal of the work himself; however, when this cost is amortized over a period of several years, it will be found that such a plant will provide a cheap source of fuel and a sanitary method of waste treatment. In countries where it has been the custom to burn manure for fuel, a digester plant will be especially economical because not only will fuel be obtained but also needed nitrogen will be reclaimed. Where one installation is used for two adjacent compounds, a saving can be effected by having only one set of digesters and one gas-holder.

The operating and maintenance costs are relatively insignificant. The loading and removal of material is a matter of labour, part of which would be expended in the normal handling of the manure from the barns to a stack. The maintenance of the equipment amounts to painting the metal parts to prevent corrosion. Such a plant, if well built and protected from corrosion, should last over 25 years.

### **Construction of Plant**

#### *Choice of construction materials*

Most of the materials required for the construction of a manure-gas plant can usually be found locally. These are sand and gravel for making concrete, and stones or bricks for masonry. Concrete structures are preferred because they can be made water and gas tight and may be easily reinforced to resist inside water pressure when built above ground level. They require for their construction forms, however, reinforcing steel and more cement than is needed for masonry-built tanks. In some areas, this may constitute a serious disadvantage owing to the unavailability or excessive cost of cement and steel.

Tanks may also be built of stones or bricks, using a good cement mortar for the joints. Masonry walls should be designed to sustain water pressure, and inside surfaces should be lined with a thick coat of rich sand-cement-lime plaster in order to make the tanks water and gas tight.

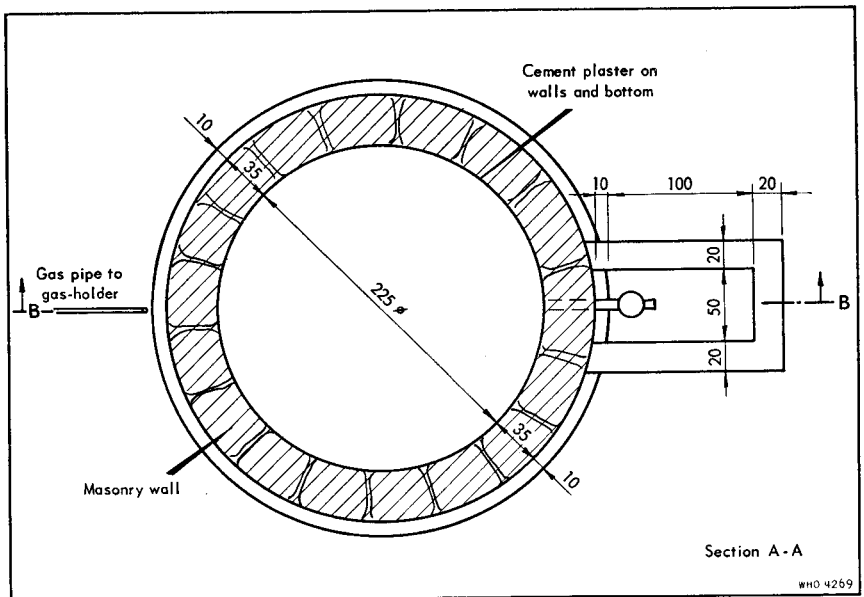
#### *Digestion tanks*

Rectangular tanks are easier to build than circular tanks, but in the course of operation in cooler climates, they lose relatively more heat because of their greater surface/volume ratio. Circular structures are more resistant to both inside water pressure and outside earth pressure, if any, and consequently require comparatively thinner walls.

Each tank should be provided with a manhole for loading, unloading, and occasional cleaning. Once a tank is ready for operation, this opening should be kept tightly closed in order to prevent escape of gas. This may be achieved by inserting a rubber gasket, or a wet clay and cow dung mixture, between the border of the cover and the tank.

Fig. 39 and 40 show an individual circular digester built of masonry and lined with plaster. In this plant, the gas-holder is a separate unit (see Fig. 46). Several individual digesters may be utilized. The gas from all digesters would be fed to the one gas-holder.

FIG. 39. PLAN OF INDIVIDUAL DIGESTER UNIT

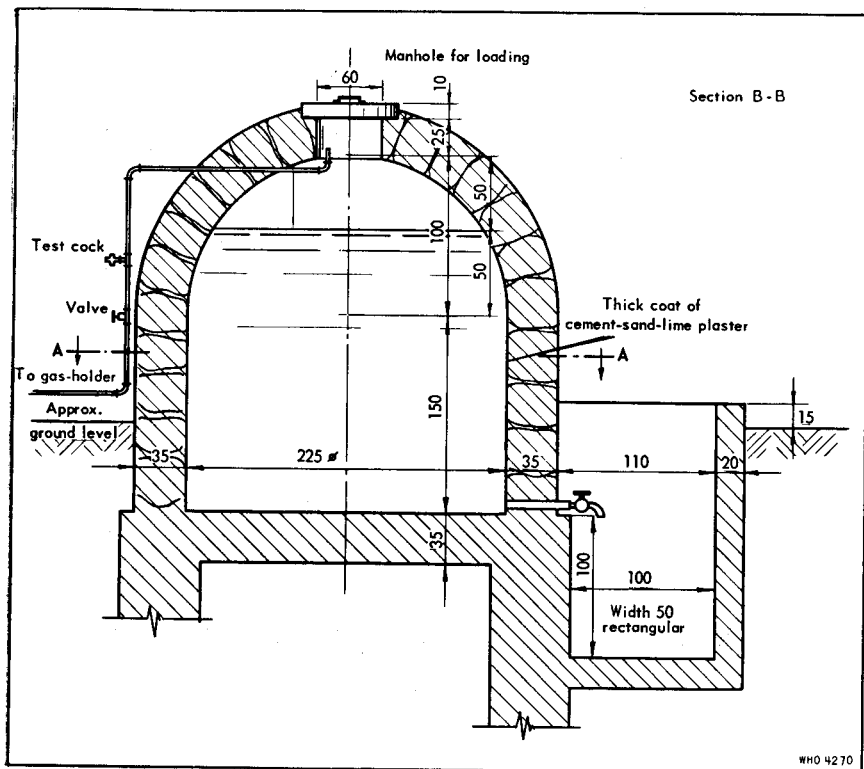


*All measurements are in centimetres.*

Another type of individual digester, which uses a floating cover for gas storage, is shown in Fig. 47. The cover is removed for loading. The digester can be circular, square, or rectangular, depending upon the ease and economy of construction. Circular covers are easier to keep from binding in raising and lowering.

In areas where night-soil is commonly used as a fertilizer, it will be found advantageous to combine latrines and digestion tanks in the manner illustrated in Fig. 41-45. Fig. 41 shows the view of the plant with the housing for the latrine. The housing can be of solid wood, of interlocked

FIG. 40. CROSS-SECTION OF INDIVIDUAL DIGESTER UNIT

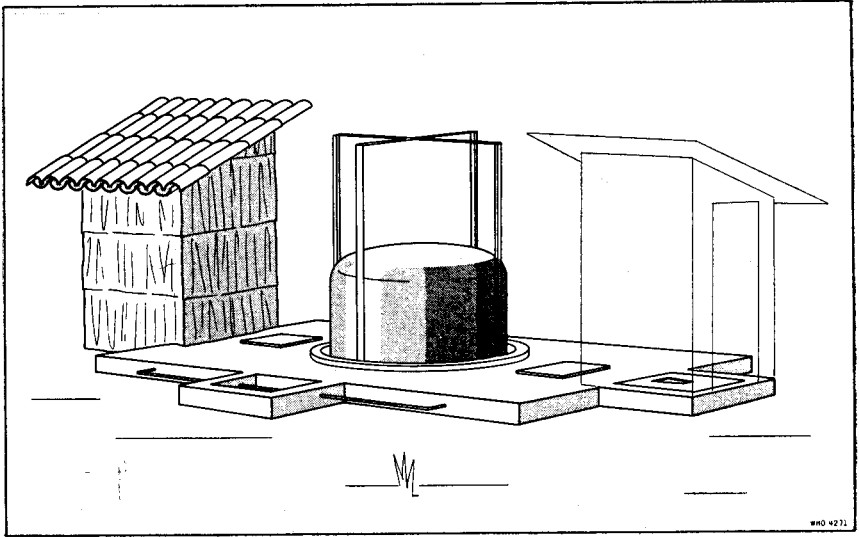


*Maximum manure-storage capacity of digester : 7.860 m<sup>3</sup>  
All measurements are in centimetres.*

split bamboo poles, of poles with palm or grass thatching, or of any other suitable local materials. The door should be arranged so that the latrine cover can easily be raised for adding manure, straw, or other wastes to the digestion tank. Fig. 42 and 43 show the plan of the plant and details of its cross-section, respectively. Fig. 44 and 45 show the gas-holder and gas-piping details.

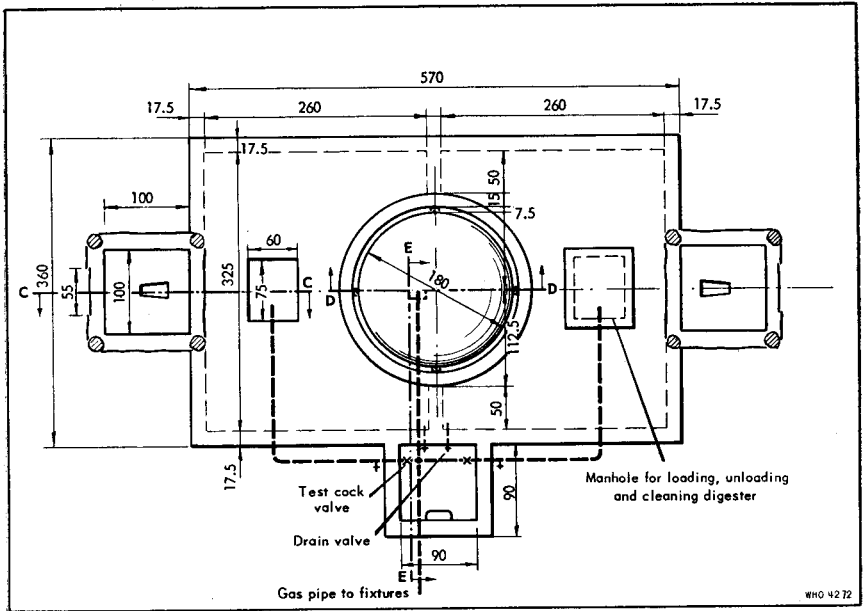
A suitable baffle should be provided between the digestion tank and the latrine pit to prevent the escape of valuable gas. Care should be taken during operation of the plant to see that this seal is maintained. It will also be necessary to maintain in the latrine an adequate level of water in order to ensure operation in a clean and sanitary manner. In the design shown, the digesters are placed partly below ground level so that the

FIG. 41. SKETCH OF MANURE GAS PLANT WITH LATRINES



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FIG. 42. PLAN OF MANURE GAS PLANT WITH LATRINES

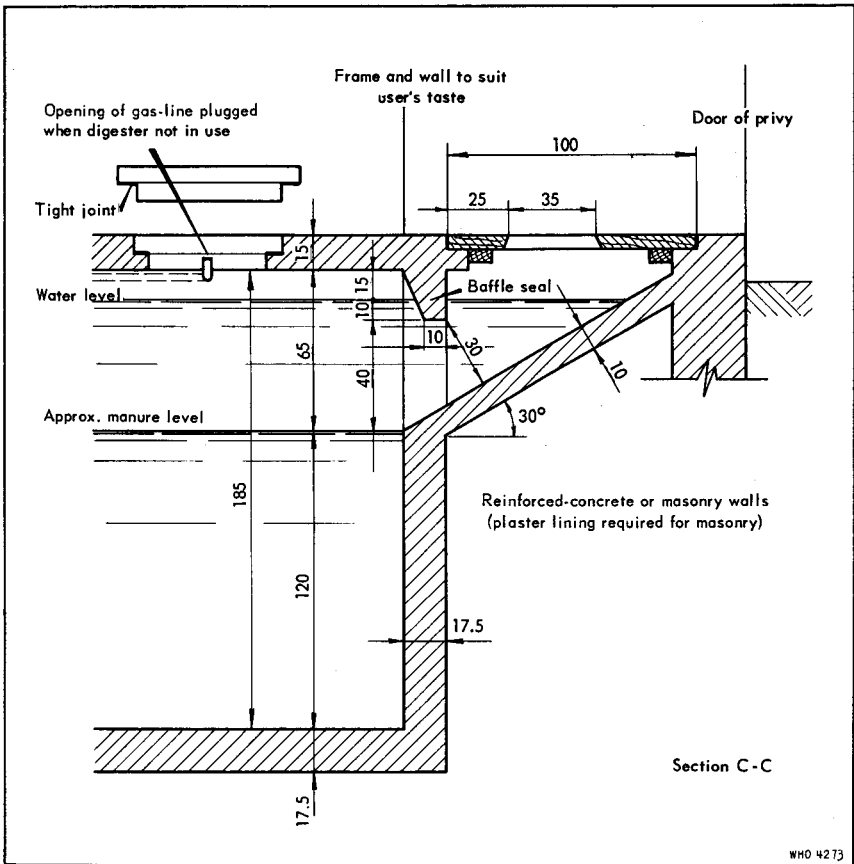


All measurements are in centimetres.

floors of the latrines are not too high above the ground. Steps could be made, however, if it were desired to have more of the tank above ground level.

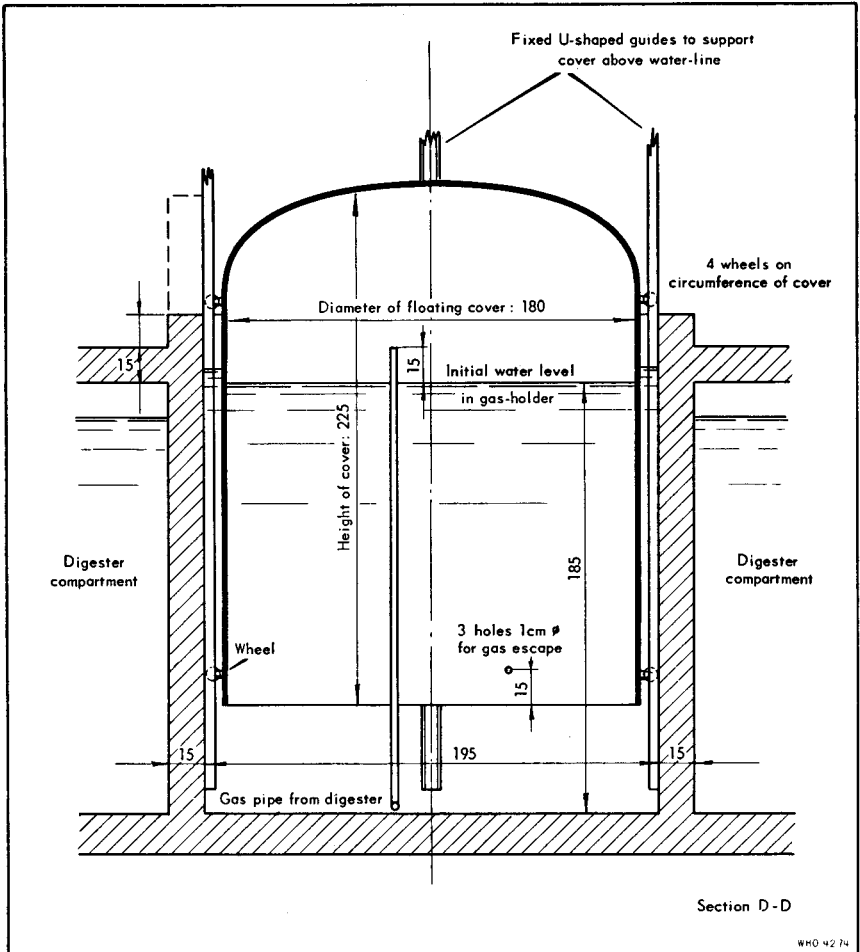
The digester's gas piping is very simple, the only requirement being that the opening of the pipe collector should be sufficiently high (12-18 cm) above water level to prevent it from becoming clogged by floating scum. In some tanks a bell-shaped dome is built as part of the roof for easier collection of gas. Outside the digester, a pet-cock followed by a shut-off valve should be installed, the pet-cock for occasional testing of gas-burning quality and the valve for shutting off and isolating the digester compartment when so desired.

FIG. 43. CROSS-SECTION OF DIGESTER AND LATRINE



All measurements are in centimetres.

FIG. 44. CROSS-SECTION OF GAS-HOLDER FOR MANURE GAS PLANT

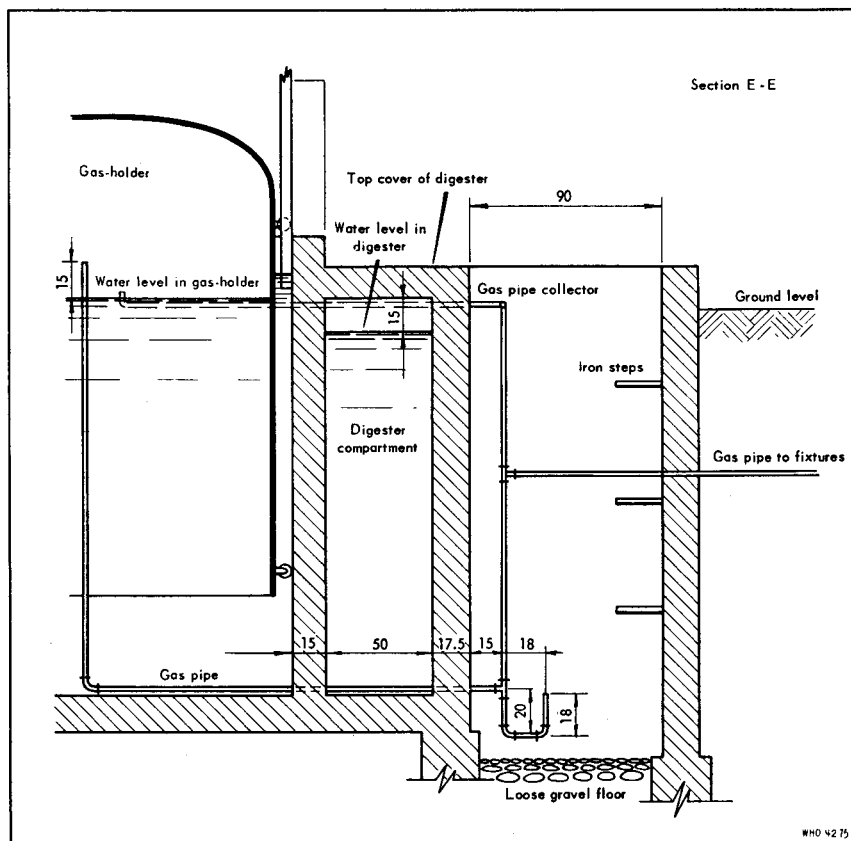


All measurements are in centimetres.

The proportion of height to diameter of cover may be changed, but the equivalent volume should be maintained.

The digester should also be provided with a short discharge pipe, leading outside to a spigot or valve, through which the tank's liquid can be drained into a lined pit. As explained previously, this liquid is rich in nutrients and is seeded with micro-organisms which are adapted to the environment. The liquid should be used again with the next batch of manure loaded into the digester, the excess being put on the farm land. The capacity of the pit need only be  $\frac{1}{2}$ -1 m<sup>3</sup> for each 10 m<sup>3</sup> of digester space.

FIG. 45. CROSS-SECTION OF MANURE GAS PLANT SHOWING PIPING



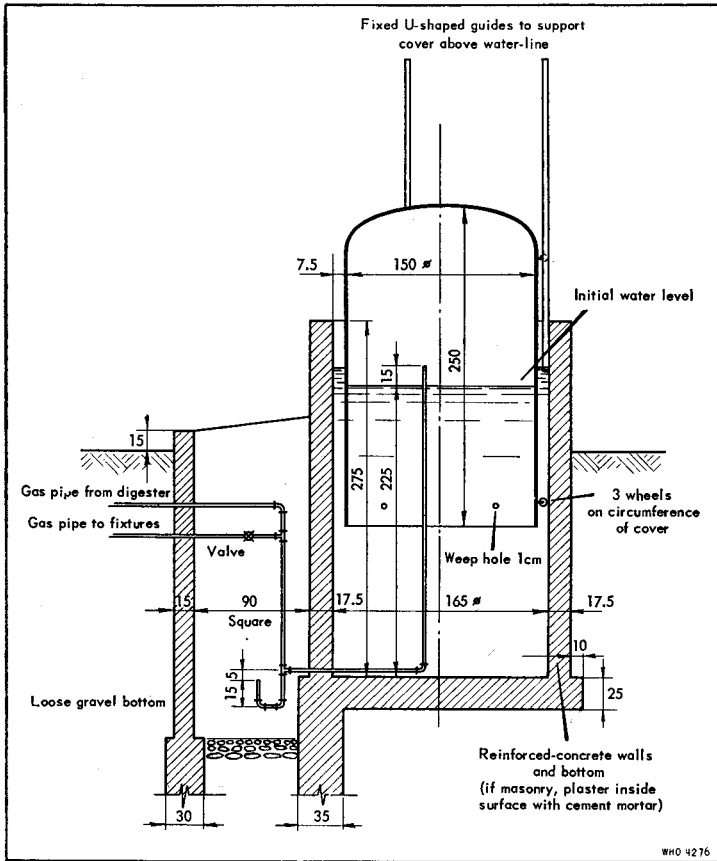
*All measurements are in centimetres.*

### *Gas-holder*

The gas-holder consists essentially of a reinforced-concrete or masonry tank, filled with water and equipped with a floating cover, which moves up and down through the water according to the quantity of gas which it receives from the digester(s) (Fig. 46). The water caught in the annular space between the cover and the tank walls maintains a permanent seal against any escape of gas. The gas-holder may be any shape, but circular is usually the most satisfactory.

Under the pressure of gas arriving from the digester, the cover moves upwards, the water under it is pressed downwards, and, at the same time, the water level in the annular space between the cover and the tank's

FIG. 46. CROSS-SECTION OF GAS-HOLDER SHOWING GAS-LINE DRAIN

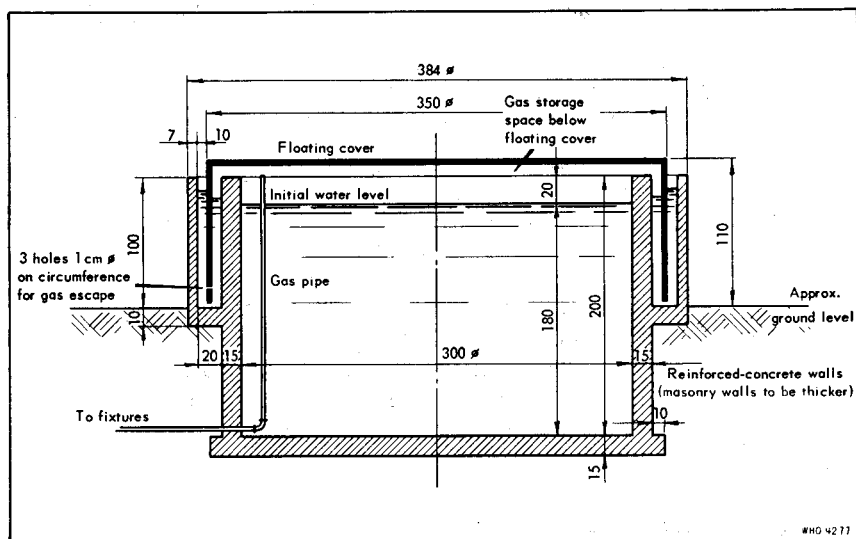


*All measurements are in centimetres.*

walls moves upwards, the difference in water levels corresponding to the actual pressure of gas stored under the cover. In designing floating covers for digesters, allowance should be made in the freeboard on the tank to account for the difference in water elevation inside and outside the cover (Fig. 47).

The tank should preferably be sunk in the ground for structural reasons, and to help in preventing freezing of the water in cold climates. It is good practice to build the tank walls slightly higher than the bell-shaped cover. The cover is usually made of sheet iron, 2-3 mm thick, and should be strengthened and framed with angle iron or cross-braces, otherwise the thin iron sheets may warp and bind against the wall surfaces of the tank.

FIG. 47. CROSS-SECTION OF MANURE DIGESTER WITH FLOATING COVER FOR GAS-HOLDER



*All measurements are in centimetres.*

It is also necessary to guide the floating cover in its vertical movements. This is done by the installation of a system of rollers and U-shaped iron guides, fastened to the cover by welding or other means. Cylindrical floating covers require three guides, while rectangular covers need a minimum of four. It is also desirable to provide one or more weep-holes 5-8 cm from the bottom of the bell cover through which excess gas may escape when the gas-holder is full and has reached the top of its run.

It is the weight of the floating cover which imparts pressure to the gas. If the cover is too heavy, it may be necessary to install a counter-weight system to reduce excessive gas pressure at points of use. If, on the contrary, the cover is too light, additional weight is necessary to provide the recommended gas pressure of 10-20 g per cm<sup>2</sup> (4-8 inches of water) at the outlet of the gas-holder, assuming that the latter is situated at a reasonable distance from the house and the apparatus which it serves. A heavy concrete cover might be used if counter-weights on pulleys were provided to reduce the pressure. A cover with a thin shell of concrete reinforced with a woven bamboo strip basket could be built, but it would be rather heavy for placing in the gas-holder and any cracks developed in handling would cause it to leak gas.

The following is an example of the determination of gas pressure in the circular gas-holder illustrated in Fig. 44. It has been assumed that the cover is built of sheet iron 2 mm thick, weighing 16 kg per m<sup>2</sup>.

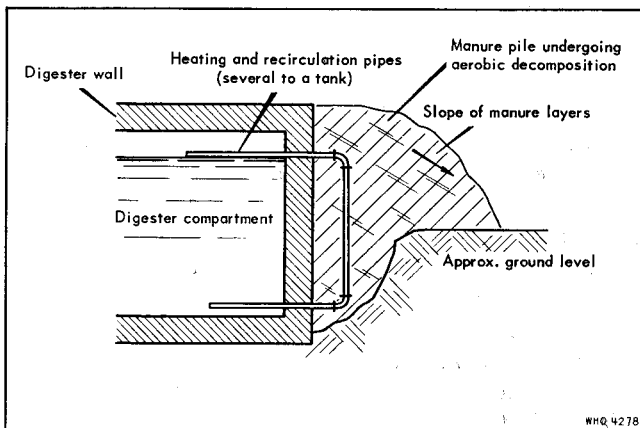
Area of top of floating cover = 2.54 m<sup>2</sup>  
 Area of walls of floating cover = 12.72 m<sup>2</sup>  
 Total surface area of floating cover = 15.26 m<sup>2</sup>  
 Weight of cover's shell = 15.26 × 16 = 244 kg  
 Weight of shell reinforcement and iron guides = 56 kg (approximately)  
 Total weight of floating cover = 300 kg  
 Pressure of gas = total weight divided by surface area of top of cover  
 = 300/2.54 = 118 kg per m<sup>2</sup> = 11.8 g per cm<sup>2</sup>

The piping of the gas-holder can be conveniently arranged in the manner shown in Fig. 45 and 46. A single gas pipe enters at the bottom and serves both to bring in the gas from the digester and to convey it to the points of use. The trap mounted at the lowest point on the gas piping in the adjoining pit collects and evacuates water condensation from the gas piping.

#### *Heating of digesters and gas-holders*

Various systems have been designed for insulating or heating digesters and gas-holders in cold climates. For insulation purposes, double walls are sometimes built, the annular space being filled with straw, sawdust, or fibre-glass. The simplest and most economical method of heating tanks consists in surrounding them with a manure pile of one metre, or more, thickness, as shown in Fig. 48. The pile is built in layers leaning

FIG. 48. CROSS-SECTION OF DIGESTER WITH MANURE PILE FOR HEATING



*Note that the pipes are embedded in the manure pile.*

against the tank's outside surfaces, but sloping away from them. In this way, the heat generated in the pile is deflected upwards and sideways towards the tank walls. The top of the tank may also be covered with such a manure pile. The latter should be renewed every 2-3 months, in order to make use of its maximum heating potential.

This method may be improved by heating the digester's liquid through the heat generated in an outside manure pile and recirculating it by means of pipes installed as shown in Fig. 48. The heated liquid enters the tank at the top, the cold layers at the same time being drawn into the lower branches of the pipes. In this way, constant recirculation is ensured.

In large installations some of the gas can be used to heat water in a boiler; the hot water is then circulated through heat-exchange coils in the digester.

### Operation of Digesters

#### *Materials and initial loading*

Considerable care should be exercised in putting a plant into operation. Until the conditions have become satisfactory for the growth of large numbers of the types of organisms necessary for good anaerobic decomposition and methane production, there is a danger of acid formation, which will retard digestion and inhibit gas production. In first starting a digester, material which has been partly decomposed by aerobic fermentation for a period of 1-2 weeks should be introduced. This initial aerobic fermentation will eliminate some of the components which may cause production of acids. After loading, the material should be allowed to ferment aerobically for a further period of about three days to develop a high temperature. If available, it is best to add some digested humus and liquid from another plant which has been in operation and producing gas for some time. The remaining volume of the digester is then filled with water.

After the tank has been sealed to provide anaerobic conditions, the material will undergo a maturing period of several days before gas production starts. If the initial material is not satisfactorily decomposed and seeding from another tank is not possible, acid conditions can develop and it may be a month or more before the conditions become favourable for gas production. The addition of lime or of an alkali or ammonium phosphate will help to correct an acid condition and facilitate earlier gas production. Horse and cow manures are more alkaline, and usually less difficulty will be experienced if the digester is started with these materials after partial aerobic decomposition.

The desirable pH is in the range of 6.8 to 7.5, with an optimum value above 7.0. If by some rare circumstance the initial material is highly alkaline, i.e., pH up to 9.5, the pH will soon be lowered by the  $\text{CO}_2$  produced by decomposition. Hence the need for correction of the initial pH by the addition of acid is extremely unusual. In no case should sulfuric acid be added since it would contribute to hydrogen sulfide production.

The conditions for good decomposition and gas production will be established more rapidly if the temperature can be maintained near  $35^\circ\text{C}$ . While it is not necessary to have this high temperature for developing digestion, it is most desirable to maintain a temperature of above  $20^\circ\text{C}$  during the initial stages.

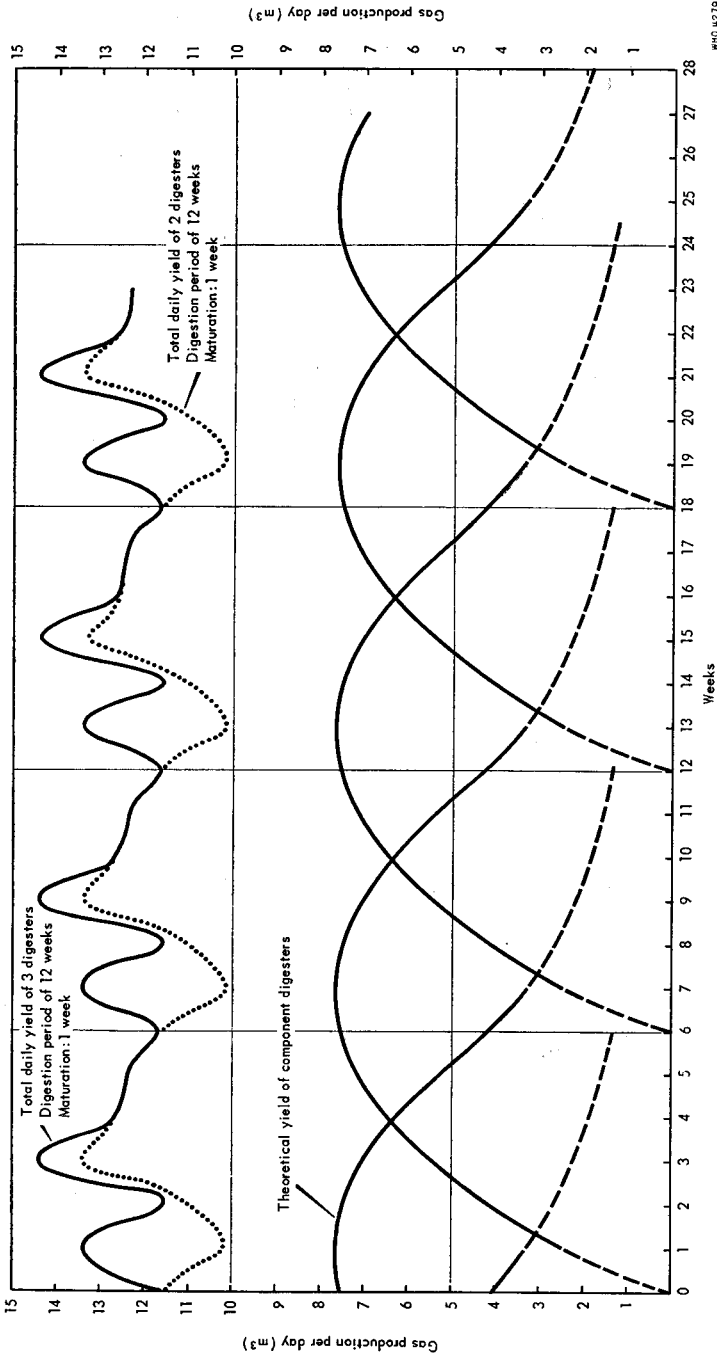
The valve on the pipe to the gas-holder should be closed while digestion is being established. The pet-cock which precedes it should be open to permit any air in the tank to escape as decomposition starts. After two or three days gases of decomposition, containing mostly carbon dioxide, will begin to escape. An attempt to ignite the gas should then be made. The pet-cock can then be closed. Further attempts to determine whether methane production has started should be made daily by trying to ignite the gas as it escapes when the pet-cock is opened. It will take one or two weeks or often longer to establish the production of a satisfactory gas, the time depending upon the temperature and the success in avoiding the development of initial highly acid conditions in the digester. When the escaping gas will provide a continuous flame it is ready for use, and the valve to the gas-holder and distribution lines should be opened, and the pet-cock closed.

The rate of gas production may be determined when desired by diverting all the gas to the gas-holder for a known time and noting the change in volume, e.g., if one cubic metre of gas were collected in the gas-holder during 6 hours, the gas production would be  $4 \text{ m}^3$  per day.

#### *Duration of digestion for maximum gas production*

During the digestion period, at any temperature, the rate of gas production in a batch operation will gradually increase at first, will then reach a maximum-rate plateau, and will finally decrease when a large part of the material has undergone decomposition. At the higher temperatures the rate of gas production will be greater and the digestion cycle will be shorter. The total amount of gas produced per ton of material in a cycle will, however, be approximately the same for temperatures from  $15^\circ$  to  $35^\circ\text{C}$ . At  $15^\circ\text{C}$  the cycle would be about 12 months while at  $35^\circ\text{C}$  it would be about one month.

FIG. 49. GAS PRODUCTION FROM MULTIPLE DIGESTERS



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Since the rate of gas production from a single digester is greatest during the middle part of the digestion cycle, it is desirable when two or more digestion tanks are used to stagger the digestion cycles so that the maximum rate of gas production for one tank will occur at the time when the rate for the other tank or tanks is low. When three or more digesters are used, gas production can be maintained at a quite uniform rate, as illustrated in Fig. 49. The operation of digesters of the type shown in Fig. 41-43 on a more or less continuous basis, by intermittently charging and removing material through the latrine-submerged inlet, will result in a continuous rate of gas production.

In relatively warm areas, or when an outside source of heat is provided, the digestion period will be 2-3 months for most efficient utilization of plant capacity. In cooler areas where the digester temperature averages about 20°C a digestion period of 4-6 months may be the most efficient. At the end of these periods about 70%-80% of the gas available from the materials has been evolved.

#### *Emptying and reloading*

Before a digester is emptied, the valve in the gas line should be closed and the pet-cock opened to let the remaining gas escape. The digesters are emptied by removing the cover and forking out the decomposed material. Special attention must be paid to not smoking, lighting matches, or creating sparks, which would ignite the gas in the digester when it is first opened. After the gas has been completely diluted with air there is no danger of ignition or explosion. However, when the digester tank has been emptied and only a little material remains, care should be taken to permit the gas generated by the remaining material to escape and not accumulate in the tank. The cover should be left off and air fanned into the tank before working inside it or reloading.

About 5-10 cm of digested humus, and about half of the liquid, should be left in the digester to provide seeding for the next load. When three or more digesters are used, the liquid from a tank which is ready for emptying can be transferred to a tank which is loaded and ready to start digesting, to facilitate the development of conditions for gas production.

The digester is usually filled by forking manure and other materials from accumulated piles or from the stable. If the plant has three or more digesters, one can be left open for filling as the necessary materials accumulate, and digestion again started when the tank is filled. In large installations it will be economical to convey the manure and wastes from the barn and dump them in an empty digester by means of a moving bucket on a tight cable or overhead rail. A crane-type frame and clam-shell-type bucket can be used to remove the material from the digester.

After the cover has been sealed to prevent entrance or escape of air, the operation is similar to that described for the initial starting of a digestion tank. The valve to the gas-holder is left closed and gas from the pet-cock is sampled daily to determine when gas production has again started. In the case of reloading a tank, gas production will start quite soon because of the digested humus and liquid which were left in the tank.

When removing humus from a digester such as that shown in Fig. 42 and 43, which is more or less continuously operated, care should be taken to collect material from the bottom which has been reasonably decomposed and to avoid lowering the water level below the baffle seal. When night-soil is added to this type of installation and two digester compartments are used, the additions to a compartment should cease at least a month or more before it is emptied. If the latrine is combined with the digestion tank, this may be accomplished by providing latrines on both tanks which can be used alternately.

In areas where the temperatures may occasionally drop below freezing-point, a one-centimetre layer of oil on the water surface of the gas-holder will help to prevent the formation of a layer of ice, which would stop the operation of the gas-holder. This layer of oil will also protect the gas-holder cover from corrosion. Straw or manure insulation of the gas-holder is effective against freezing.



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