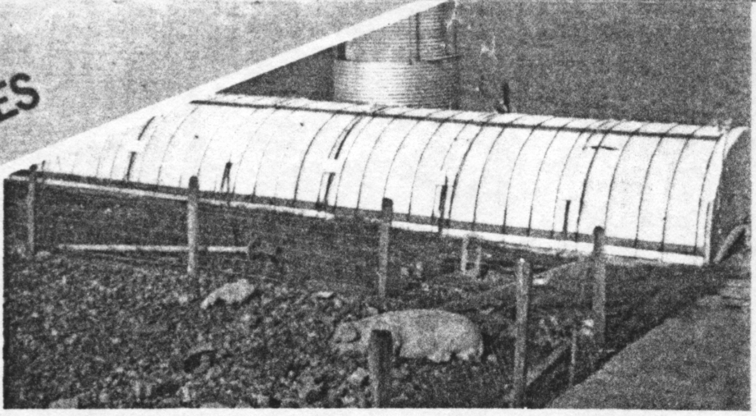

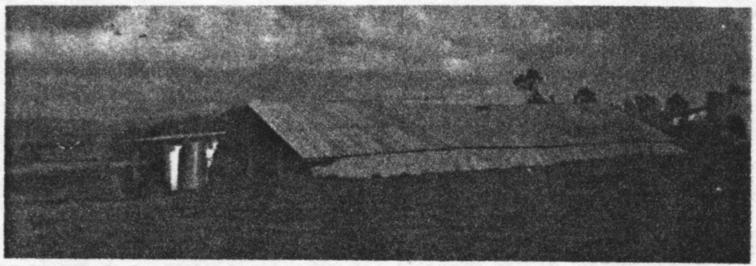

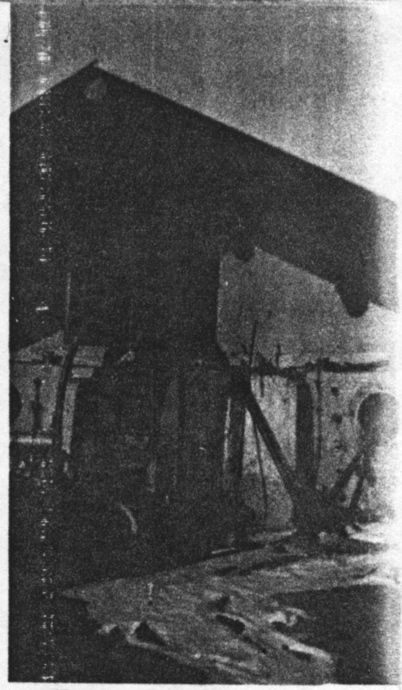

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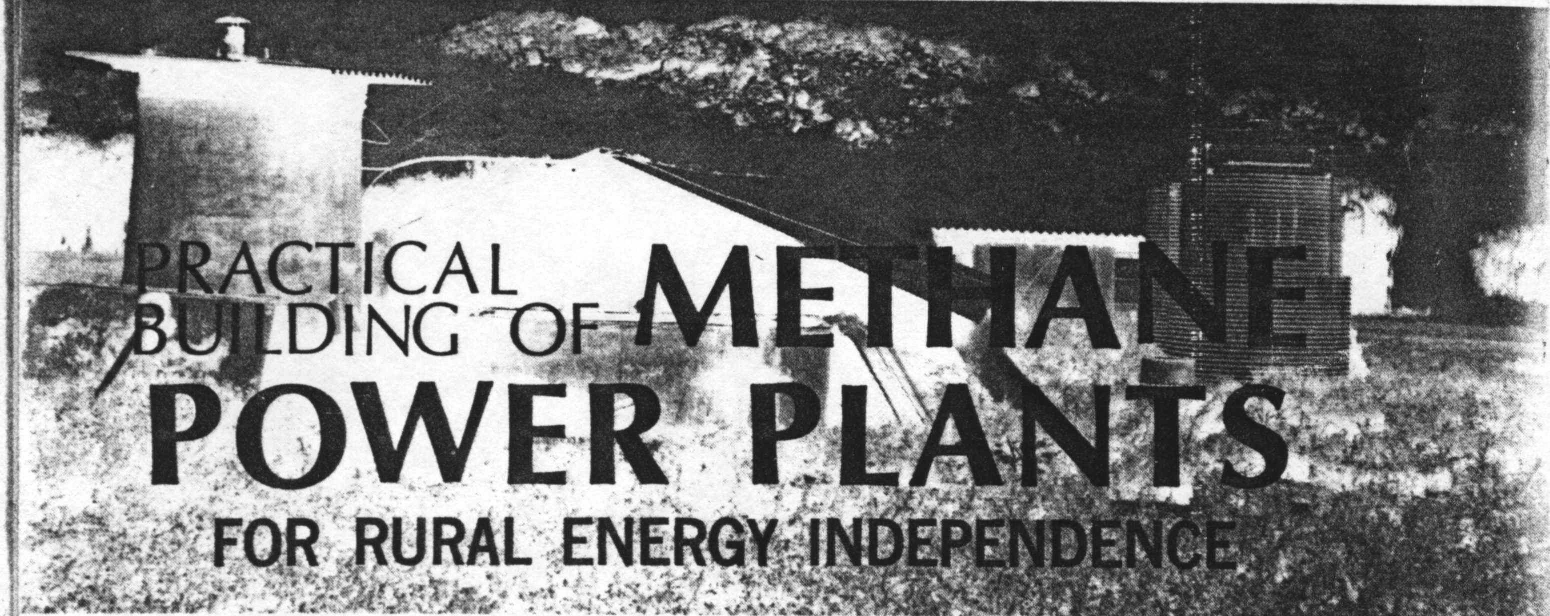
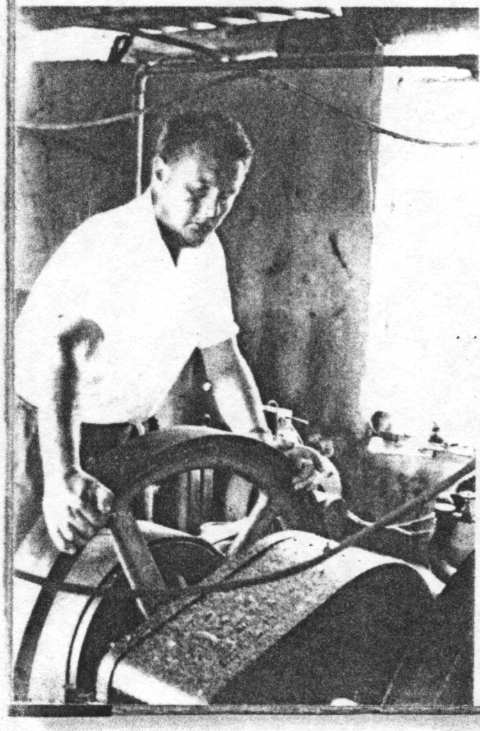
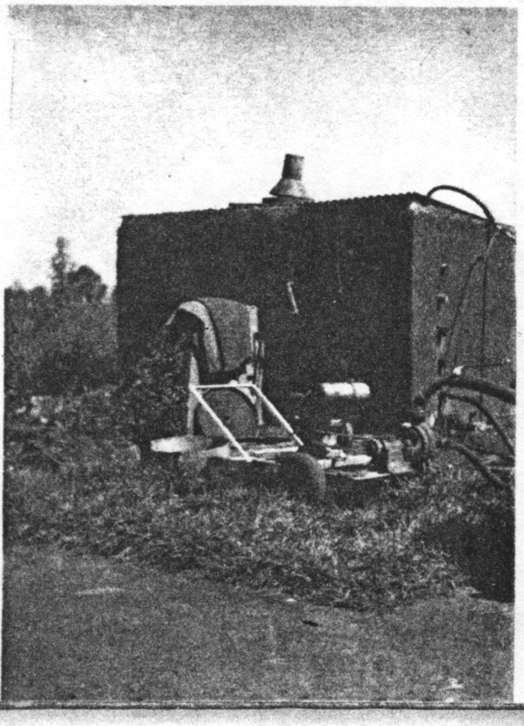


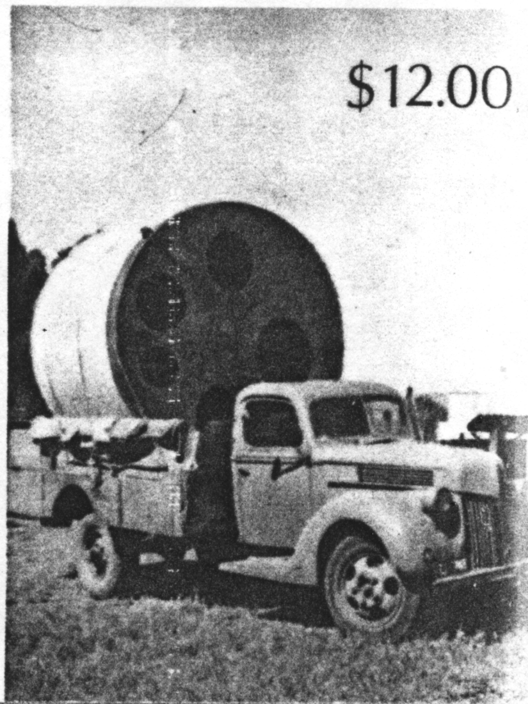
PRACTICAL BUILDING OF METHANE POWER PLANTS

FOR RURAL ENERGY INDEPENDENCE

By L. John Fry – Pioneer of the First Displacement Digester







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- **ANALYZING** the **economics** of methane power plant operation.
- **PROMOTING** a new-age technology wherein waste organic matter is **recycled** to produce fuel and fertilizer (hence food) while helping clean up the environment.

FIGURES:

FIGURES (on my S. African farm):
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METHANE DIGESTERS

FOR FUEL GAS AND FERTILIZER

L. JOHN FRY
1223 North Nopal Street
Santa Barbara, Calif. 93103

WITH COMPLETE INSTRUCTIONS FOR TWO WORKING MODELS

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My thanks go also to the thousands of people in this country and abroad who have written and telephoned me to offer encouragement, moral support, and feedback on my continuing work.

DEDICATION

To my wife Joan who worked to support the family while I struggled to bring out the potential benefits of methane power plants, helped to write the book, and encouraged me through years of frustration. To my daughters, Carol, Wendy and Merle for their interest and forbearance, and to my parents (both now deceased) Rev. L.G.P. Fry, MA (Cambridge) and Elizabeth Fry for teaching me to observe.

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METHANE DIGESTERS
For Fuel Gas and Fertilizer

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Introduction

In my lifetime I have been witness to the scramble for fuel in many forms — from Nomads scouring the last twigs of vegetation in a parched African desert to despairing miners scratching at the dreary recesses of Welsh coal mines. I have seen the oil-slicked beaches that are results of today's fortune hunts. The prospects are worse, with grim pictures of our planet torn to pieces for shale and yet more coal, and irradiated with lethal nuclear matter from the accident that is inevitable sooner or later. The crisis of fuel is stated in deadly terms with reference both to lives and economies of nations.

This book shows another path — one Mother Nature devised at the very beginning of time and one too-long ignored. This path has always been a gentle approach toward a prime requisite of this century — power. It is an ecologically sound path.

Microscopic methane bacteria, among the earliest forms of life on this planet, are nature's agents for breaking down wastes in conditions where air cannot penetrate, such as in bodies of water. Yet this prehistoric life can help solve three major problems facing the 20th century: The need for energy, for fertilizer, and for an end to one form of pollution. That help is at hand now; it is available simply, inexpensively, and without a great deal of further initial research.

The abundantly available manure produced by animals in the U.S., once digested in methane power plants, could supply all the power needs of every tractor and combine in this country, and still leave over 50% for other uses such as crop drying. Or it could supply 7% of the natural gas consumed in 1971 (statistic from U.S. Bureau of Mines).

I claim that back in 1957 I pioneered a means to harness, control, and accelerate nature's own methods by studying the ideal conditions for the bacteria to work and multiply, and by adapting those principles to practical application. A drainage sump on my farm provided a means to observe methane bacteria in action. It was the exercise of that power of observation that led to a chain of thoughts. Also, I soon discovered that unlike other forms of fermentation where a batch of raw material goes through a cycle and stops, methane fermentation continues indefinitely, given regular feeding and the right conditions.

Complex, space age technology is not required. The production of methane gas through the fermentation of waste is relatively simple and although technical treatises exist on the complex biological processes that take place in methane digestion, one need not think that these microbes are beyond the comprehension of mere mortals, or only within the ken of trained sewage plant engineers. Far from it! A head hunter in Borneo could get to understand that an inner tube digester requires the loading of just one shovelfull of manure per day to function at peak performance, but that four shovels per day, or just a fistfull, would not work.

Animal manure is ideally suited to the methane-digestion process in that it is a waste product to start with; it is finely ground up and ready for the bacterial "attack", and it is available in everlasting quantity — unlike the fossil fuels we have all squandered for so many decades. Manure is an efficient source of methane gas: One pound of it will yield five cubic feet of gas. This means that 100 tons (dry weight) of manure could yield one million cubic feet of gas of 120 octane rating usable in all ways energy is used. Other organic raw materials also hold the potential to replace millions of barrels of oil imported daily. However, there are pitfalls to digestion, and in this book I will explain how to deal with them.

My role in all this is as an innovator and it is my sincere hope that this book will serve as a guide to prospective builders of methane power plants all over the world. Seeing a plant starting up has a peculiar, singular fascination for me and I know others wish to share it. I discovered long ago that though much work on methane bacterial decomposition had been done in laboratories, and that still more had gone into the writing of theoretical aspects, not much was known about the practical side of the subject. As an R.A.F. pilot, turned farmer, turned innovator, I offer you, then, the results of that pioneering work on the production of methane gas from animal manure, started some 18 years ago on my South African farm where, besides investing time, effort and money I discovered I would have to roll up my sleeves and not be afraid to get my hands, wrists, and even elbows dirty.

L. JOHN FRY

Glossary of Terms

Algae: Primitive plants, one or many celled, usually aquatic and capable of elaborating their foodstuffs by photosynthesis.

Bacteria: Primitive organisms, generally free of pigment, which reproduce by dividing in one, two or three planes. They occur as single cells, groups, chains or filaments, and do not require light for their life processes. They may be grown by special culturing out of their native habitat. For purposes of this book, bacteria is broken down into three sub-catagories:

- **Aerobic** — bacteria which require free (elementary) oxygen for their growth.
- **Anaerobic** — bacteria which grow in the absence of free oxygen and derive oxygen from breaking down complex substances.
- **Pathogenic** — bacteria which can cause disease.

Buffer: The action of certain solutions in opposing change of composition, especially of hydrogen-ion concentration (measured by pH).

Digester: A tank in which solids are stored for the purpose of permitting anaerobic decomposition to the point of rendering the product nonputrescible and inoffensive. Erroneously called digestor.

Effluent: A liquid which flows out of a containing space. In this case processed slurry in the form of sludge and/or supernatant.

Fermentation: Anaerobic decomposition.

Humus: The dark or carboniferous residue in the soil resulting from the decomposition of vegetable tissues of plants originally growing therein.

Lagoon, sludge: A shallow basin or natural depression used for storage or digestion of manures (once called a cesspool).

Liquor: Any liquid.

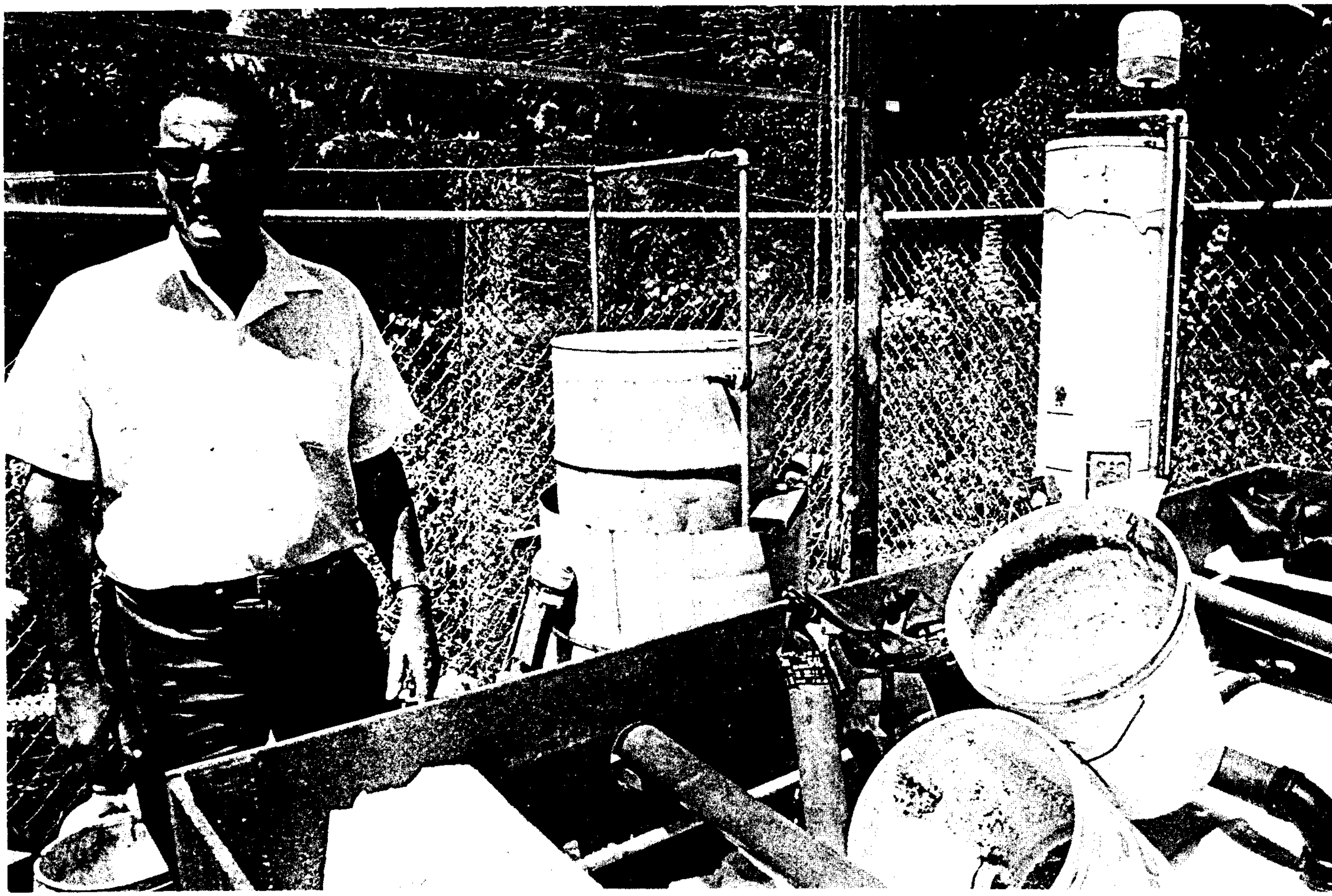
Loading: The feeding in of raw material to a digester.

Loading Rate: The amount fed in relation to time.

Photosynthesis: Synthesis by green plants of organic compounds from water and carbon dioxide using energy absorbed from sunlight.

Scrubbing: Removal of carbon dioxide, sulphur compounds, water vapour and other gases which are produced during the digestion in addition to methane.

Supernatant: Liquid lying above sludge, or above (super) that which is dormant (natant).



Mr. L. John Fry beside a three digester unit he made in 1973. Gas holder center, water-heater on the right. Buckets in the foreground were for loading raw materials. This unit was taken down in 1974.

Recently, attention has turned to methane digesters as a source of fuel gas and fertilizer. The interest is understandable in view of the mounting shortages of energy sources (whether real or political) and the increasing desire of many to develop a more self—sufficient pattern of living...... especially in rural areas.

However, much of the information concerning digesters and digester systems has been misleading and overly complex. It has avoided basic questions such as: how much raw organic material can be expected from the plant or animal wastes available? How much gas will they produce? What kind and size of digester should be built? (so that it suits the needs and resources of whoever builds it). And how is the digester started?

The answers to these questions aren't that difficult, and we have found that productive digester operations can be built and maintained by knowing some things about the biology of digestion, and the properties of the raw materials going into the digester. Of course, this knowledge is useless without direct experience with small-scale models (which can be constructed cheaply from easily available materials). Once the digester is understood at this level, larger units can be built with more sophisticated ways of using methane gas energy and recycling sludge back into the biological systems.

In this newsletter we would like to: (1) present a general background of the raw materials and processes of digestion; (2) discuss some preliminary ideas for using methand gas and sludge; (3) describe two designs for building simple working models of digesters; and (4) develop feedback from readers who are working on digester projects across the country.

BACKGROUND

When organic material decays it yields useful by-products. The kind of by-product depends on the conditions under which decay takes place. Decay can be aerobic (with oxygen) or anaerobic (without oxygen). Any kind of organic matter can be broken down either way, but the end products will be quite different (Fig. 1).

It is possible to mimic and hasten the natural anaerobic process by putting organic wastes (manure and vegetable matter) into insulated, air-tight containers called digesters. Digesters are of two types: (1) Batch-load digesters which are filled all at once, sealed, and emptied when the raw material has stopped producing gas; and (2) Continuous-load digesters which are fed a little, regularly, so that gas and fertilizer are produced continuously.

The digester is fed with a mixture of water and wastes, called "slurry." Inside the digester, each daily load of fresh slurry flows in one end and displaces the previous day's load which bacteria and other microbes have already started to digest.

Each load progresses down the length of the digester to a point where the methane bacteria are active. At this point large bubbles force their way to the surface where the gas accumulates. The gas is very similar to natural gas and can be burned directly for heat and light, stored for future use, or compressed to power heat engines.

Digestion gradually slows down toward the outlet end of the digester and the residue begins to stratify into distinct layers (Fig. 2).

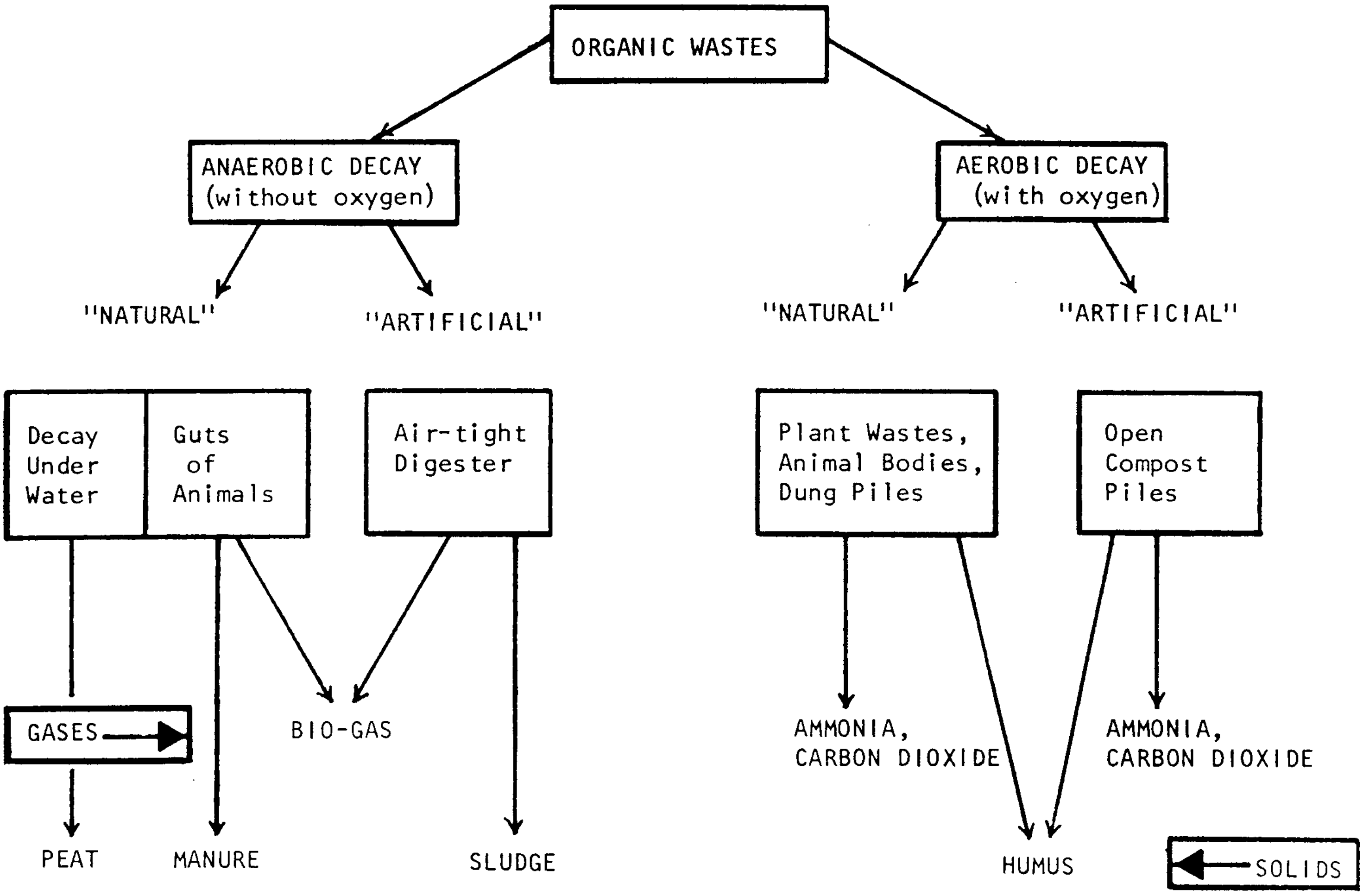


FIG.1 End Products of Organic Decay

Sand and Inorganic Materials at the bottom.

Sludge, the spent solids of the original manure reduced to about 40% of the volume it occupied in the raw state. Liquid or dry sludge makes an excellent fertilizer for crops and pond cultures.

Supernatant, the spent liquids of the original slurry. Note that the fertilizing value of the liquid is as great as sludge, since the dissolved solids remain.

Scum, a mixture of coarse fibrous material, released from the raw manure, gas, and liquid. The accumulation and removal of scum is one of the most serious problems with digesters. In moderate amounts, scum can act as an insulation. But in large amounts it can virtually shut down a digester.

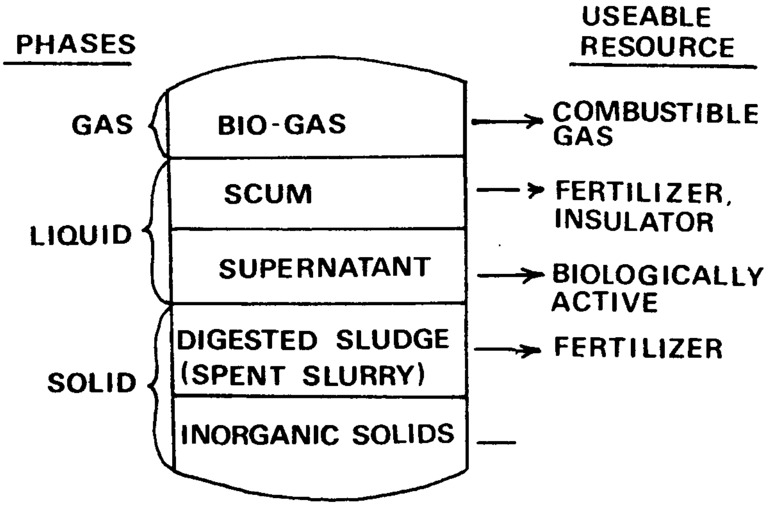


FIG.2 Layering of By-Products In the Digester

For perspective, consider the total fuel value of methane that could be produced from the available organic wastes in the United States.

I.	Fuel Value of U.S. Methane Resources (From Ref. 1)	
A.	Organic wastes in U.S./year	2 billion tons (wet weight) 800 million tons (dry weight)
B.	Dry organic waste readily collectable	136.3 million tons
C.	Methane available from "B" (@10,000 ft^3/ton)*	1.36 trillion ft^3/year
D.	Fuel value of methane from "C" (1000 BTU/ft^3)	1,360 trillion BTU/yr
II.	Fuel Consumption of U.S. Farm Equipment (From Ref. 2)	
A.	Total gasoline consumed (1965)	7 billion gallons/year
B.	Total energy consumed by "A" (1 gallon gasoline = 135,000 BTU)	945 trillion BTU/year
III.	Total U.S. Natural Gas Consumption (1970)	19,000 trillion BTU
IV.	Total U.S. Energy Consumption (1970)	64,000 trillion BTU

*Urban refuse; higher figure for manure and agricultural wastes.

Table 1. Total Fuel Value of U.S. Methane Resources Supplied by Digestion of Readily Collectable, Dry, Ash-Free Organic Wastes.

So, speaking generally, methane gas converted from easily available organic wastes could supply about 150% of the gasoline energy used by all U.S. farm equipment (1965), 7% of the 1970 natural gas energy, and 2% of the total 1970 U.S. energy demands.

Methane-Gas Plant: Synergy at Work

When we consider digesters on a homestead scale, there are two general questions to ask: (1) with the organic wastes and resources at hand, what kind of digester should be built, and how big should it be? and (2) what is the best way of using the gas and sludge produced to satisfy the energy needs of the people involved? (whether the sludge should be used to fertilize crops, fish or algae ponds, and whether the gas should be used directly for heat, and light, or stored, or fed back to the digester to heat it, etc. Fig. 3).

The first question involves the digester itself, which is just the heart of a whole energy system. The second question is synergistic; you can choose which products are to be generated by digestion and how to use them or feed them back to the digester, creating an almost endless cycle if you wished (Fig. 4).

The model in Figure 4 is idealized from oriental aquaculture systems and other ideas, both old and new. A single pathway can be developed exclusively (have your digester produce only sludge to feed an algae pond) or you can develop the potential synergy (many possible systems working together as an integrated whole, Fig. 5).

* * *

The small farmer or rural homesteader can take a step toward ecological self-sufficiency by producing some of his fuel and fertilizer needs using a digester to convert local wastes.

Total dependence on conventional fuels, especially in rural areas, is likely to become a serious handicap in the years to come as reserve shortages and specialized technologies hike the costs of fossil and nuclear fuels. But by producing energy from local resources, it is possible to be partially freed from remote sources of increasingly expensive fuel supplies.

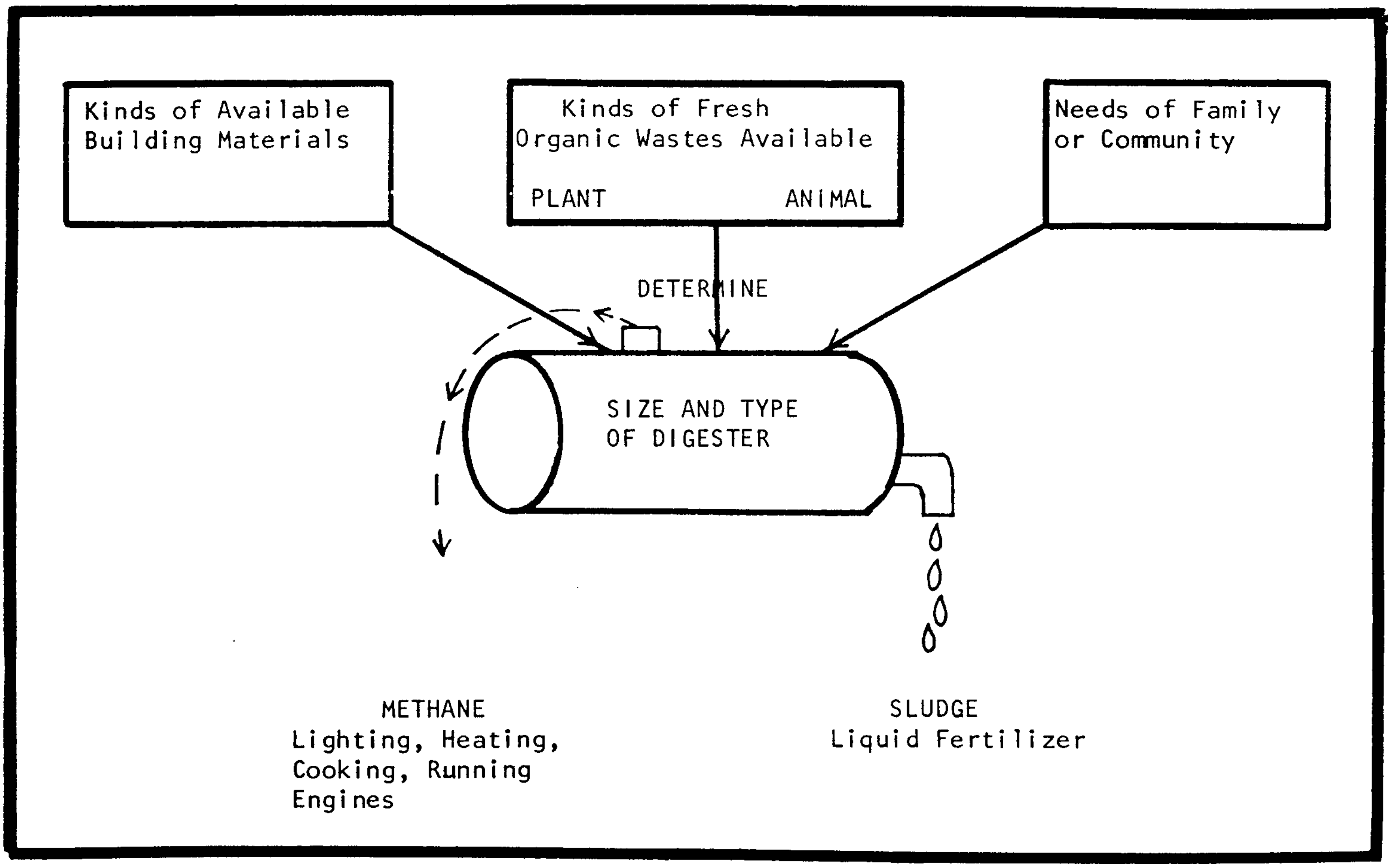


FIG.3 Related Considerations of a Digester Operation

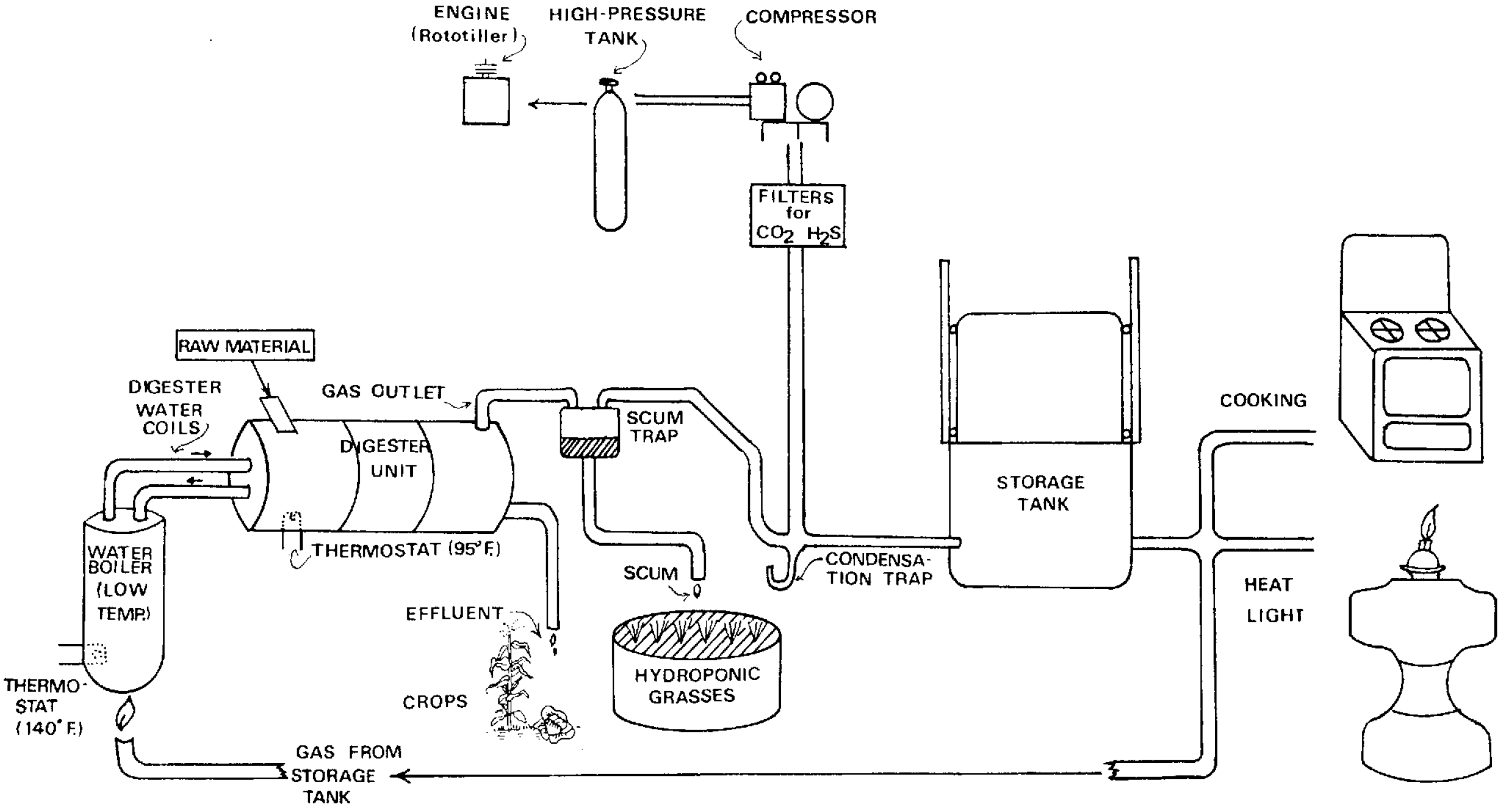
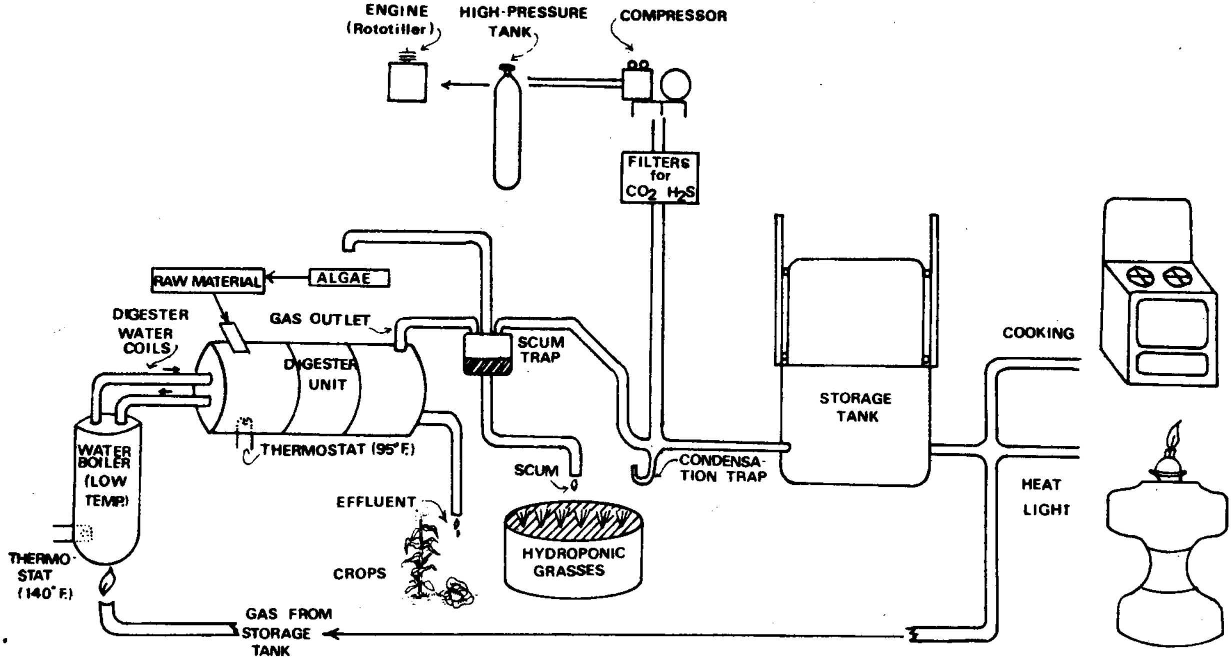


FIG.5 Integrated Organic Digester Operation
(Using 50 gallon drums for digester)


ENGINE
(Rototiller)
HIGH-PRESSURE
TANK
COMPRESSOR
FILTERS
for
CO_2 H_2S
RAW MATERIAL
ALGAE
DIGESTER
WATER
COILS
GAS OUTLET
DIGESTER
UNIT
SCUM
TRAP
STORAGE
TANK
COOKING
WATER
BOILER
(LOW
TEMP.)
THERMOSTAT (95° F.)
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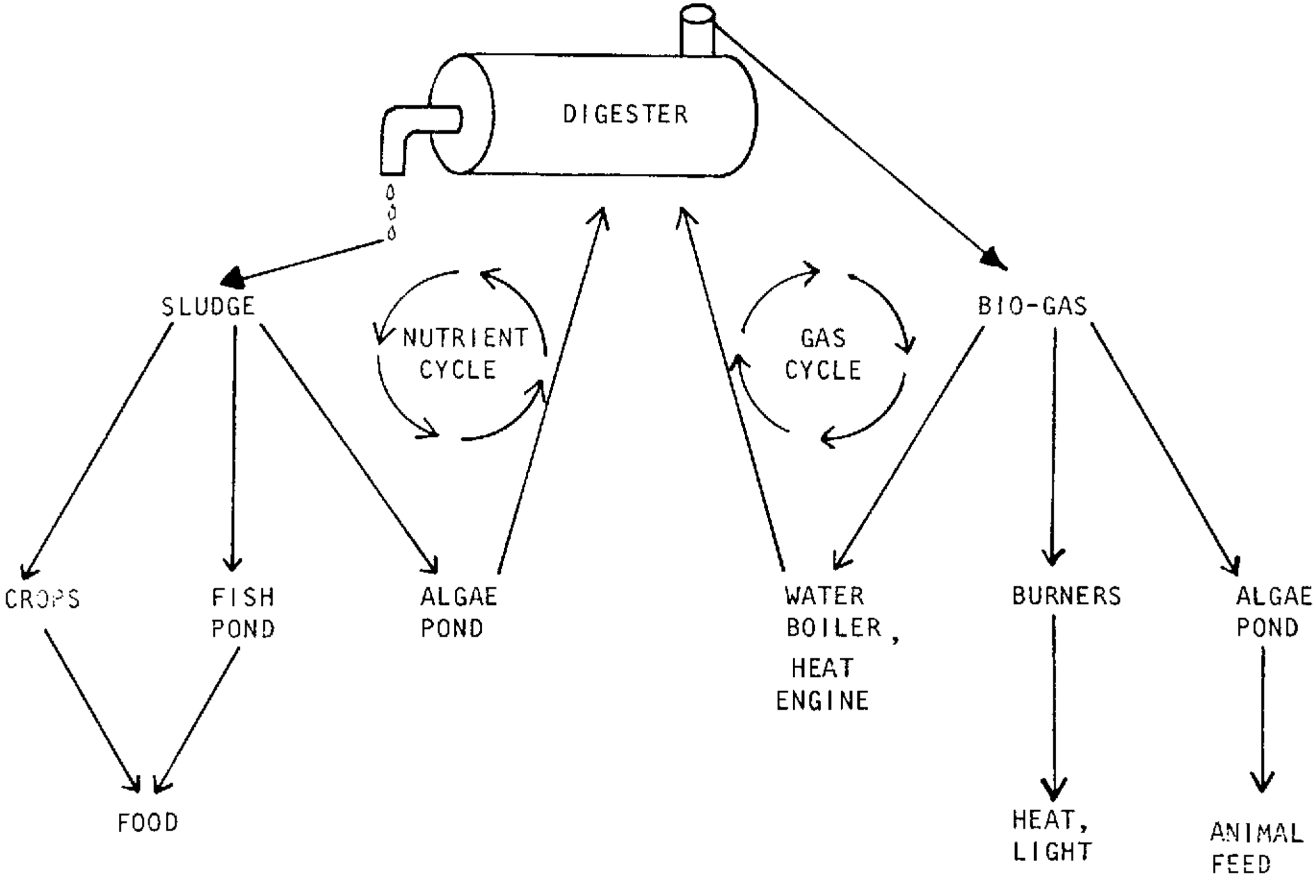


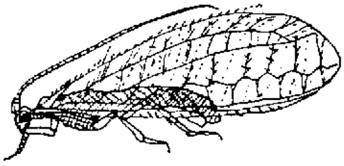


FIG.4 The Closed Nutrient System of a Complete Digester Operation

HISTORY

In nature, anaerobic decay is probably one of the earth's oldest processes for decomposing wastes. Organic material covered by a pool of warm water will first turn acid and smell rank, then slowly over about six months will turn alkali. The methane bacteria, always present, will take over and decompose it, and gas bubbles will rise to the surface.

Anaerobic decay is one of the few natural processes that hasn't been fully exploited until recent times. Pasteur once discussed the possibilities of methane production from farmyard manure. And (according to a report issued from China April 26, 1960) the Chinese have used "covered lagoons" to supply methane fuel to communes and factories for decades. But the first attempt to build a digester to produce methane gas from organic wastes (cow dung) appears to have been in Bombay, India in 1900. At about this time, sewage plants started digesting sewage sludge in order to improve its quality. This started a mass of laboratory and small-scale experiments during the 20's and 30's (many of them summarized by Acharya, Ref. 3).

During World War II, the shortage of fuel in Germany led to the development of methane plants in rural areas, where the gas was used to power tractors. The idea spread into Western Europe, until fossil fuels once again became available (although, today, many farmers in France and Germany continue to use home digesters to produce their own methane fuel gas).

Currently the focus of organic digester/bio-gas research is in India. India's impetus has been the overwhelming need of a developing country to raise the standard of living of the rural poor. Cows in India produce over 800 million tons of manure per year; over half of this is burned for fuel and thus lost as a much needed crop fertilizer.[4] The problem of how to obtain cheap fuel and fertilizer at a local level led to several studies by the Indian Agricultural Research Institute in the 1940's to determine the basic chemistry of anaerobic decay. In the 1950's, simple digester models were developed which were suitable for village homes. These early models established clearly that bio-gas plants could: (1) provide light and heat in rural villages, eliminating the need to import fuel, to burn cow dung, or to deforest land; (2) could provide a rich fertilizer from the digested wastes; and (3) could improve health conditions by providing air-tight digester containers, thus reducing disease borne by exposed dung.

More ambitious designs were tested by the Planning Research and Action Institute in the late 1950's. Successes led to the start of the Gobar Gas Research Station at Ajitmal where, with practical experience from the Khadi and Village Industries Commission, two important pamphlets[5,6] were published on the design of village and homestead "bio-gas" plants in India.

In America, where the problem is waste disposal, rather than waste use, organic digesters have been limited to sewage treatment plants.[7,8] In some cases sludge is recycled on land or sold as fertilizer,[9,10] and methane gas is used to power generators and pumps in the treatment plants.[11] The Hyperion sewage treatment plant in Los Angeles generates enough methane from its primary treatment alone to power its 24-2,000 hp. diesel engines. Usually, however, both sludge and gas are still regarded as waste problems.

Much information on digestion and small-scale digester operations comes from experiences in India, Western Europe and South Africa and journals such as: Compost Science, Water Sewage Work, Soils and Fertilizer, Waste Engineering, Sewage and Industrial Wastes and recent publications of the U.S. Environmental Protection Agency and Solid Waste Conferences (see Bibliography at end). An excellent book to learn from is called: Manual of Instruction for Sewage Plant Operators, put out by the New York State Dept. of Health and available from the Health Education Service, P.O. Box 7283, Albany, New York 12224.

A great deal of information can be found in pre-WW II sewage journals, especially Sewage Works Journal. After WW II, as with most other kinds of science and technology, waste treatment research became a victim of the trend to make machines ever bigger, and information increasingly incomprehensible.

BIOLOGY OF DIGESTION

Bio-Succession In The Digester

Perhaps the most important thing to remember is that digestion is a biological process.

The "anaerobic" bacteria responsible for digestion can't survive with even the slightest trace of oxygen. So, because of the oxygen in the manure mixture fed to the digester, there is a long period after loading before actual digestion takes place. During this initial "aerobic" period, traces of oxygen are used up by oxygen-loving bacteria, and large amounts of carbon dioxide (CO_2) are released.

When oxygen disappears, the digestion process can begin. That process involves a series of reactions by several kinds of anaerobic bacteria feeding on the raw organic matter. As different kinds of these bacteria become active, the by-products of the first kind of bacteria provide the food for the other kind (Fig. 6). In the first stages of digestion, organic material which is digestible (fats, proteins and most starches) are broken down by acid producing bacteria into simple compounds. The acid bacteria are capable of rapid reproduction and are not very sensitive to changes in their environment. Their role is to excrete enzymes, liquefy the raw materials and convert the complex materials into simpler substances (especially volatile acids, which are low molecular weight organic acids - See Raw Materials Section). The most important volatile acid is acetic acid (table vinegar is dilute acetic acid), a very common by-product of all fat, starch and protein digestion. About 70% of the methane produced during fermentation comes from acetic acid.[12]

Once the raw material has been liquefied by the acid producing bacteria, methane producing bacteria convert the volatile acids

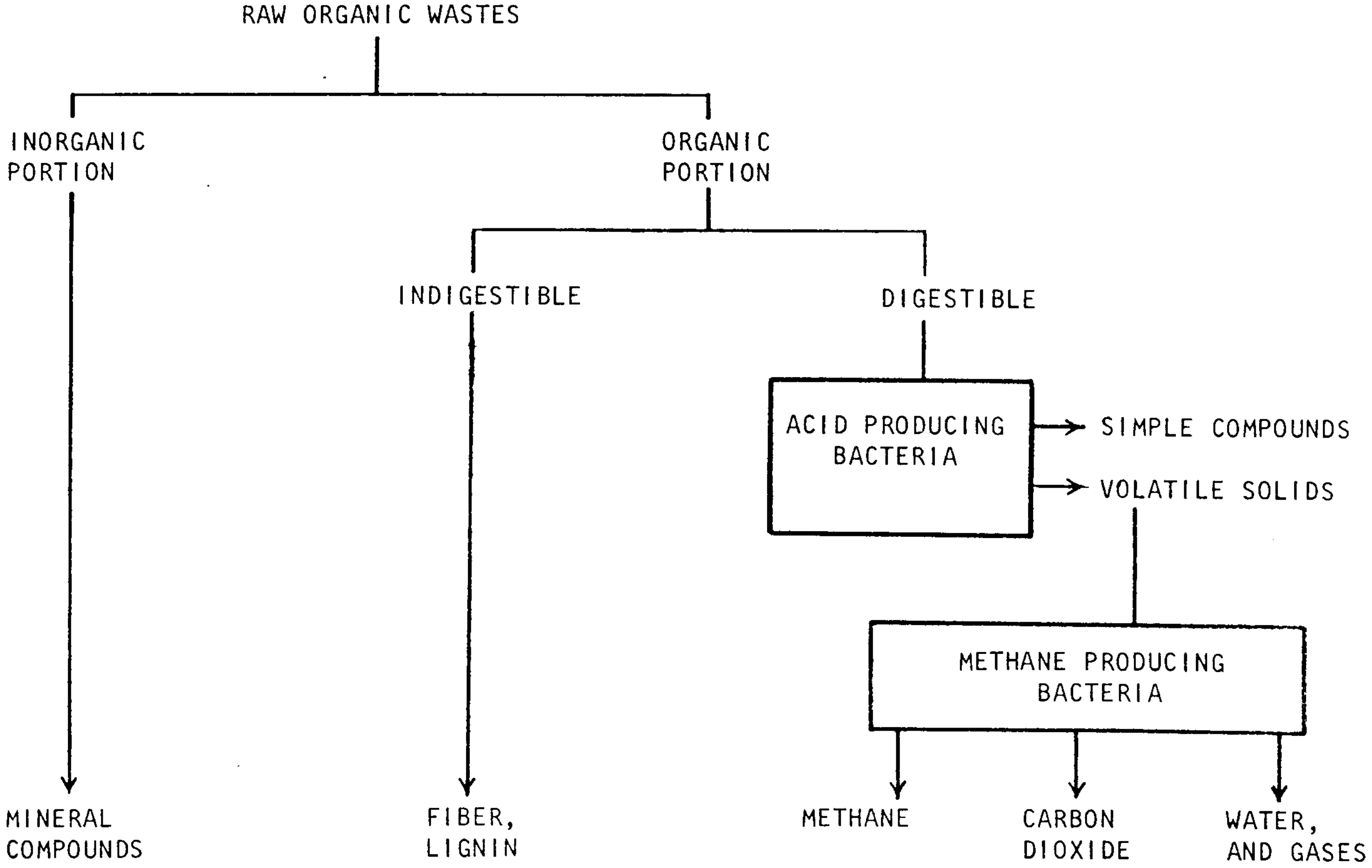


FIG.6 The Biological Breakdown of Wastes in the Digester

into methane gas. Unlike the acid bacteria, methane bacteria reproduce slowly and are very sensitive to changes in the conditions of their environment. (More information on the biology of methane fermentation can be found in Ref. 13 and 14.)

Biologically, then, successful digestion depends upon achieving and (for continuous-load digesters) maintaining a balance between those bacteria which produce organic acids and those bacteria which produce methane gas from the organic acids. This balance is achieved by a regular feeding with enough liquid (see Feeding Section) and by the proper pH, temperature and the quality of raw materials in the digester.

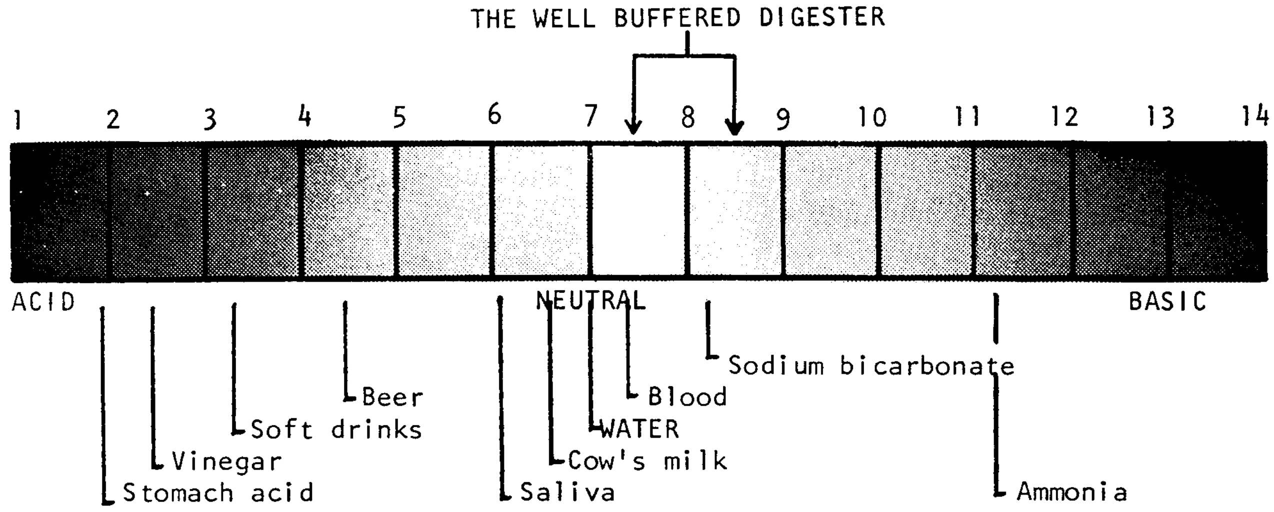


FIG.7 The pH Scale

pH and the Well-Buffered Digester

To measure the acid or alkaline condition of a material, the symbol "pH" is used. A neutral solution has pH = 7; an acid solution has pH below 7; and an alkaline solution has pH above 7. The pH has a profound effect on biological activity, and the maintenance of a stable pH is essential to all life. Most living processes take place in the range of pH 5 to 9. The pH requirements of a digester are more strict (pH 7.5-8.5, Fig. 7).

During the initial acid phase of digestion, which may last about two weeks, the pH may drop to 6 or lower, while a great deal of CO_2 is given off. This is followed by about three months of a slow decrease in acidity during which volatile acids and nitrogen compounds are digested, and ammonia compounds are formed (this ammonia becomes important when we consider the fertilizer value of sludge). As digestion proceeds, less CO_2 and more methane is produced and the pH rises slowly to about 7. As the mixture becomes less acid, methane fermentation takes over. The pH then rises above the neutral point (pH = 7), to between pH 7.5 and 8.5. After this point, the mixture becomes well <u>buffered</u>; that is, even when large amounts of acid or alkali are added, the mixture will adjust to stabilize itself at pH 7.5 to 8.5.

Once the mixture has become well buffered, it is possible to add small amounts of raw material periodically and maintain a constant supply of gas and sludge (continuous load digesters). If you don't feed a digester regularly (batch-load digesters), enzymes begin to accumulate, organic solids become exhausted and methane production ceases.

After digestion has stabilized, the pH should remain around 8.0 to 8.5. The ideal pH values of effluent in sewage treatment plants is 7 to 7.5, and these values are usually given as the best pH range for digesters in general. From our experience, a slightly more alkaline mixture is best for digesters using raw animal or plant wastes.

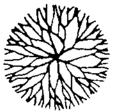
You can measure the pH of your digester with "litmus" or pH paper which can be bought at most drug stores. Dip the pH paper into the effluent as it is drawn off. Litmus paper turns red in acid solutions (pH 1 to 7) and blue in alkaline solutions (pH 7 to 14). You can get more precise measurements using pH paper which changes colors within a narrow range of pH values.

Condition	Possible Reasons	"Cure"
Too acid (pH 6 or less)	1) Adding raw materials too fast 2) Wide temperature fluctuation 3) Toxic Substances 4) Build-up of scum	Reduce feeding rate; Ammonia Stabilize temperature Remove scum
Too Alkaline (pH 9 or more)	1) Initial raw material too alkaline	Patience Never put acid into digester

Table 2. Problems with pH.

If the pH in the continuous-load digester becomes too acidic (Table 2), you can bring it up to normal again by adding fresh effluent to the inlet end, or by reducing the amount of raw material fed to the digester, or as a last resort, by adding a little ammonia. If the effluent becomes too alkaline, a great deal of CO_2 will be produced, which will have the effect of making the mixture more acidic, thus correcting itself. Patience is the best "cure" in both cases. NEVER add acid to your digester. This will only increase the production of hydrogen sulfide.

Temperature



For the digesting bacteria to work at the greatest efficiency, a temperature of 95°F (36°C) is best. Gas production can proceed in two ranges of temperature: 85°-105° and 120°-140°F. Different sets of acid-producing and methane bacteria thrive in each of these different ranges. Those active in the higher range are called heat-loving or "thermophilic" bacteria (Fig. 8). Some raw materials, like algae, require this higher range for digestion. But digesters are not commonly operated at this higher range because: (1) most materials digest well at the lower range, (2) the Thermophilic Bacteria are <u>very</u> sensitive to any changes in the digester, (3) the sludge they produce is of poor fertilizer quality, and (4) because it is difficult to maintain such a high temperature, especially in temperate climates.

The bacteria that produce methane in the "normal range" 90°-95°F are more stable and produce a high quality sludge. It is not difficult to maintain a digester temperature of 95°F (See Digester Heating Section).

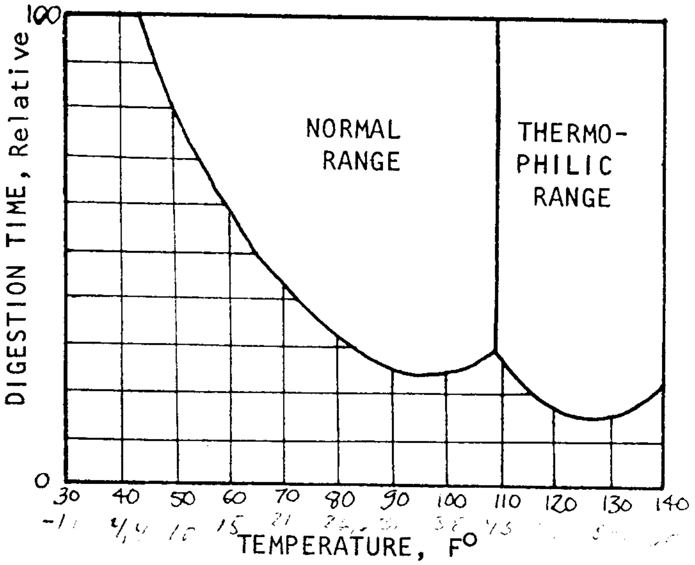


FIG.8 Digestion Time and Temperature

(after Ref. 7)

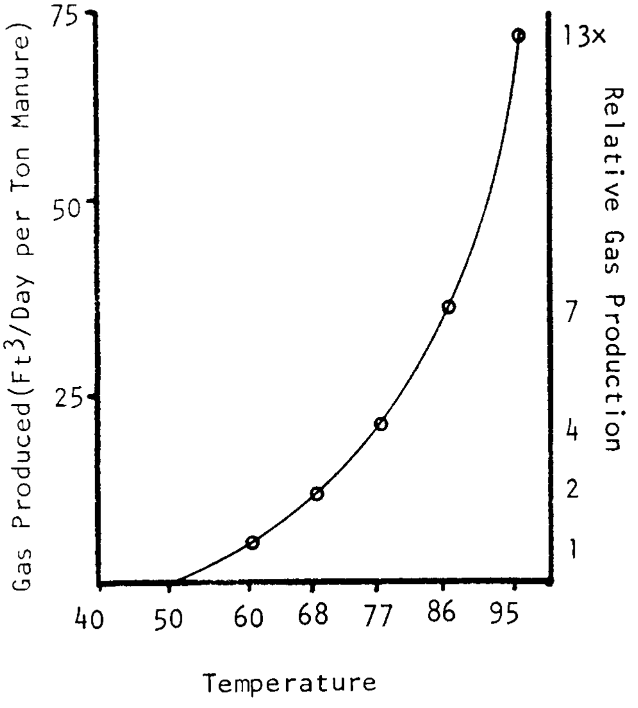


FIG.9 Gas Production and Temperature (after Ref. 15)

The same mass of manure will digest twice as fast at 95° than it will at 60° (Fig. 8) and it produces nearly 15 times more gas in the same amount of time!(Fig. 9)(See how the amount of gas produced improves with temperature to 80°-100°F, where production is optimum.) In Fig. 10 it can be seen how a different amount of gas is produced when the digester is kept at 60° than when it is kept at 95°.

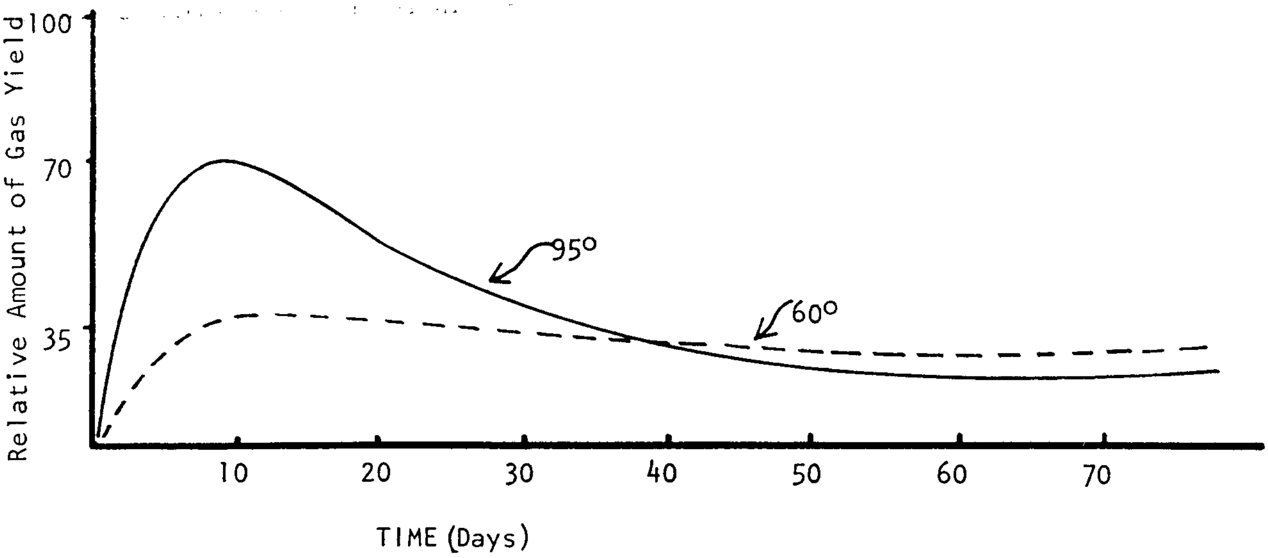


FIG.10 Comparison of Gas Production Rates at 60°F and 95°F (Measured from time new sludge added to buffered digester).

RAW MATERIALS

The amount and characteristics of organic materials (both plant and animal wastes) available for digestion vary widely. In rural areas, the digestible material will depend upon the climate, the type of agriculture practiced, the animals used and their degree of confinement, the methods of collecting wastes, etc. There are also degrees of quality and availability unique to urban wastes. Because of all these things, it is practically impossible to devise or use any formula or rule-of-thumb method for determining the amount and quality of organic wastes to be expected from any given source. There is, however, some basic information which is useful when you start wondering how much waste you can feed your digester.

Digestible Properties of Organic Matter

When raw materials are digested in a container, only part of the waste is actually converted into methane and sludge. Some of it is indigestible to varying degrees, and accumulates in the digester or passes out with the effluent and scum. The "digestibility" and other basic properties of organic matter are usually expressed in the following terms (see Ref. 16):

MOISTURE: The weight of water lost upon drying at 220°F until no more weight is lost.

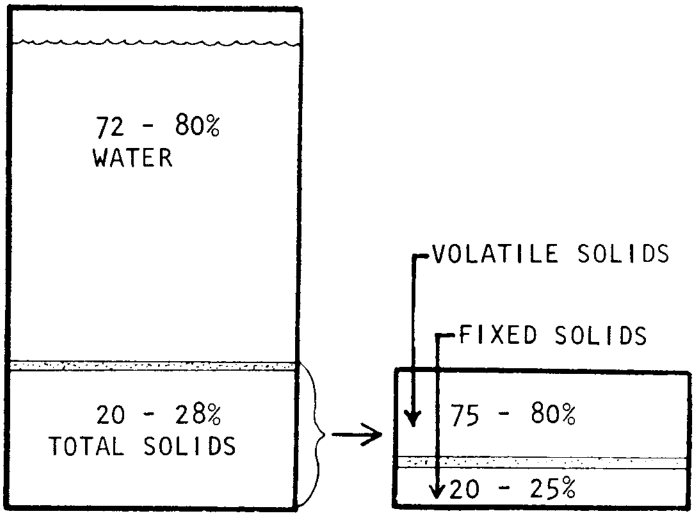
TOTAL SOLIDS (TS): The weight of dry material remaining after drying as above. TS weight is usually equivalent to "dry weight." (However, if you dry your material in the sun, assume that it will still contain around 30% moisture.) TS is composed of digestible organic or "Volatile Solids" (VS), and indigestible residues or "Fixed Solids."

Volatile Solids(VS): The weight of organic solids burned off when dry material is "ignited" (heated to around 1000°F). This is a handy property of organic matter to know, since VS can be considered as the amount of solids actually converted by the bacteria.

Fixed Solids (FS): Weight remaining after ignition. This is biologically inert material.

As an example, consider the make-up of fresh chicken manure.[17]

So if we had 100 pounds of fresh chicken manure, 72-80 pounds of this would be water, and only 15-24 pounds (75-80% Volatile Solids of the 20-28% Total Solids) would be available for actual digestion (Fig. 11).



Composition of Chicken Manure

Composition of Total Solids in Chicken Manure

FIG.11 Properties of Chicken Manure

Amount of Manure Collectable

When you see a table which shows the amount of manure produced by different kinds of livestock, it's important to know that the amount on the table may not be the amount that is actually available from your animals. There are three major reasons for this:

1) The Size (Age) Of The Animal

Consider the total wet manure production of different sized pigs:

Hog Weight	Total Manure Lbs/Day	Feces	Urine	Ratio Manure/ Hog Wt.
40-80	5.6	2.7	2.9	1:11
80-120	11.5	5.4	6.1	1:9
120-160	14.6	6.5	8.1	1:10
160-200	17.6	8.5	9.1	1:10

(From 37)

Table 3

So the size (age) of your livestock has a lot to do with the amount of manure produced. Notice that the ratio of total wet manure production to the weight of the pig is fairly constant. It is likely that similar ratios could be worked out for other kinds of livestock, enabling you to estimate the production of manure from the size of livestock.

2) The Degree of Livestock Confinement

Often the values given for manure production are for commercial animals which are totally confined. All of their manure can be collected. On the homestead or small farm, total confinement of the livestock is not always possible or even desirable. (Foraging and uncrowded livestock are less likely to contact diseases and more likely to increase the quality of their diet with naturally occurring foods.) Because of this, a large proportion of the manure is deposited in fields and thus hard to collect. For example, the fresh manure production of commerical chickens in total confinement is about 0.4 lbs. per chicken per day.[17,28] However, for small-scale operations like homesteads and small farms, where preference tends to favor the well-being of the chickens rather than the economics of egg production, chickens are often allowed to forage all day and confined only at night. In such cases, only manure dropped during the night from roosts can be conveniently collected. In our experience, this may amount to only about 0.1 to 0.2 pounds of fresh manure per day per adult chicken. Similar reasoning holds for other livestock.

3) The Kind of Manure that is Collected

a) All the fresh excretement (feces and urine).
b) All the fresh excretement plus the bedding material.
c) Wet feces only.
d) Dry feces only.

Manure Production and the Livestock Unit

Keeping in mind all these factors that can affect the type and amount of manure that can be collected, we can assemble a general manure production table. The table only shows rough average values obtained for many sources.[15,17,21-39] Values are expressed as the amount in pounds of wet manure, dry manure and volatile solids that could be expected from various adult livestock per day. For the table, an adult animal is: cow - 1000 lbs; horse - 850 lbs; swine - 160 lbs; human - 150 lbs; sheep - 67 lbs; turkey - 15 lbs; duck - 6 lbs; chicken - 3½ lbs. (We need information on goats and rabbits.)

Table 4 enables us to get some idea of the production of readily digestible material (volatile solids) from different animals. Only the feces is considered for cows, horses, swine, and sheep, since their urine is difficult to collect. However, for humans and fowl, both urine and feces are given, since they are conveniently collected together.

The relative values of digestible wastes produced are not given in pounds of manure per animal per day, but in a more convenient relative unit called the "Livestock Unit." The table shows that on the average one medium horse would produce as much digestible manure as 4 large pigs, 12½ ewes, 20 adult humans or 100 chickens.

Carbon to Nitrogen Ratio (C/N)

From a biological point of view, digesters can be considered as a culture of bacteria feeding upon and converting organic wastes. The elements carbon (in the form of carbohydrates) and nitrogen (as protein, nitrates, ammonia, etc.) are the chief foods of anaerobic bacteria. Carbon is utilized for energy and the nitrogen for building cell structures. These bacteria use up carbon about 30 times faster than they use nitrogen.

Anaerobic digestion proceeds best when raw material fed to the bacteria contains a certain amount of carbon and nitrogen together. The carbon to nitrogen ratio (C/N) represents the proportion of the two elements. A material with 15 times more carbon than nitrogen would have a C/N ratio of 15 to 1 (written C/N = 15/1, or simply 15).

A C/N ratio of 30 (C/N = 30/1, 30 times as much carbon as nitrogen) will permit digestion to proceed at an optimum rate, if other conditions are favorable, of course. If there is too much carbon (high C/N ratio; 60/1 for example) in the raw wastes, nitrogen will be used up first, with carbon left over. This will make the digester slow down. On the other hand, if there is too much nitrogen (low C/N ratio; 30/15 for example, or simply 2), the carbon soon becomes exhausted and fermentation stops. The remaining nitrogen will be lost as ammonia gas (NH_3). This loss of nitrogen decreases the fertility of the effluent sludge.

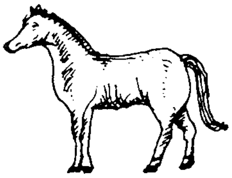
Average Adult Animal	lbs/day/animal Urine	Feces	Total Solids/ Day 20% of Feces	Volatile Solids/Day 80% of TS - 85% for Swine	Livestock Units
BOVINE (1000 lbs.)	20	52	10	8.0	
Bulls					130-150
Dairy cow					120
Under 2 yrs					50
Calves					10
HORSES (850 lbs.)	8	36	7	5.5	
Heavy					130-150
Medium					100
Pony					50-70
SWINE (160 lbs.)	4.0	7.5	1.5	1.3	
Boar, sow					25
Pig >160 lbs					20
Pig <160 lbs					10
Weaners					2
SHEEP (67 lbs.)	1.5	3	0.5	0.4	
Ewes, rams					8
Lambs					4

	Portion	Amount	%TS	TS/Day	%VS	VS/Day	
HUMANS (150 lbs.)	Urine	2 pints, 2.2 lbs	6%	.13	75%	.10	5
	Feces	0.5 lbs	27%	.14	92%	.13	
	Both	2.7 lbs	11%	.3	84%	.25	
FOWL	Geese, Turkey (15 lb.)	0.5					2
	Ducks (6 lb.)						1.5
	Layer Chicken (3½ lb.)	0.3	35%	.1	65%	.06	1
	Broiler Chicken	0.1					

TABLE 4. Manure and the Livestock Unit

There are many standard tables listing the C/N ratios of various organic materials, but they can be very misleading for at least two reasons:

1) The ratio of carbon to nitrogen measured chemically in the laboratory is often not the same as the ratio of carbon and nitrogen available to the bacteria as food (some of the food could be indigestible to the bacteria; straw, lignin, etc.).
2) The nitrogen and carbon content of even a specific kind of plant or animal waste can vary tremendously according to the age and growing conditions of the plant; and the diet, age, degree of confinement, etc., of the animal.



Nitrogen: Because nitrogen exists in so many chemical forms in nature (ammonia, NH_3; nitrates, NO_3; proteins, etc.), there are no reliable "quick" tests for measuring the total amount of nitrogen in a given material. One kind of test might measure the organic and ammonia nitrogen (the Kjeldahl test), another might measure the nitrate/nitrite nitrogen, etc. Also, nitrogen can be measured in terms of wet weight, dry weight or volatile solids content of the material; all of which will give different values for the proportion of nitrogen. Finally, the nitrogen content of a specific kind of manure or plant waste can vary, depending on the growing conditions, age, diet, and so forth.

For example, one study reported a field of barley which contained 39% protein on the 21st day of growth, 12% protein on the 49th day (bloom stage), and only 4% protein on the 86th day.[18] You can see how much the protein nitrogen depends on the age of the plant.

The nitrogen content of manure also varies a great deal. Generally, manures consist of feces, urine and any bedding material (straw, corn stalks, hay, etc.) that may be used in the livestock shelters. Because urine is the animal's way of getting rid of excess nitrogen, the nitrogen content of manures is strongly affected by how much urine is collected with the feces.

For example, birds naturally excrete feces and urine in the same load, so that the nitrogen content of chickens, turkeys, ducks, and pigeons are highest of the animal manures in nitrogen content. Next in nitrogen content, because of their varied diets or grazing habits are humans, pigs, sheep, and then horses. Cattle and other ruminants (cud chewers) which rely on bacteria in their gut to digest plant foods, have a low content of manure nitrogen because much of the available nitrogen is used to feed their intestinal bacteria. (Fig.12)

Even with the same kind of animal there are big differences in the amount of manure-nitrogen. For example, stable manure of horses may have more nitrogen than pasture manure because feces and urine are excreted and collected in the same small place.

Since there are so many variables, and because anaerobic bacteria can use most forms of nitrogen, the available nitrogen content of organic materials can best be generalized and presented as total nitrogen (% of dry weight).

Carbon: Unlike nitrogen, carbon exists in many forms which are not directly useable by bacteria. The most common indigestible form of carbon is lignin, a complex plant compound which makes land plants rigid and decay-resistant. Lignin can enter a digester either directly with plant wastes themselves or indirectly as bedding or undigested plant food in manure. Thus, a more accurate picture of the C part of the C/N ratio is obtained when we consider the "non-lignin" carbon content of plant wastes.

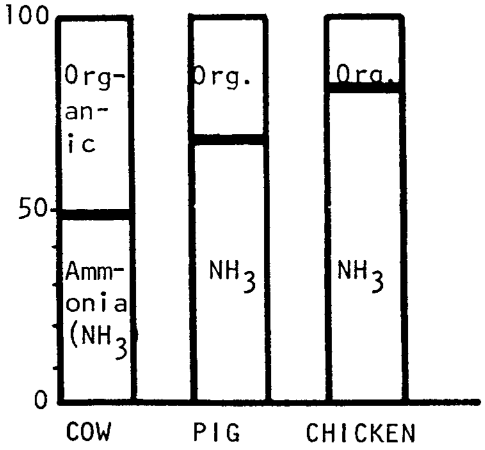
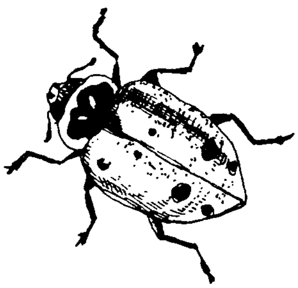


FIG.12 Types of Nitrogen Found in Different Kinds of Manure



Calculating C/N Ratios

Table 5 can be used to calculate roughly the C/N ratios of mixed raw materials. Consider the following examples:

Example 1: Calculate the C/N ratio of 50 lbs horse manure (C/N=25) and 50 lbs dry wheat straw (C/N=150).

Nitrogen in 50 lbs horse manure = 2.3% x 50 = 1.2 lbs
Carbon in 50 lbs horse manure = 25 times more than nitrogen = 25 x 1.2 = 30 lbs

Nitrogen in 50 lbs wheat straw = 0.5% x 50 = .25 lbs
Carbon in 50 lbs wheat straw = 150 times more than nitrogen = 150 x .25 = 37.5 lbs

	Manure	Straw	Total
Carbon	30	37.5	67.5 lbs
Nitrogen	1.2	.25	1.45 lbs

C/N ratio = 67.5/1.45 = 46.5

Although a bit high, this would be a satisfactory ratio for most digestion purposes.

Example 2: Calculate the C/N ratio of 8 lbs grass clippings (C/N=12) and 2 lbs of chicken manure (C/N=15).

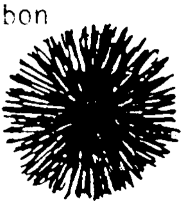
Nitrogen in 8 lbs grass clippings = 4% x 8 = .32 lbs
Carbon in 8 lbs grass clippings = 12 times more than nitrogen = 3.8 lbs

Nitrogen in 2 lbs chicken manure = 6.3% x 2 = .13 lbs
Carbon in 2 lbs chicken manure = 15 times more than nitrogen = 1.9 lbs

	Manure	Grass	Total
Carbon	3.8	1.9	5.7
Nitrogen	.32	.13	.45

C/N ratio = 5.7/.45 = 12.6

The C/N ratio of this mixture is low. We might want to add a higher proportion of chicken manure since it contains more carbon per weight than the grass.



The following table is a summary of the important chemical properties of organic materials. Values are averages derived from many sources[14,16,18-33] and should be used only for approximation.

	Total Nitrogen % Dry Weight	C/N Ratio
ANIMAL WASTES		
Urine	16	0.8
Blood	12	3.5
Bone Meal		3.5
Animal Tankage		4.1*
Dry Fish Scraps		5.1*
MANURE		
Human, feces	6	6-10
, urine	18	
Chicken	6.3	15
Sheep	3.8	
Pig	3.8	
Horse	2.3	25*
Cow	1.7	18*
SLUDGE		
Milorganite		5.4*
Activated	5	6
Fresh Sewage		11*
PLANT MEALS		
Soybean		5
Cottonseed		5*
Peanut Hull		36*
PLANT WASTES		
Hay, Young Grass	4	12
Hay, Alfalfa	2.8	17*
Hay, Blue Grass	2.5	19
Seaweed	1.9	19
Non-Legume Vegetables	2.5-4	11-19
Red Clover	1.8	27
Straw, Oat	1.1	48
Straw, Wheat	0.5	150
Sawdust	0.1	200-500

Nitrogen is total nitrogen dry weight and carbon is either total carbon (dry weight) or (*) non-lignin carbon (dry weight).

Table 5. Carbon & Nitrogen Values of Wastes

THE GAS

Composition

The gas produced by digestion, known as marsh gas, sewage gas, dungas, or bio-gas, is about 70% methane (CH_4) and 29% carbon dioxide (CO_2) with insignificant traces of oxygen and sulfurated hydrogen (H_2S) which gives the gas a distinct odor. (Although it smells like rotten eggs, this odor has the advantage of being able to trace leaks easily.)

The basic gas producing reaction in the digester is: carbon plus water = methane plus carbon dioxide ($2C + 2H_2O = CH_4 + CO_2$). The methane has a specific gravity of .55 in relation to air. In other words, it is about half the weight of air and so rises when released to the atmosphere. Carbon dioxide is more than twice the weight of air, so the resultant combination of gases, or simply bio-gas, when released to atmosphere, will rise slowly and dissipate.

CH_4	methane	54 - 70%
CO_2	carbon dioxide	27 - 45%
N_2	nitrogen	.5 - 3%
H_2	hydrogen	1 - 10%
CO	carbon monoxide	0.1%
O_2	oxygen	0.1%
H_2S	hydrogen sulfide	trace

Table 6. General Composition of Bio-Gas Produced From Farm Wastes

Fuel Value

The fuel value of bio-gas is directly proportional to the amount of methane it contains (the more methane, the more combustible the bio-gas). This is because the gases, other than methane, are either non-combustible, or occur in quantities so small that they are insignificant. Since tables of "Fuel Values of Bio-Gas" may not show how much combustible methane is in the gas, different tables show a wide variety of fuel values for the same kind of gas, depending on the amount of methane in the gas of each individual table.

As a general rule, pure methane gas has a heat value of about 1,000 British Thermal Units (BTU) per cubic foot (ft^3). One BTU is the amount of heat required to raise one pound (one pint) of water by 1°F. Five ft^3, or 5000 BTU of gas is enough to bring ½ gallon of water to the boil and keep it there 20 minutes. If you have a volume of bio-gas which is 60% methane, it will have a fuel value of about 600 BTU/ft^3, etc.

Fuel Gas	Fuel Value (BTU/ft^3)
Coal (town) gas	450-500
Bio-gas	540-700
Methane	896-1069
Natural gas (methane or propane-based)	1050-2200
Propane	2200-2600
Butane	2900-3400

Table 7. Fuel Value of Bio-Gas and Other Major Fuel Gases

The composition and fuel value of bio-gas from different kinds of organic wastes depends on several things:

1) The temperature at which digestion takes place. This has already been discussed.
2) The nature of the raw material. According to Ram Bux Singh:[2] "pound for pound, vegetable waste results in the production of 7 times more gas than animal waste." In our experience, pressed plant fluids from succulent plants (cactus), greatly increases the amount of gas produced, but certainly not by a factor of 7. Harold Bates (the chicken manure car) has noted that more gas is produced from manure with a little straw added. But, we are more interested in the production of methane than bio-gas. Laboratory experiments[40,41] have shown that plant materials produce bio-gas with a high proportion of carbon dioxide. So, the extra gas produced by plants may be less valuable for our purposes of fuel production.

The general quality of bio-gas can be estimated from the C/N ratio of the raw materials used. (Table 8)

With good temperature and raw materials, 50 to 70% of the raw materials fed into the digester will be converted to bio-gas.

Amount of Gas From Different Wastes

The actual amount of gas produced from different raw materials is extremely variable depending upon the properties of the raw material, the temperature, the amount of material added regularly, etc. Again, for general rule-of-thumb purposes, the following combinations of wastes from a laboratory experiment can be considered as minimum values: (Table 9)

		Methane	CO_2	Hydrogen	Nitrogen
C/N Low (high nitrogen)	blood, urine	little	much	little	much
C/N High (low nitrogen)	sawdust, straw, sugar and starches such as potatoes, corn, sugar beet wastes	little	much	much	little
C/N Balanced (C/N = near 30)	manures, garbage	much	some	little	little

Table 8. Gas Production According to C/N Ratios of Raw Wastes

Material	Proportion	Ft^3 Gas Per lb VS Added	CH_4 Content of Gas (%)
Chicken Manure	100%	5.0	59.8
Chicken Manure & Paper Pulp	31% 69%	7.8	60.0
Chicken Manure & Newspaper	50% 50%	4.1	66.1
Chicken Manure & Grass Clippings	50% 50%	5.9	68.1
Steer Manure	100%	1.4	65.2
Steer Manure & Grass Clippings	50% 50%	4.3	51.1

Table 9. Cubic Feet of Gas Produced by Volatile Solids of Combined Wastes (Ref. 40)

Other values for gas production are from working digester operations. These are shown as cubic feet of gas produced by the Total Solids and are more liberal values than in Table 9.

Manure	Ft^3/lb of Dry Matter (TS)
Pig	6.0 - 8.0
Cow (India)	3.1 - 4.7
Chicken	6.0 - 13.2
Conventional Sewage	6.0 - 9.0

From Ref. 5, 7, 8, 17, 42

Table 10. Gas Produced By Total Solids of Wastes

As an example, suppose we had 100 chickens which were allowed to forage during the day, but were cooped at night, so that only about half of their manure was collectable. At 0.1 lb/chicken/day this would amount to about 10 lbs of wet or 3.5 lbs dry (Table 4) manure per day. Other conditions being equal, this could be equivalent to about 20-40 ft^3 of bio-gas (assuming 60% methane) 12-24 ft^3 of methane gas per day.

DIGESTERS

Basic Digester Design

Digesters can be designed for batch-feeding or for continuous feeding. With batch digesters a full charge of raw material is placed into the digester which is then sealed off and left to ferment as long as gas is produced. When gas production has ceased, the digester is emptied and refilled with a new batch of raw materials.

Batch digesters have advantages where the availability of raw materials is sporadic or limited to coarse plant wastes (which contain undigestible materials that can be conveniently removed when batch digesters are reloaded). Also, batch digesters require little daily attention. Batch digesters have disadvantages, however, in that a great deal of energy is required to empty and load them; also gas and sludge production tend to be quite sporadic. You can get around this problem by constructing multiple batch digesters connected to the same gas storage. In this way individual digesters can be refilled in staggered sequence to ensure a relatively constant supply of gas. Most early digesters were of the batch type.

With continuous-load digesters, a small quantity of raw material is added to the digester every day or so. In this way the rate of production of both gas and sludge is more or less continuous and reliable. Continuous-load digesters are especially efficient when raw materials consist of a regular supply of easily digestible wastes from nearby sources such as livestock manures, seaweed, river or lake flotsam or algae from production sludge-ponds. The first continuous-load digester seems to have been built in India by Patel in 1950.[43]

Continuous-feeding digesters can be of two basic designs: vertical-mixing or displacement (Fig. 12). Vertical-mixing digesters consist of vertical chambers into which raw materials are added. The slurry rises through the digester and overflows at the top. In single-chamber designs the digested or "spent" slurry can be withdrawn directly from effluent pipes. In double-chamber designs the spent slurry, as it overflows the top, flows into a second chamber where digestion continues to a greater degree of completion.

Displacement digesters consist of a long cylinder lying parallel to the ground (e.g., inner tubes, oil drums welded end on end, tank cars, etc.). As it is digested the slurry is gradually displaced toward the opposite end, passing a point of maximum fermentation on the way.

The displacement digester design seems to have distinct advantages over vertical-mixing designs popularized in India: (1) In vertical-mixing digesters raw material is subject to a vertical pumping motion and often escapes the localized action of digesting bacteria. Slurry introduced at one time can easily be withdrawn soon afterwards as incompletely digested material. In displacement digesters slurry must pass an area of maximum fermentation activity so that all raw materials are effectively digested (much like the intestines of an animal). (2) From a practical point of view, displacement digesters are easier to operate. If digester contents begin to sour for one reason or another, strongly buffered material at the far end can be recirculated efficiently by simply reversing the flow of material along the line of the cylinder. In addition, raw materials can be digested to any desired degree without the need for constructing additional chambers or digesters. (3) The problem of scum accumulation is reduced in displacement digesters. Since scum forms evenly on the surface of the digesting slurry, the larger the surface area, the longer it takes to accumulate to the point where it inhibits digestion. A prone cylinder has a larger surface area than an upright one. (4) Any continuous-load digester will eventually accumulate enough scum and undigested solid particles so that it will have to be cleaned. The periodical washing out of displacement digesters is considerably easier than vertical-mixing digesters.

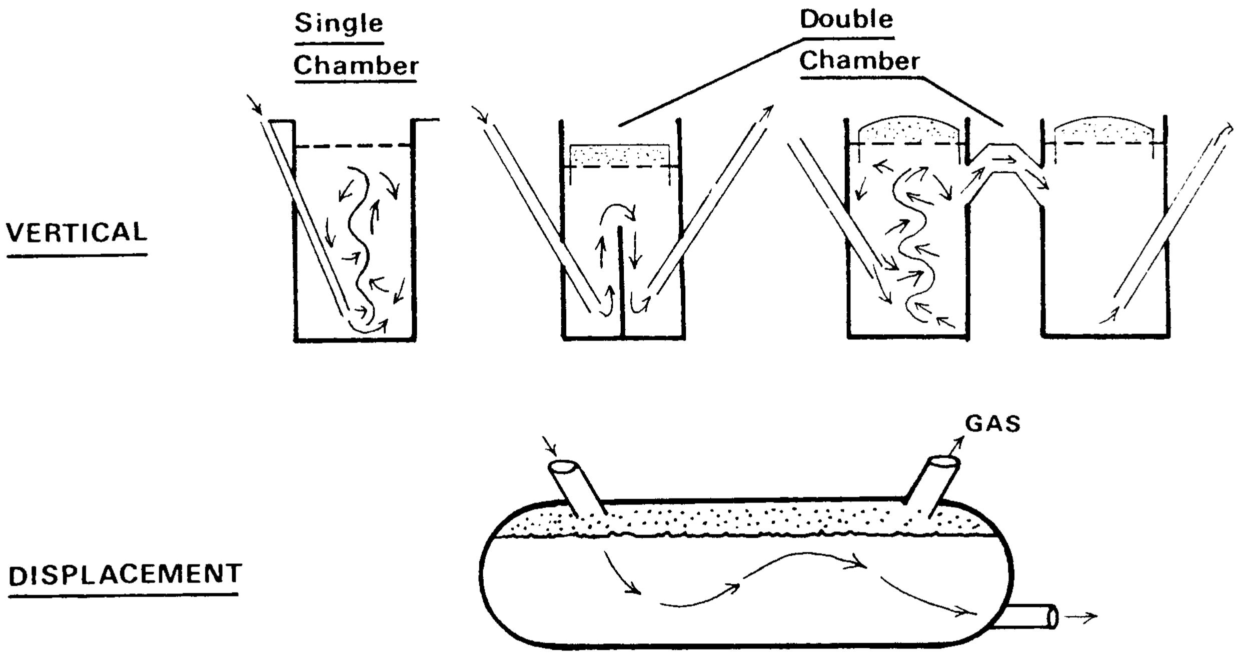


FIG.13 Types of Continuous-Feeding Digesters

The first large-scale displacement digester was designed and built by L. John Fry during the late 1950's on his pig farm in South Africa.[42,44] Mr. Fry, now a resident of Santa Barbara, is acting consultant for the New Alchemy digester project which is currently focusing attention on the design and utilization of small-scale displacement digesters.

Raw Materials and Digester Design

Plant Wastes: The primary advantage to plant wastes is their availability. Their disadvantage for a small farm operation is that plant wastes can often be put to better use as livestock feed or compost. Also, plants tend to be bulky and to accumulate lignin and other indigestible materials that must be regularly removed from digesters. This severely limits the use of plant wastes in continuous-feeding digesters.

There seem to be three possible ways to take advantage of plant wastes in continuous digesters: (1) Press plant fluids out of succulent plants (e.g., cacti, iceplant, etc.) and digest juices directly, or use them as a diluter for swill. (2) Culture algae for digestion. (3) Digest plants not containing lignin (e.g., seaweed).

Animal Manures: The main advantage to animal manure, with respect to continuous digesters, is that it is easy to collect (with proper design of livestock shelters) and easy to mix as slurry and load into digesters. Successful continuous digesters have been set up using pig manure,[26,42,44] cow dung[3,5,6] and chicken manure.[17] The general consensus seems to be that, among animal manures, chicken manure "is easily digested, produces large quantities of gas and makes a fertilizer very high in nitrogen."[45]

Human Waste: Human waste or "night soil" has long been used as a fertilizer, especially in the Orient.[46,47] However, there seems to be little information on using human wastes as raw materials for anaerobic digesters. A few ideas involving outhouses and latrines are described by Gotaas[15] in his chapter, Manure and Night Soil Digesters for Methane Recovery on Farms and in Villages. It seems possible, also, that digesters could be incorporated into aerobic dry toilet designs of the "Clivus" type.[48] This may be especially fruitful since the main drawback to using human wastes from flush toilets is the excess water that is carried with it which inhibits digestion. A well-designed privy digester which paid special attention to the transmission of diseases peculiar to humans would be a real asset to homestead technology. A solution to this problem would be welcomed. One suggestion is a seat with a clip-on plastic bag. When filled it could be dropped into a digester intact. The plastic would have to be a material which would decompose only in the presence of methane bacteria, or liquids generally after so many hours.

Loading Rate, Detention Time and Digester Size

In calculating the size of a continuous-load digester the most important factors are loading rate and detention time.

Loading Rate: Is defined as the amount of raw material (usually pounds of volatile solids) fed to the digester per day per ft^3 of digester space. Most municipal sewage plants operate at a loading rate of .06-.15 lb VS/day/ft^3. With good conditions, much higher rates are possible (up to .4 lbs VS/day/ft^3). Again, as with most aspects of digesters, the optimum situation is a compromise. If you load too much raw material into the digester at a time, acids will accumulate and fermentation will stop. The main advantage to a higher loading rate is that by stuffing a lot into a little space, the size (and therefore cost) of the digester can be reduced.

> Example: Suppose you had 10 lbs of fresh chicken manure (total manure from about 30 chickens) available for digestion every day: 10 lbs fresh chicken manure = 2.3 volatile solids (Table 4). At a loading rate of .2 lbs VS/day/ft^3 this would require a digester 2.3/.2 = 12 ft^3 in volume (about the size of 2-50-gallon drums). At a loading rate of .1 lb VS/day/ft^3, this would double the necessary size of the digester with the same amount of manure.

Detention Time: Is the number of days that a given mass of raw material remains in a digester. Since it is very difficult to load straight manure into a digester it is usually necessary to dilute it with water into a slurry. If too much water is added, the mixture will become physically unstable and settle quickly into separate layers within the digester, thus inhibiting good fermentation. The general rule-of-thumb is a slurry about the consistency of cream. The important point here is that as you dilute the raw material you reduce its detention time.

> Example: The volume of 10 lbs of fresh chicken manure is about .2 ft^3. If this is diluted 1:1 with water the volume becomes about .4 ft^3. With the 12 ft^3 digester described above, this would mean a detention period of .4/12 = 36 days. If the manure were diluted more, say 2:1, the volume would be .6 ft^3 and the detention period would be reduced to .6/12 = 20 days.

Up to a point, then (usually no less than 6% solids), diluting raw materials will produce the same amount of gas in a shorter period of time.

These relationships between loading rate, detention time and digester size reveal themselves more clearly after direct experience with continuous-load digesters. However, generalities can be of some use in the beginning.

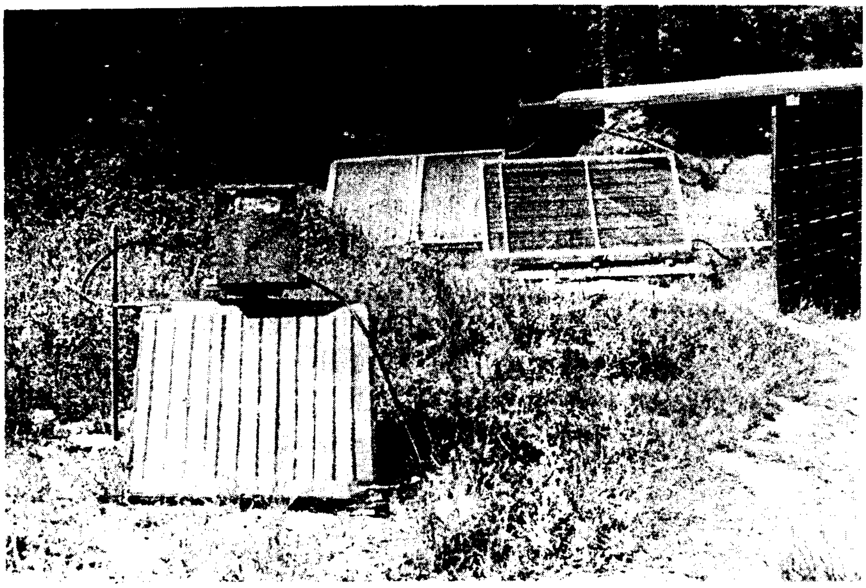


FIG.14 Solar Water Heaters (Built by Irving Thomas of Santa Barbara)

Heating Digesters

For the most efficient operation, especially in temperate climates, digesters should be supplied with an external supply of heat to keep them around 95°F; there are several ways to do this. Methods which heat the outside of digesters (e.g., compost piles, light bulbs, and water jackets) could be more effectively used as insulation since much of their heat dissipates to the surroundings. (Since digesters should be constantly warmed rather than sporadically heated, compost "blankets" are not very practical unless you coordinate a regular program of composting with digestion.) Similarly, green houses built over digesters tend to overheat the digester during the day and cool it down at night.

The most effective method of keeping digesters warm is to circulate heated water through pipes or coils placed within the digester. The water can be heated by solar collectors or by water boilers heated with methane.

Gas-heated water boilers are a good idea since they allow the digestion process to feed back on itself, thus increasing efficiency. One practical gas-heater design we have used is shown in Figure 5. The thermostat in the water boiler is set at 140°F because slurry will cake on surfaces (e.g., the water coils) warmer than this. The digester thermostat is set at the optimum 95°F. Until the digester begins producing methane, propane can be used as a fuel source for the water boiler.

For optimum heat exchange within the digester, a ratio of 1 ft^2 coil area per 100 ft^3 of digester volume is recommended.[8]

Insulating Digesters

A word of caution if you insulate your digester. Methane is not only combustible but highly explosive when it makes up more than 9% of the surrounding air in confined spaces. If you use synthetic insulation, avoid porous materials such as spun glass which can trap gas mixtures. It's easy to scrounge styrofoam sheets since they are so commonly used as packing material and regularly discarded. Styrofoam is one of the best insulating materials, although it is slightly flammable.

USING GAS

Properties of Methane

Specific Gravity (air = 1.0)	.55
Dry Weight, lb/ft^3	.04 (gas)
Liquid Weight, lb/gal	3.5 (liquid)
Fuel Value, BTU/ft^3	950-1050
Air for Combustion, ft^3/ft^3	9.5
Flammability in Air, % Methane	5-14

Uses of Methane

General: Methane can of course be used in any appliance or utility that uses natural gas. The natural gas requirements of an average person with a U.S. standard of living is about 60 ft^3/day. This is equivalent to 10 lbs of chicken or pig manure per day (7 pigs and 100 chickens) or 20 lbs of horse manure (about 2 horses). Other uses and methane requirements are listed in Table 11.

Use	Ft^3	Rate
Lighting	2.5	per mantle per hour
Cooking	8-16	per hour per 2-4" burner
	12-15	per person per day
Incubator	.5-.7	ft^3 per hour per ft^3 incubator
Gas Refrigerator	1.2	ft^3 per hour per ft^3 refrigerator
Gasoline Engine*		
CH_4	11	per brake horsepower per hour
Bio-Gas	16	per brake horsepower per hour
For Gasoline		
CH_4	135-160	per gallon
Bio-Gas	180-250	per gallon
For Diesel Oil		
CH_4	150-188	per gallon
Bio-Gas	200-278	per gallon

*25% efficiency

Table 11. Uses for Methane

Heat Engines: Methane, the lightest organic gas, has two fundamental drawbacks to its use in heat engines: it has a relatively low fuel value (Table 7), and it takes nearly 5,000 psi to liquefy it for easy storage. (87.7 ft^3 methane gas = 1 gallon of liquid methane or 1 ft^3 methane gas = 9 tablespoons liquid methane.) So a great deal of storage is required of methane for a given amount of work. For comparison, propane liquefies around 250 psi. Consider the following example where methane is compressed to just 1,000 psi in a small bottle and used to power a rototiller of 6 brake horsepower

Example:
1 horsepower hr = 2540 BTU
Fuel value of methane = 950 BTU/ft^3
TV (tank vol.) = 2' x 6" cylinder = 678 in^3 = 0.39 ft^3
TP (tank pressure) = 1000 psi = 68 atmos
EV (effective vol.) = (TP) (TV) = 26.7 ft^3 = 25,300 BTU
hp = brake horsepower of engine
hr = hours of running
x = heat value of gas (BTU/ft^3)
y = efficiency of engine (25% for conventional gas engines

Methane Gas Consumption (G) (ft^3)

of general heat engine:

$$G = \frac{(hp)\ (2540)\ (hr)}{(x)\ (y)}$$

of gasoline engine on methane:

$$G = \frac{(hp)\ (2540)\ (hr)}{(0.25)\ (9.50)} = (10.7\ \text{ft}^3/\text{hp-hr})$$

for a 6 hp rototiller

$$G = (hp)(hr)(10.7\ \text{units}) = (64.2\ \text{ft}^3/\text{hr})(hr)$$

Operating Time (OT)

$$OT = \frac{EV}{G} = 0.414\ \text{hr} = 25\ \text{minutes/tank}$$

$$\text{Useful Work Supplied} = 2.5\ \text{hp hr} = 6{,}350\ \text{BTU} = (25{,}300\ \text{BTU/tank})\ (25\%\ \text{eff})$$

At 25% compressor efficiency it would take .52 hp-hr to compress the gas (1320 BTU). In other words, it would take 1320 BTU to compress 25,300 BTU worth of gas that provides 6,350 BTU worth of work. Clearly the system is not very "efficient" in the sense that 21% of the resulting work energy is needed for compression while 75% of the available energy is lost as heat.

Methane has been used in tractors[49,50] and automobiles.[51] The gas bottles carried by such vehicles are often about 5 ft long by 9 in diameter (1.9 ft^3) charged to 2800 psi so that about 420 ft^3 of methane is carried (about 3½ gal. gasoline). However, it seems that the most efficient use of methane would be in stationary heat engines located near the digester (e.g., compressors and generators). There are two reasons for this: (1) The engine's waste heat can be recirculated in digester coils instead of dissipating in the open. (2) Gas can be used directly as it is produced, without the need of compressors. For example, bio-gas produced from pig manure was used at ordinary pressures by John Fry to power a Crossley Diesel engine. The diesel ran an electric generator and the waste heat was recirculated directly back into the digesters.[52] It is likely that bio-gas produced from mixed wastes would have to be "scrubbed" of corrosive hydrogen sulfide (by passing through iron filings), and possibly CO_2 (by passing through lime water).

EFFICIENCY OF DIGESTION

The efficiency of anaerobic digestion can be estimated by comparing the energy available in a specific amount of raw material to the energy of the methane produced from that material. Four such estimates are given below. (Fig. 15)

It seems fair to conclude that anaerobic digestion is about 60-70% "efficient" in converting organic waste to methane. However, it would probably be more accurate to call this a conversion rate since, like all biological processes, a great deal of energy is required to maintain the system, and most of this extra energy is not included in the conversion. For example, consider how much energy is needed just to keep a digester warm in a general temperate climate.

Example: Direct-heating hot water boilers have an efficiency of about 70%. Gas engines have a power efficiency of 20-25% and a water heating efficiency of about 50%.[7] As hot water heaters, then, heat engines are about as efficient as water boilers. In either case about 20-30% of the gas energy derived from digestion must be put back into the system to heat digesters. Without even considering the energy needed to collect raw materials or load and clean the digesters, the conversion efficiency of digestion should be closer to 50%

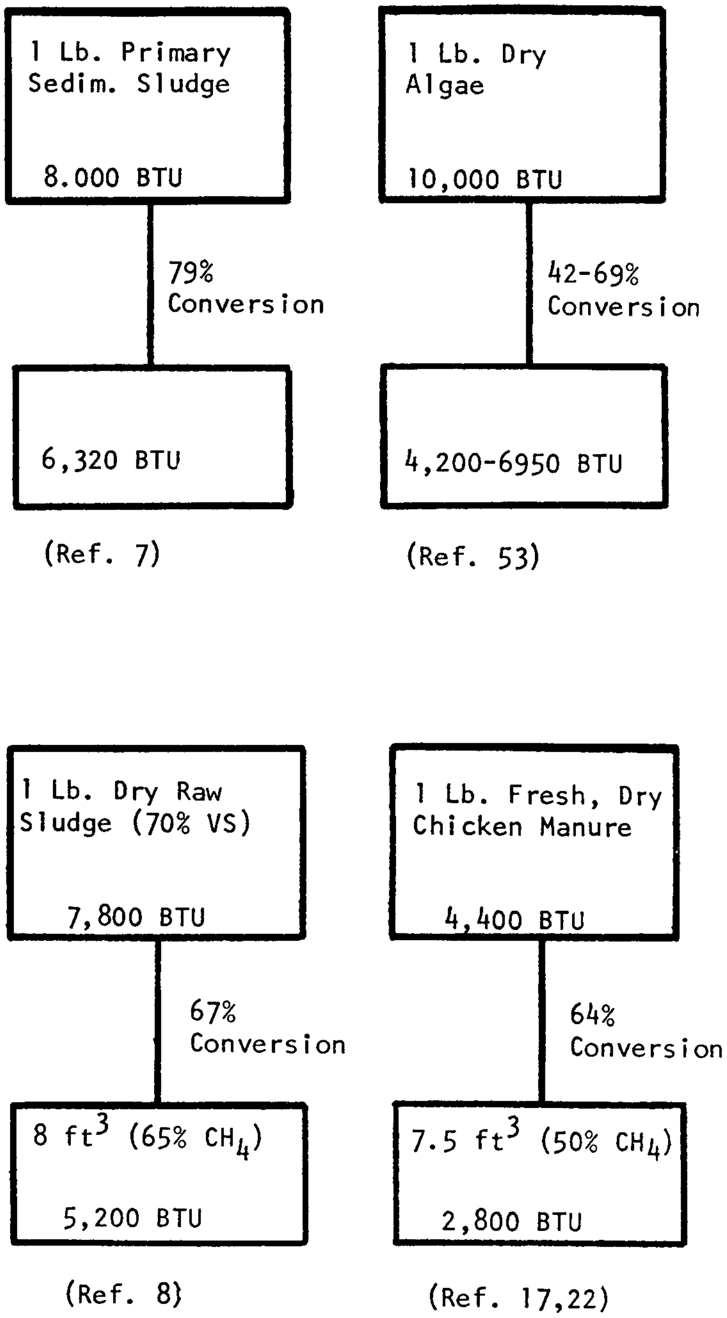


FIG.15 Efficiency of Methane Production from Different Materials

USING SLUDGE

Sludge as a Fertilizer

Most solids not converted into methane settle out in the digester as a liquid sludge. Although varying with the raw materials used and the conditions of digestion, this sludge contains many elements essential to plant life: nitrogen, phosphorous, potassium plus small amounts of metallic salts (trace elements) indispensible for plant growth such as boron, calcium, copper, iron, magnesium, sulfur, zinc, etc.

Nitrogen is considered especially important because of its vital role in plant nutrition and growth. Digested sludge contains nitrogen mainly in the form of ammonium (NH_4), whereas nitrogen in aerobic organic wastes (activated sludge, compost) is mostly in oxidized forms (nitrates, nitrites). Increasing evidence suggests that for many land and water plants ammonium may be more valuable as a nitrogen source than oxidized nitrogen; in the soil it is much less apt to leach away and more apt to become fixed to exchange particles (clay and humus). Likewise, important water algae appear to be able to utilize ammonium easier than nitrates.[54] Generally speaking, this is a reversal from the earlier belief by fertilizer scientists that oxidized nitrogen always presented the most available form of nitrogen for plants. Because of these things, it has been suggested that liquid digested sludge produces an increase of nitrogen comparable with those of inorganic fertilizers in equivalent amounts.[55]

Most of the information showing the poor fertilizer value of sludge has been based on municipal sewage sludge. It is a bad measure of the fertilizer value of digested sludge in general. (Municipal treatment flushes away all the fertilizer rich liquid effluent.) In one case[7] digested sewage sludge was found to contain only about ½ the amount of nitrogen in fresh sewage, whereas elsewhere[26] digested pig manure was found to be 1.4 times richer in nitrogen content than raw pig manure. Similar results have been found with digested chicken manure.

Sludge from your digester can be recycled in a wide variety of ways, both on land and in water and pond cultures. The possibilities are many and only brief descriptions of potentials can be given here.

	N (% dry wt.)	Reference
RAW SEWAGE	1.0-3.5	56
DIGESTED SLUDGE		
10 municipalitites	1.8-3.1	9
12 Ohio municipalities	0.9-3.0	9
51 samples, 21 cities	1.8-2.3	10,57
General average	2.0	9
General average	1.0-4.0	56
ACTIVATED SLUDGE		
5 municipalities	4.3-6.4	9
General average	4.0-6.0	9
General average	4.0-7.0	56
DIGESTED MANURE SLUDGE		
Hog	6.1-9.1	26
Chicken	5.3-9.0	23
Cow	2.7-4.9	23
FINISHED COMPOST		
Municipal	.4-1.6	58
Garbage	.4-4.0	58
Garden	1.4-3.5	58

Table 12. Nitrogen Fertilizer Value of Various Sludges and Finished Compost

Sludge Gardening and Farming

The application of digested sludge to crops serves a double purpose since it is both a soil conditioner and fertilizer. The sludge humus, besides furnishing plant foods, benefits the soil by increasing the water-holding capacity and improving its structure. In some preliminary experiments with garden and house plants we have obtained astounding results with the use of sludge from our chicken manure digester. However, there are some things to consider first: (1) Fresh digested sludge, especially from manures, contains high amounts of ammonia, and in this state may act like a chemical fertilizer by force-feeding large amounts of nitrogen into the plant and increasing the accumulation of toxic nitrogen compounds.[59,60] There is no direct evidence for this, but the possibility exists. For this reason it is probably best

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Sludge-Pond Cultures

There are at least three general ways to integrate pond cultures with organic digesters: hydroponic crops, sludge-algae-fish and sludge-algae-methane systems. All have their advantages depending on local needs and resources.

Sludge Hydroponics: Hydroponics is the process of growing plants directly in nutrient solution rather than soil. The nutrients may consist of soluble salts (i.e., chemical fertilizers) or liquid organic wastes like digested sludge and effluent. Plants grown hydroponically in sludge-enriched solutions can serve a variety of purposes for organic digester operations: (1) They can do away with the cost and energy of transporting liquid fertilizer to crop lands since they can be grown conveniently near to digesters. (2) They tend to be more productive than conventional soil crops, and thus can serve as a high-yield source of fodder, compost, mulch or silage. (3) They can serve as convenient high-yield sources of raw materials for the digester itself.

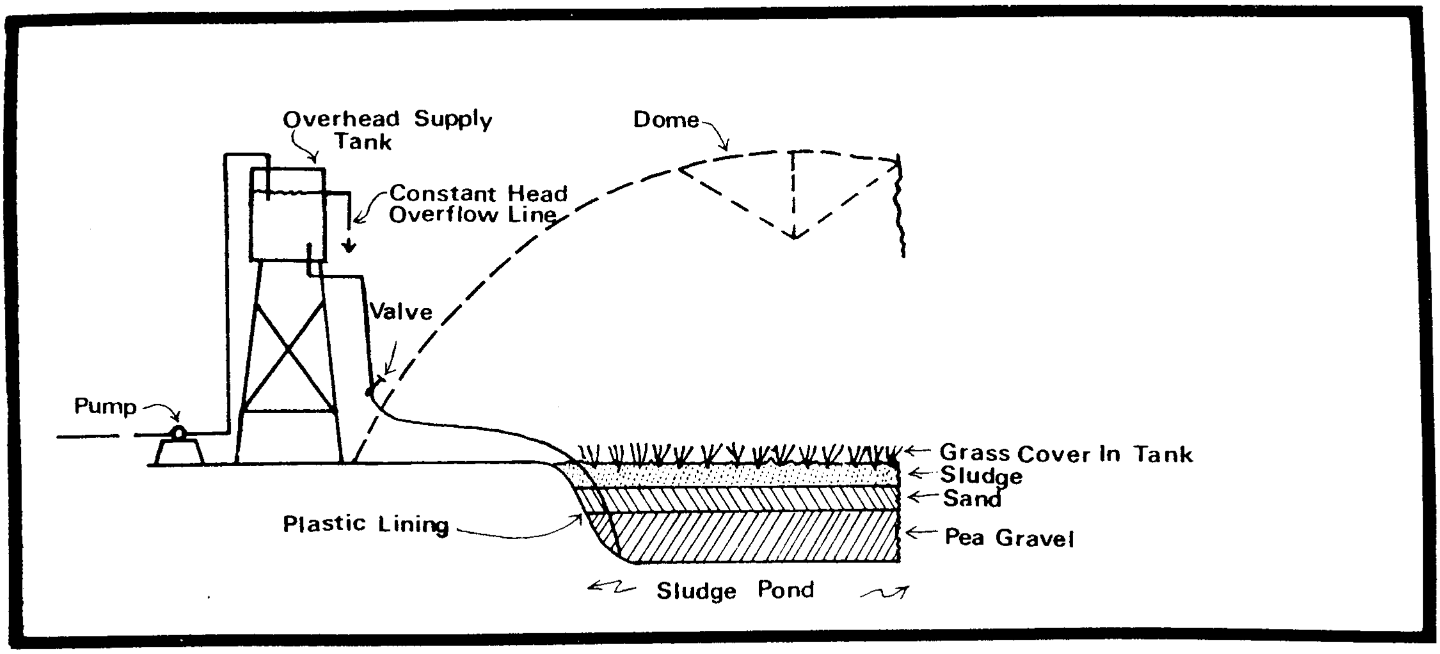


FIG.16 Hydroponic Sludge Culture of Pasture Grasses

Information about the use of sludge to fertilize water plants comes from projects to treat waste water in run-off areas or "sewage lagoons."[61,62] Some plants, for example water hyacinth, Ipomoea repens and some cool season pasture grasses such as rye, fescue and canary grass, have the ability to grow well in waste water and to take up great amounts of nutrients efficiently, thus helping to control polluted waters. These crops have the added advantage that they are easy to harvest for livestock feed, thus giving an efficient method of converting sludge nutrients into animal protein.

Usually, the plants are grown in shallow ponds filled with a diluted sludge solution. The process consists of slowly adding sludge under a gravel bed lining the pond and covered with a layer of fine sand. Over the sand, plants are sprouted in containers floating on the effluent that percolates up through the gravel and sand layers. After sprouting the grasses then root and anchor in the sand and gravel.

Sludge-Algae-Fish: The essence of the sludge-algae-fish or "aquaculture" system consists of placing sludge into ponds and stimulating the growth of algae. The algae are then used as feed for small invertebrates or fish growing in the pond. The idea is modeled after Oriental aquaculture systems. During the last two years, under the direction of Bill McLarney, New Alchemy has established preliminary models for experimental fish cultures (Tilapia). A general description of small-scale fish farming methods using organic fertilizers and invertebrate fish food cultures has been presented elsewhere.[63-65]

Sludge-Algae-Methane: In the Sludge-algae-methane system green algae is grown in diluted sludge, then harvested, dried and digested to produce methane for power and sludge for recycling. This procedure of transforming solar energy and sludge nutrients into the chemical energy of methane is potentially a very efficient and rapid biological process: (1) It is a closed nutritional system and (2) the rate of turnover is extremely high; organic matter is decomposed relatively quickly by anaerobic bacteria in the pond while it is most rapidly made by green algae. The complete sludge-algae-methane system involves a series of processes. The principle features of the system are integration of the algae culture with the gas in such a manner that nutrients and water are recycled from one process to the other (Fig. 17). Most of the information concerning this system has been developed by researchers at Berkeley in a manner

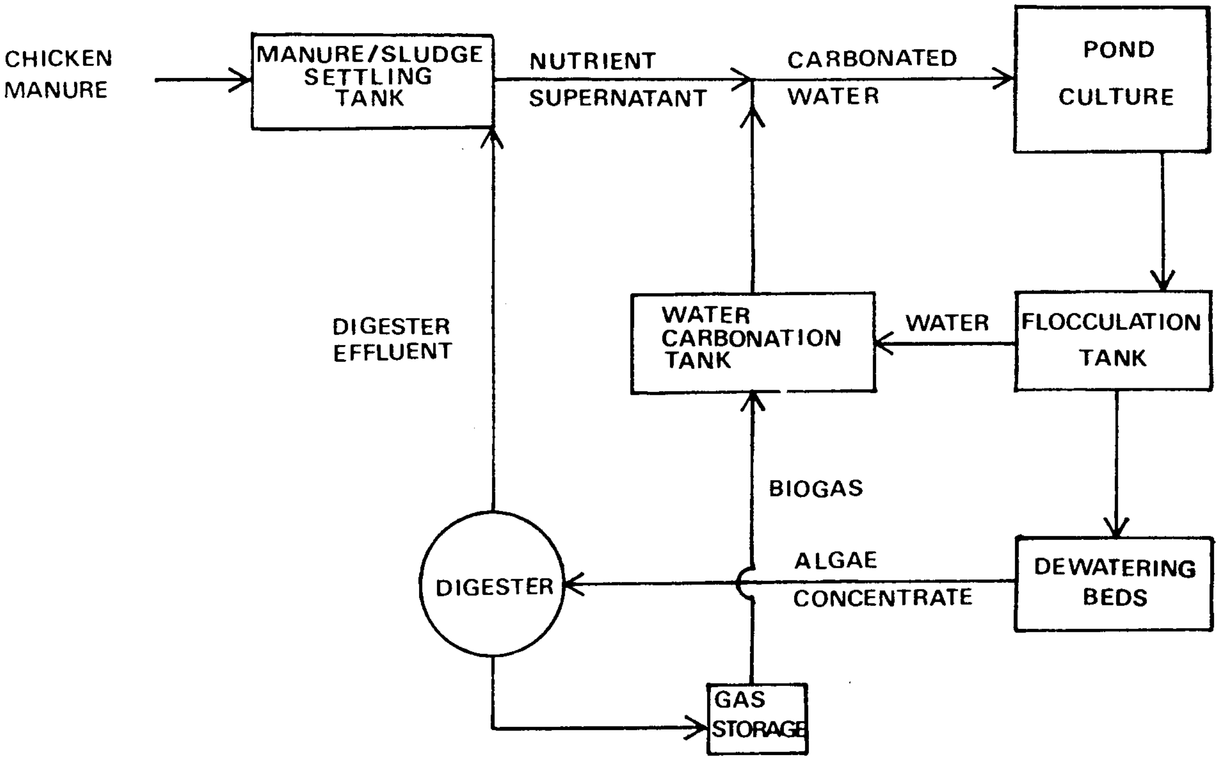
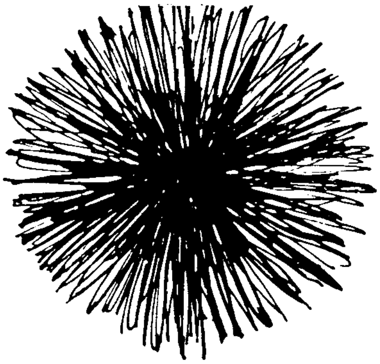
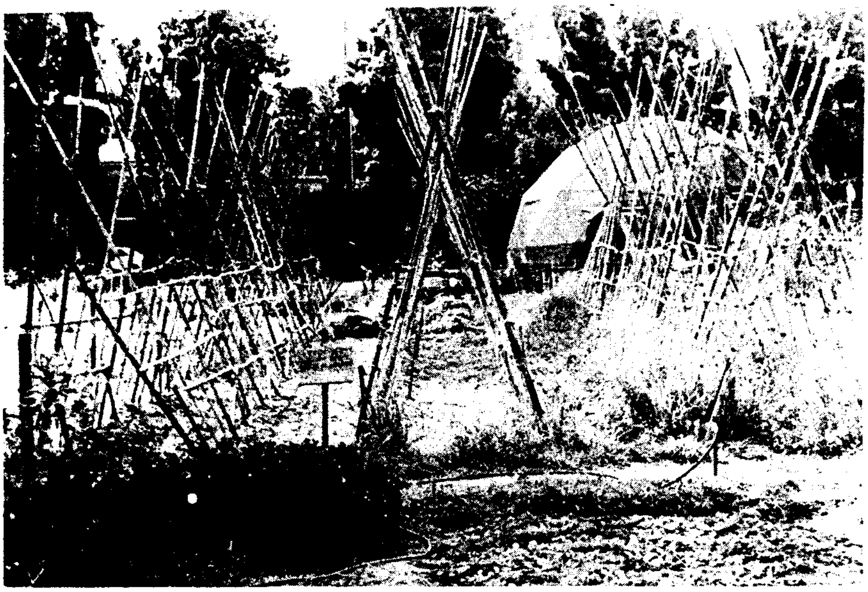
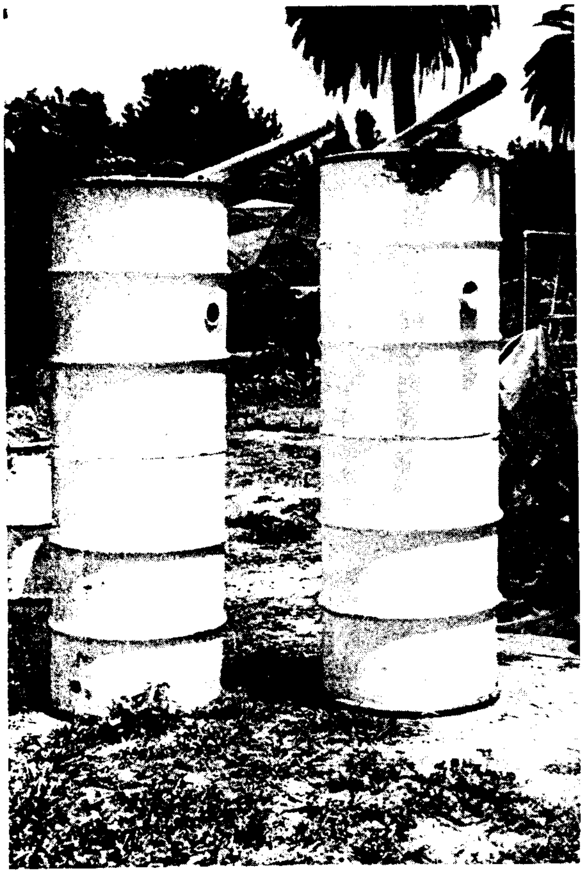


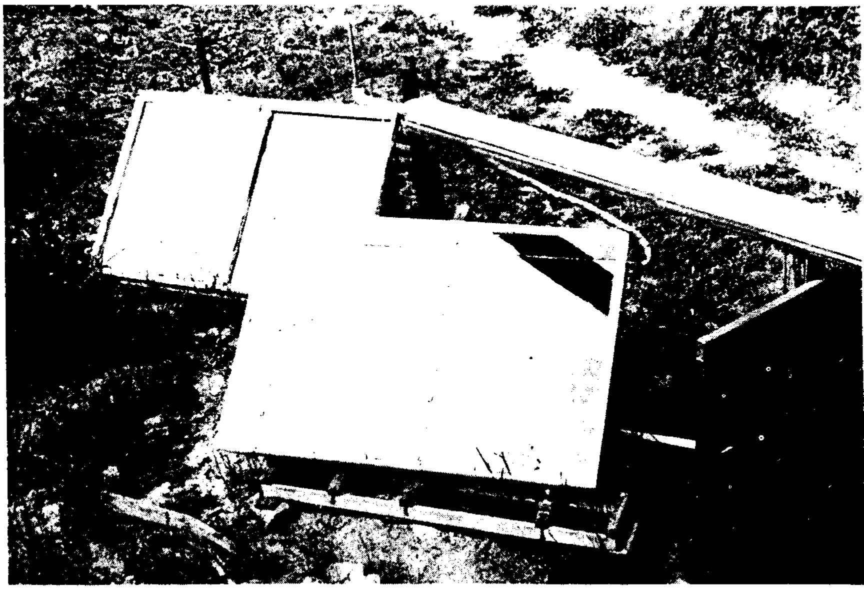
FIG.17 Flow Diagram of Sludge-Algae-Methane Conversion System

that has real potential for the homestead or small farm.[53,66-69] Space does not permit even a brief discussion of the considerations: (1) cultivated algae, (2) pond design and operation, (3) harvesting of algae, (4) digestion of algae, (5) efficiency and yield. Hopefully, with experience, we can begin to develop practical aspects of these ideas in future Newsletters.









(From Upper Left,Clockwise): Chinese Bamboo Trellis with Lathe House in Background; Drum Digester Heater; Drum Digesters; Solar Water Heater.

BUILDING A SUMP DIGESTER

FIG.18 Original Sump Digester. Upper Drums Have Been Forced Up by Methane

This is the simplest type of methane digester, since gas is stored in a cover floating over the digester. It can be made very cheaply and it demonstrates that manure does decompose anaerobically (without air), and that it generates a surprising amount of gas.

Sump digesters can be made of any two cylinders which fit inside one another, such as drums, buckets, coffee cans, etc. The sump digester described below is made of a 30 gallon drum fit into a 50 gallon drum.

Making Starter Brew

Before starting, read the Safety Precautions WARNING (#11 below).

One of the first steps in the construction of any sized unit is the brewing up of a batch of starter material. (Unless you're lucky enough to have an operating digester in your area, from which you can get some bacteria.)

It takes weeks and even months to cultivate the strain of bacteria that functions best on the manure being used locally. Once you have your starter going, though, like a sourdough bread or yogurt culture, you can have it for a long time.

Starter brew can be generated in a 1 or 5 gallon glass bottle. Care must be taken to fill the bottle only about ¼ full with either (a) active supernatant from a local sewage works or (b) the runoff from the low point on the land of any intensive stock farm in your district. Fill ¼ more with fresh dung. Leave the other ½ of the bottle for fresh manure additions at weekly intervals. Never fill to near the screw cap, since foaming could block off the opening and burst the bottle. Of course, the screw cap must be left loose to keep the bottle from exploding, except when agitating the bottle. It is a pecularity of methane brews that a slight agitation when adding material is beneficial, but that continuous agitation has an adverse effect.

1) Get two metal drums, one 30 gallon with an outlet on top and one 50 gallon. (Fig. 19a.)
2) Remove the top of the 50 gallon drum and the bottom of the 30 gallon drum.
3) Fit a valve into the small outlet in the top of the 30 gallon drum. Solder or weld it securely. This will be the gas outlet.
4) Firmly tape a hose to the outlet pipe with polyvinyl chloride tape (adhesive on one side only).
5) The hose can be led to an inner tube to be filled with gas for storage (Inner Tube Digester, Section 10); or lead directly to a simple burner (Inner Tube Digester, Section 11).

6)The 50 gallon drum is ready to be filled. It should be filled only to the <u>height of the 30 gallon drum</u> with a mixture of <u>half slurry</u> and half starter "brew," Fig. 19a.

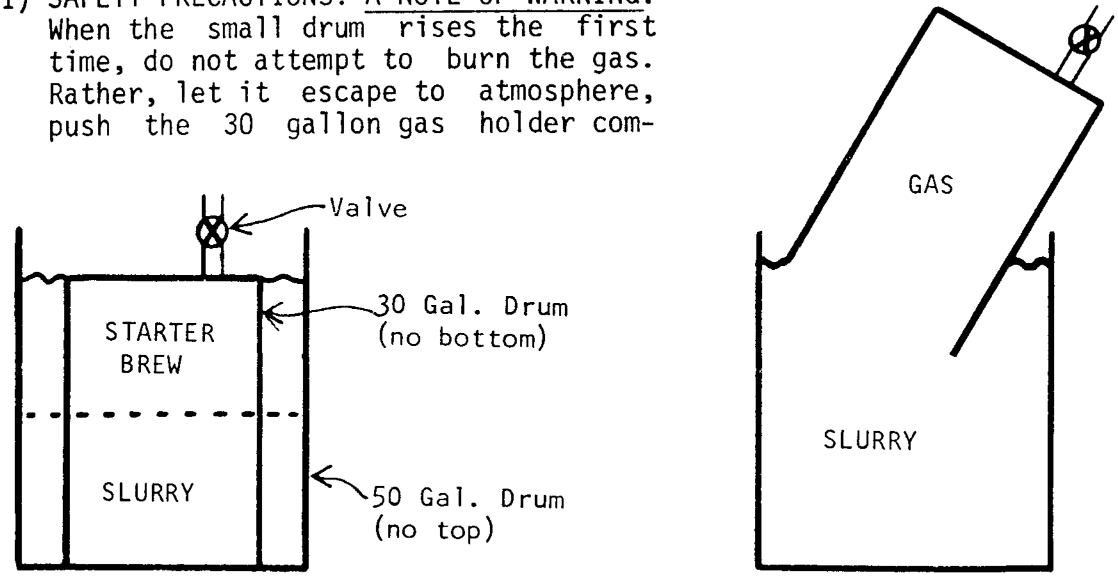
7) Make a slurry the thickness of cream by mixing fresh, raw manure with warm or hot water, 90° to 95°F.
8) To this, add an equal amount of starter "brew."
9) With the valve <u>open</u>, sink the 30 gallon drum all the way down into the slurry and starter mixture (Figure 19). This <u>must</u> exclude all the air from the 30 gallon drum. Then <u>close</u> the valve.
10) In cool climates, active compost can be packed around the outer drum, to maintain a steady temperature of between 80° and 95°F. After about three weeks, gas should begin to generate. The smaller drum will fill slowly with gas and rise above the surface of the slurry (Figures 18, 19b).
11) SAFETY PRECAUTIONS: <u>A NOTE OF WARNING</u>. When the small drum rises the first time, do not attempt to burn the gas. Rather, let it escape to atmosphere, push the 30 gallon gas holder completely down into the slurry again, shut off the valve and allow it to rise a second time. This is to insure that no air is mixed with the gas. A gas and air mixture is <u>highly explosive</u> between the range of 1 part in 4, to 1 in 14. Even outside this range it could be dangerous. Also, the first gas yield probably will not light anyway due to a high proportion of carbon dioxide when fermentation first starts. When burning the gas, open the valve only slightly, press down lightly on the 30 gallon drum to create a positive pressure on the gas. Close the valve before releasing the pressure.

In rare cases there occurs an abundance of gray foamy bubbles at about the time when fermentation starts. If this happens leave the digester alone for a few days. Do not feed any raw material. If the digester is heated, reduce the heat.

12) Periodic supplies of fresh raw material should be "fed" in to keep the digestion going. This can vary from daily to once every three months depending on the requirements of the user and the digester design.

To feed this digester it is necessary to remove the 30 gallon drum, take out about 5 gallons of material and replace it with fresh slurry. Again press down the small drum to exclude air.

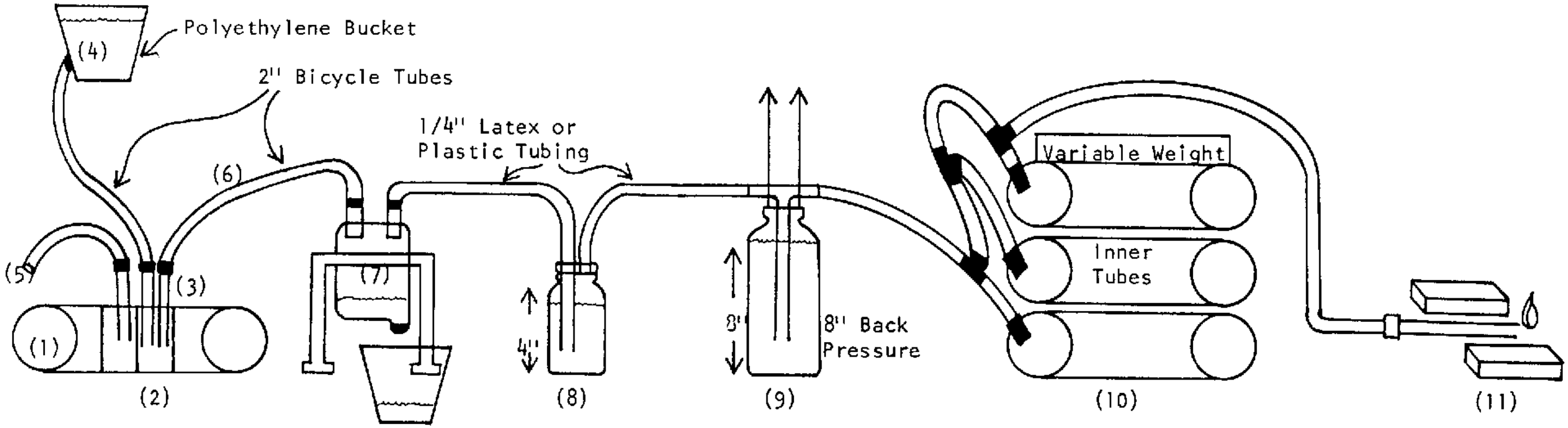
Sump designs are particularly good units to learn from since they are so easy to build and maintain.



19A (Before)

19B (After)

FIG. 19A & B Sump Digester Before and After Methane Production



(1) Main Chamber of Digester

(2) The Plastic Cylinder

(3) Inlet, Gas, and Effluent Pipes

(4) Inlet Feeding Bucket

(5) The Effluent Outlet

(6) The Gas and Scum Outlet

(7) Scum Collector

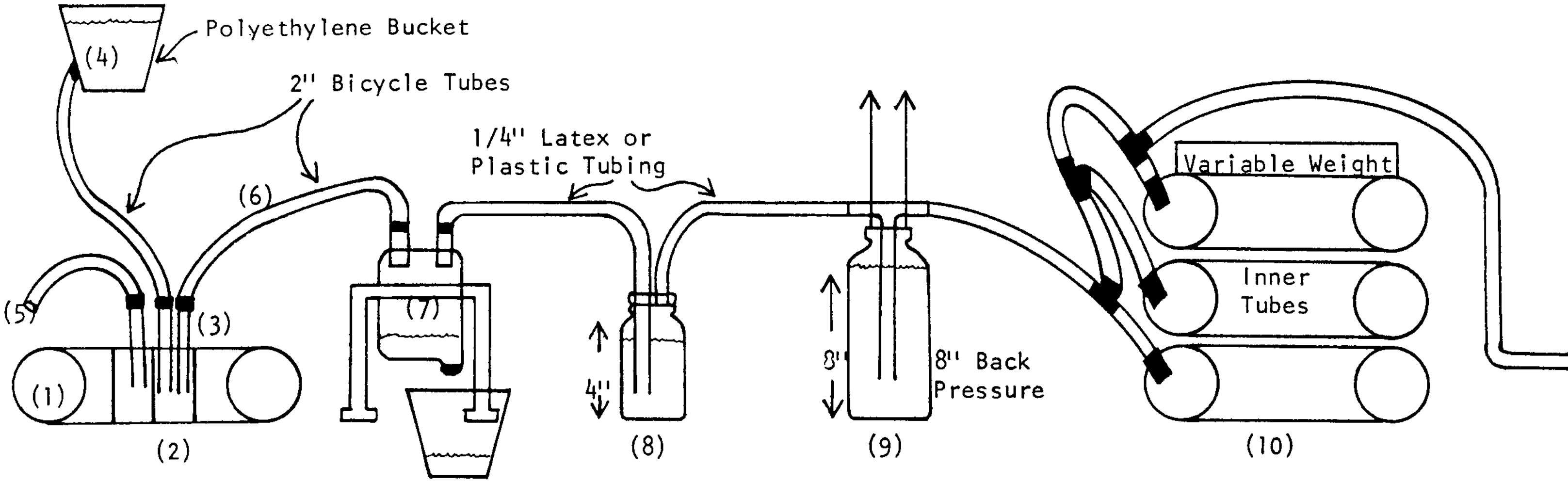
(8) Gas Yield Indicator

(9) Pressure Releaser

(10) Inner Tube Storage

(11) Burner

FIG.20 DIAGRAM OF INNER TUBE DIGESTER



(1) Main Chamber of Digester

(2) The Plastic Cylinder

(3) Inlet, Gas, and Effluent Pipes

(4) Inlet Feeding Bucket

(5) The Effluent Outlet

(6) The Gas and Scum Outlet

(7) Scum Collector

(8) Gas Yield Indicator

(9) Pressure Releaser

(10) Inner Tube Storage

(11) Burner

INNER TUBE DIGESTER

> *I hope that in these times of ever increasing pressures in the energy crisis, that this inner tube unit will be made available to the millions on millions of people around the world who could benefit from it. To those on the land eking out an existence, I dedicate this unit. As a morsel of technology, it might well benefit them more than a man standing on the moon.*
>
> *L. John Fry*

The following inner tube unit was made at a cost of about $20. If it could be produced in quantity, the cost might be as low as $2 using cheaper material.

The unit has no working parts and should last the normal life of the materials used.

This inner tube digester has been tested out in Santa Barbara for over 18 months, during which all the "bugs" have been eliminated. It is a thoroughly reliable device.

NOTE: Read "SAFETY PRECAUTIONS" (#16 below) and "STARTING THE BACTERIAL BREW" (Sump Digester) before beginning construction.

Inner Tube Digester Parts List

1. Truck or tractor sized inner tube
2. Plexiglass (1/8" thick) 7" x 28" (or circumference of inner tube). Plexiglass 10" x 10".
3. Methyl chloride liquid (hobby shop)
4. Plexiglass tubes (2" x 3')
5. 2 2-inch diameter bicycle inner tubes
6. Polyvinyl-chloride (PVC) tape
7. 3 5-gallon polyethylene buckets
8. 5-gallon container - metal or plastic - for scum collector
9. Epoxy resin
10. Rubber sealing compound
11. Rubber cement
12. Wire
13. Pipe adapter (kind that goes from steel to plastic)
14. 1/4" rubber or latex hose
15. 1 gallon jug with cork with 2 1/4-inch holes
16. Bottle
17. T pieces
18. Truck inner tubes (storage)
19. Screw type pinch clamp.

I. Main Chamber of the Digester

This consists of a discarded truck-sized (or better still, a tractor-sized) inner tube.

1. Test carefully for leaks. (Bear in mind that every part going into the digester should be carefully tested for leaks. Any gas escaping, out of even a pinhole, is a potential cause of explosion.)

2. Patch over, if necessary. If there is a large gash or hole, cut that portion completely out of the tube.
3. Make a clean cut at right angles to the long circumference of the tube. This is where the plastic cylinder will be inserted (Fig. 21).
4. Thoroughly wash and dry the inside of the tube. The inner tube is now ready for the plastic insert.

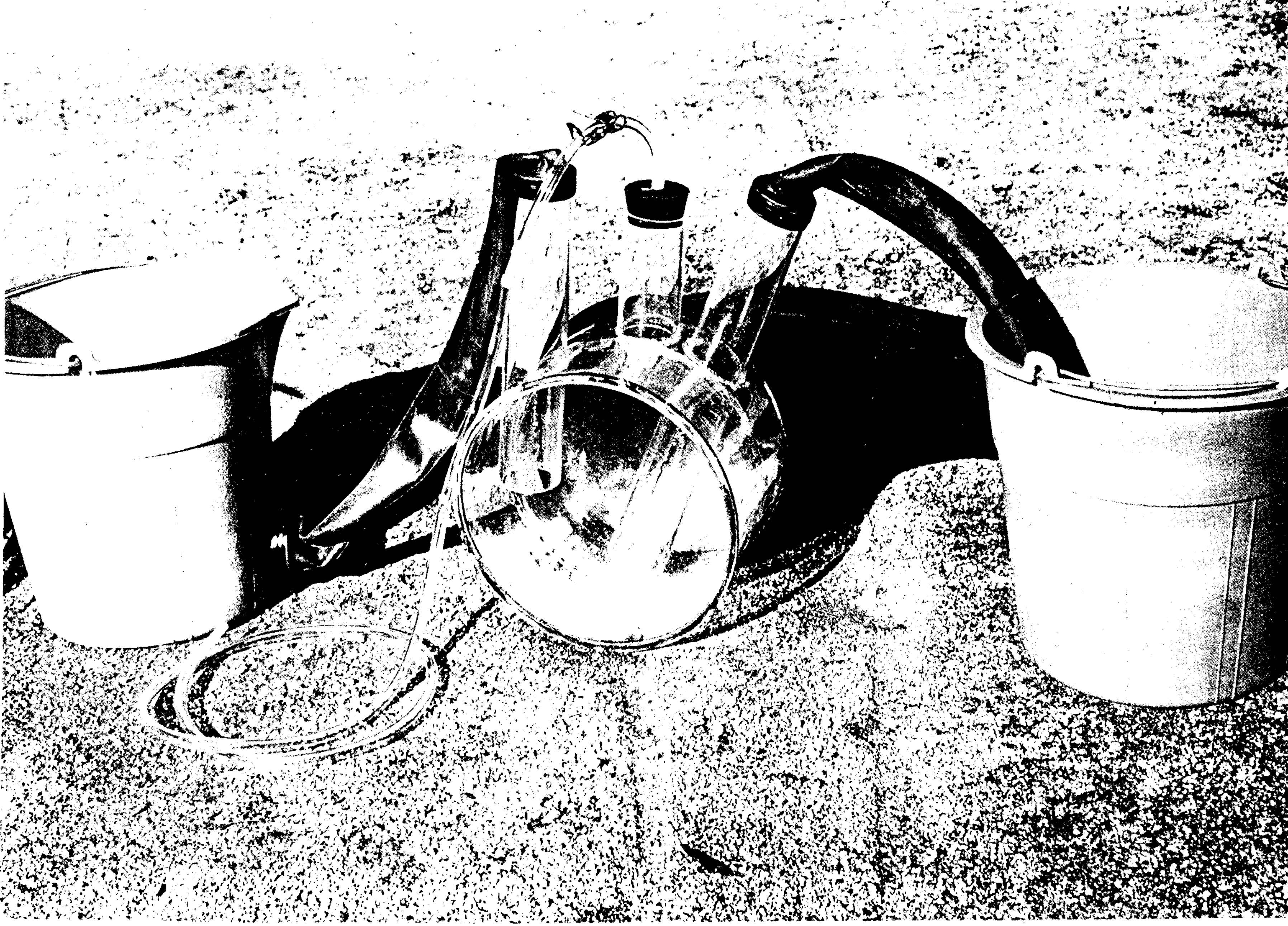


FIG.21 Attachment of Pipes and Buckets

FIG.22 Preparation of the Inner Tube

II. The Plastic Insert

A. The Plastic Cylinder

1. Heat a 1/8" thick x 7" wide x about 28" long (length should be the circumference around the opening of the inner tube, picture 2) piece of plexiglass in a 400° oven, until it will bend (about 5 minutes).
2. Bend it around a saucepan or other cylindrical object which has the same circumference as your inner tube. Make the ends of the plexiglass meet to form a cylinder.
3. Glue the ends together by generously applying methyl-chloride glue. The glue can be made by melting some acrylic scraps in methyl-chloride.
4. Cut a round flat piece of plexiglass to fit inside the cylinder, and glue this plate with methyl-chloride glue midway inside the cylinder (Figures 23,24). This will make a central dividing wall to keep the manure from circling around and around the inner tube.
5. The lip. Heat a 1/4" x 29" strip in a 400° oven for 5 or 10 minutes. Wrap around the outside edge of the plastic cylinder to form a rim. (This will help keep the inner tube from sliding off the cylinder.) Hold the hot plastic strip in place with clothespins until cold. Eyedrop straight methylchloride between the two surfaces. Keep the clothespins on until surfaces are securely stuck together. Repeat for other cylinder edge.

B. The Inlet, Gas and Effluent Pipes

These are constructed of 2" diameter, heavy-duty plexiglass tubes. The inlet pipe will be inserted on one side of the central dividing wall of the cylinder and the gas and effluent tubes on the other side, as follows (Figures 23,24):

1. Make 3, 2" diameter holes, one on one side of the center divider, two on the other side (Figures 23, 24). Exact placement is not important, but must be so close to the baffle as to touch it and in the general area shown in Figure 3. Apply a little glue at the touching point for added strength. Allow at least 1" between the tubes to the lip of the cylinder (Figure 2). We made the holes by burning around the outside edge of the hole with a simple soldering iron. A FRET saw would do a better job.

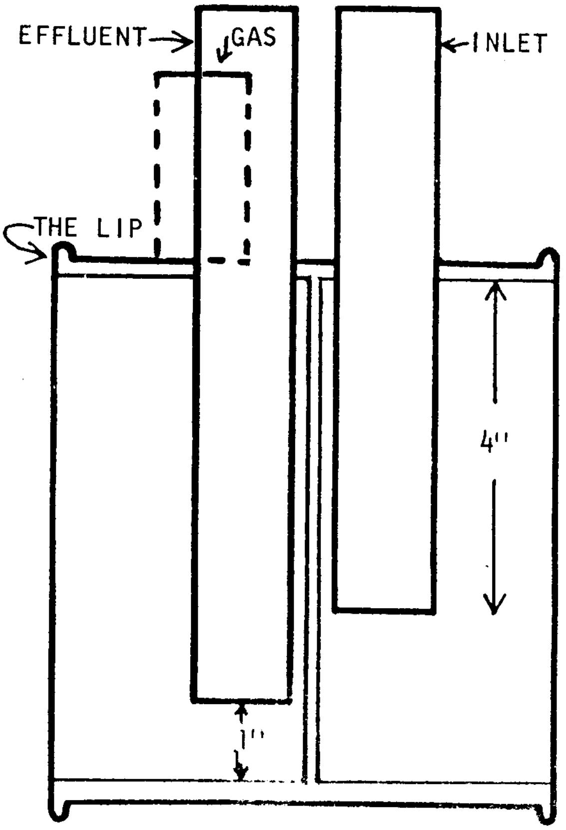


FIG.23 Cross Section of the Plastic Insert

Inlet Pipe:

2. Ream out the inlet pipe hole to allow the inlet pipe to go in at a slight angle (Figure 24). This angle helps the mixing in the inner tube, by tending to make the incoming raw slurry revolve in the tube.
3. Insert the pipe in at an angle, 4" down into the cylinder (Figure 23). The distance the pipe sticks out the top of the cylinder is not important.
4. To eliminate leaks, seal the seam around the pipe and hole with: (1) a layer of melted plexiglass and methylchloride and then (2) a layer of rubber sealing compound available in hardware stores.

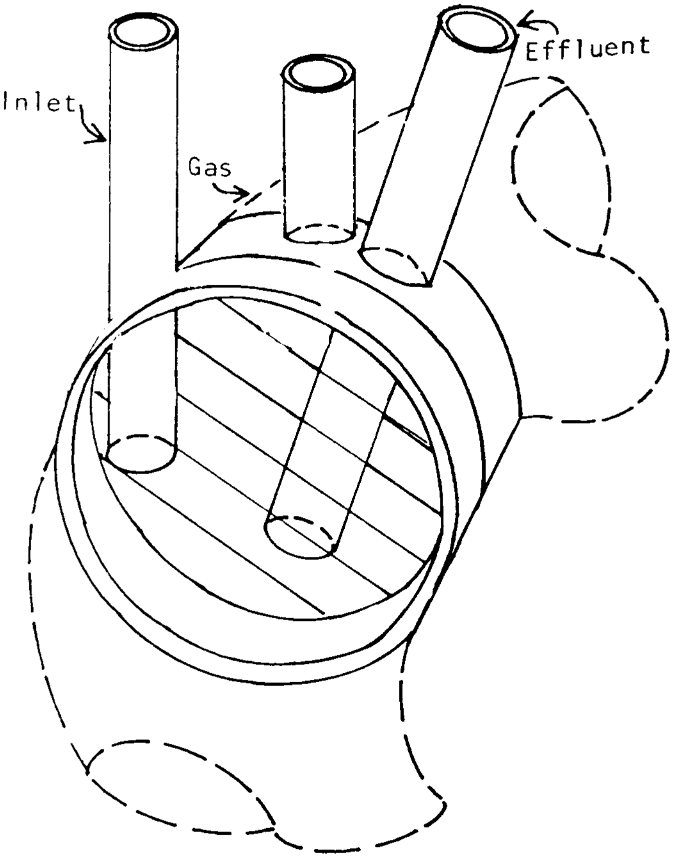


FIG.24 Placement of Pipes In Plastic Cylinder (Note Angle of Pipes)

Gas Outlet Pipe:

5. This pipe is glued to the top of the cylinder (Figure 23). Again, the length of the pipe sticking out the top of the cylinder should be about 6 inches. Length in Fig. 23 is about right.
6. Seal as above.

Effluent Pipe:

7. Insert the effluent pipe straight down into the cylinder to 1" from the bottom. (Figure 23.) Again 6" above top.
8. Seal seams as above. Where the inlet and outlet pipes touch the center baffle, apply a little glue to give added strength to them, as mentioned above.

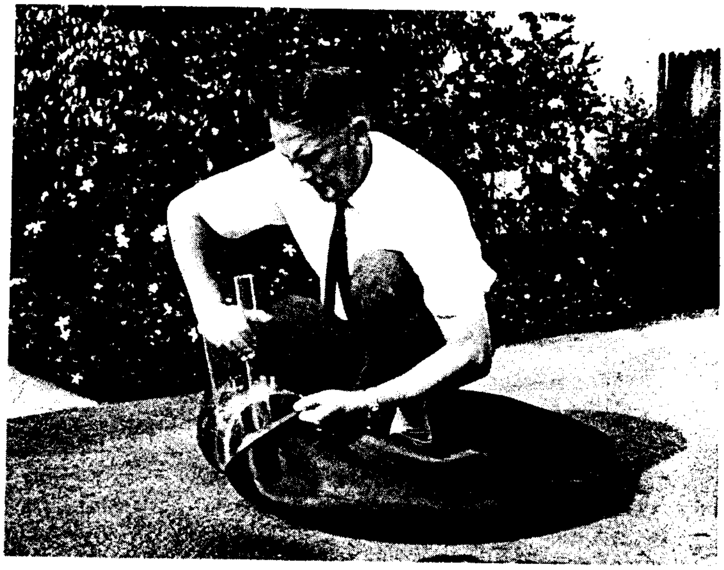
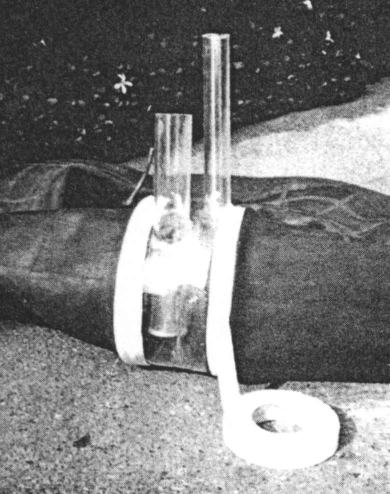


FIG.25 Placing Cylinder in The Inner Tube

III. Attaching the Cylinder to the Inner Tube

1. Paint the inside of each open end of the inner tube to a depth of about 2" with any kind of rubber cement (Fig. 22).
2. Insert the cylinder into the inner tube, past the lip, to a distance far enough to ensure a good seal (Fig. 25).
3. Tape in place with polyvinyl-chloride (PVC) tape to hold cylinder and inner tube securely in position (Fig. 26).
4. Then wind wire twice around on the tape. Twist the ends of the wire to make a very tight hold. (The wire and the tape are never removed.)



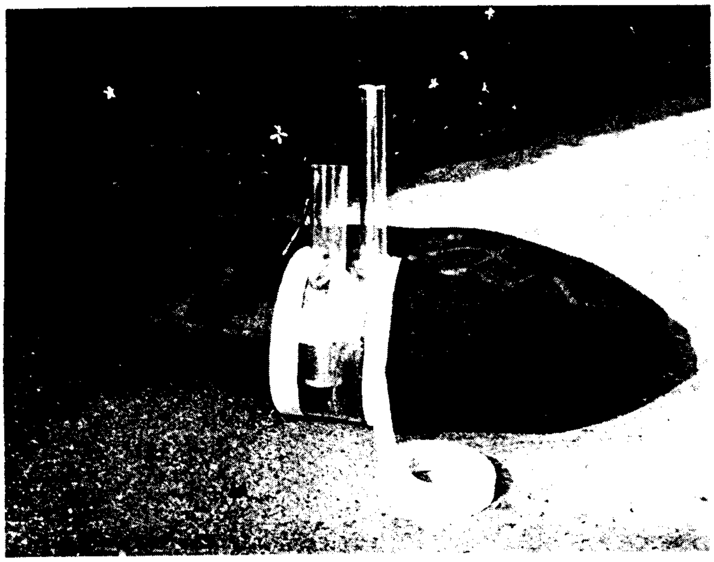


FIG.26 Fastening Tube to Plexiglass Cylinder

IV. Inlet Fittings and Attachment of the Slurry (Feeding) Bucket

1. Cut a 2" diameter balloon bicycle inner tube to a length of about 3', after checking for leaks.
2. Place it on the inlet pipe (Fig. 21).
3. Tape with PVC tape which is adhesive on one side only, by stretching the tape very tightly around the pipe and inner tube. Make sure it is taped firmly.

Attachment of Bucket:

4. Burn a hole in the polyethylene slurry bucket, 1" from the bottom of the bucket. (Figures 20 and 22.) When the hose is attached to this hole off the bottom, it will allow sand, feathers and other heavy indigestible material to settle to the bottom of the bucket and be left behind when feeding the slurry to the digester.
5. Attach an adapter in the hole of the type used to go between steel and plastic pipe
6. Attach a length of 2" bicycle inner tube to the adapter in the slurry bucket with PVC tape. The tube should be long enough to allow the bucket to be held up for gravity feeding the slurry into the digester (Figure 20).

V. Fitting the Effluent Pipe

1. Simply tape another length of 2" bicycle inner tube to the effluent pipe (Fig. 21).
2. Hang the tube in a bucket.

VI. Fitting the Gas Outlet

1. Attach a 2' or 3' length of the 2" bicycle tire tubing to the gas outlet with PVC tape.
2. Lead it to the scum collector.

VII. The Scum Collector

If you remember, scum is a mixture of (1) floating material (bedding, straw, feathers, etc.) and (2) liquid interspersed with (3) gas bubbles. Scum rises up with the gas out of the gas outlet. Scum formation is a major problem in any sized digester. On this scale, though, it is simple to eliminate.

1. Select a metal or firm polyethylene container with at least a 2" wide filler cap. We used a 5 gallon, plastic milk container. It is much easier to attach the pipes to a metal container, though.
2. Turn the container upside-down (filler cap underneath) and make a 2" hole in the top. Solder or weld a short length of 2" wide metal pipe to the top (this was the bottom of the container originally) (Fig. 27).
3. Firmly tape the inner tube coming from the gas outlet to the short length of pipe. Scum will be forced through the gas outlet, through the cycle tube and drop in the container. Gas will continue on its way to storage via:

Gas Outlet Continuation:

4. Solder or weld a second pipe at another point on the top of the container. The hole should be ¼" in diameter (Fig. 27).
5. Tape a length of ¼" rubber or latex hose to the ¼" pipe. This will go to the gas yield indicator bottle (Figure 20).

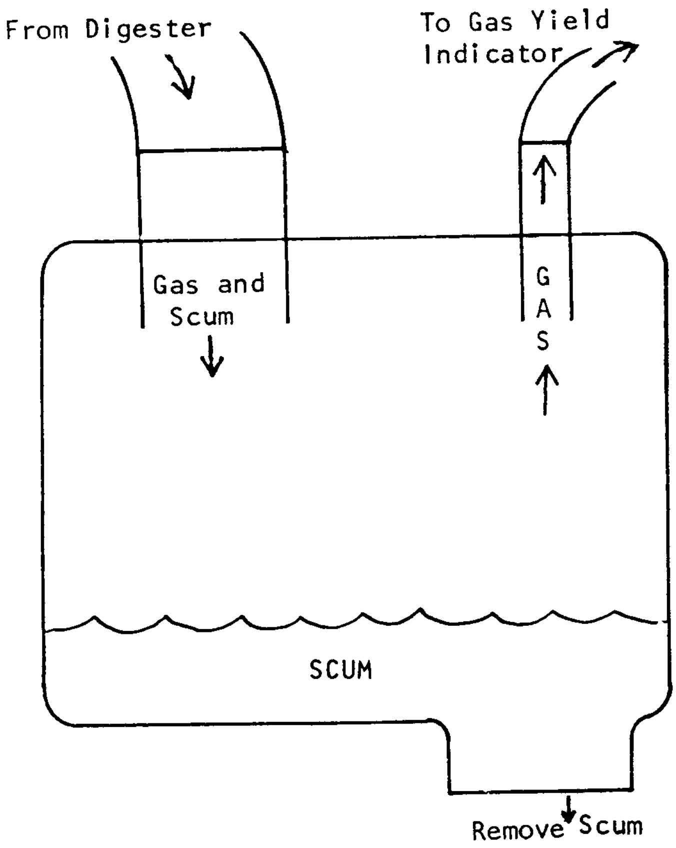


FIG.27 SCum Collector

VIII. Gas Yield Indicator

This is a jug of water, through which the gas from the digester bubbles. It is a nice way to see that your digester is producing gas. (Also, if the water is changed frequently, it will filter out some of the carbon dioxide in the gas.)

1. Take a 1 gallon jug and place a cork with two ¼" holes in the bottle's mouth (Fig. 28).
2. Place between the scum accumulator and pressure release bottle (Figure 20).
3. Fill the jug with about 6" of water.
4. Run the hose from the scum accumulator, through one cork hole and to 4" below the level of water in the bottle.
5. Run another piece of ¼" rubber or latex tubing out of the other cork hole, to the pressure release (overflow) bottle.

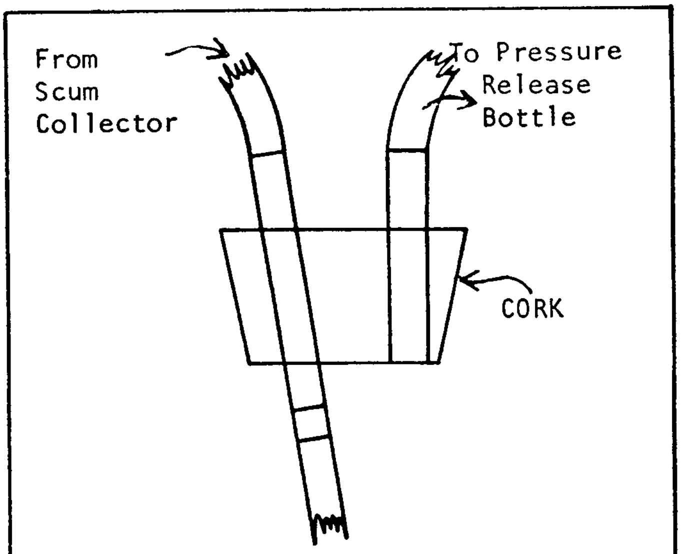


FIG.28 Gas Yield Indicator

IX. Pressure Release Bottle

This bottle is placed between the gas yield indicator and inner tube storage (Fig. 20). It allows the release of extra pressure in the inner tube storage, or overflow of gas to escape through the water in the bottle, rise to the atmosphere, and disperse harmlessly.

1. A 12" or so deep bottle is fitted with a "T" piece (Fig. 29).
2. The tubing from the gas yield indicator is attached to one arm of the "T" and a tubing to storage is attached to the other arm.
3. A plastic tubing is attached to the leg of the "T" piece and immersed in 8" of water.
4. In the event that the gas pressure is more than 8" water gauge, the gas will escape through the water, to the atmosphere.

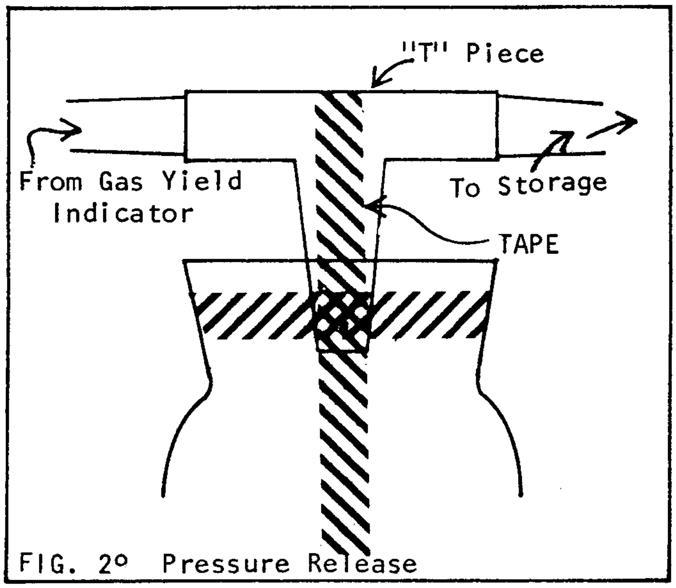


FIG. 2° Pressure Release

X. Inner Tube Storage

1. Gas can be stored in one or a number of truck inner tubes, stacked on each other and interconnected with "T" pieces (Figure 20). Check for leaks and patch if necessary.
2. A weight, such as pieces of lumber, are placed on the topmost tube to create pressure.

XI. Burner

The gas produced by this digester is about 700 BTU per cubic foot at sea level (585 BTU at 6000 ft. altitude). The average daily production of this system is 5 cubic feet; enough to bring ½ gallon of water to the boil and keep it there 20 minutes. THIS IS ENOUGH TO COOK A MEAL.

1. The simplest burner can be a piece of ½" metal pipe 18" to 2' long.
2. Place on a reducer to ¼" to fit the tubing from storage.
3. Place some sort of on/off clamp on the tubing, plus a pinch screw to regulate the amount of gas (Fig. 30).
4. The ½" pipe is laid between 2 bricks and a third brick is placed on the pipe to hold it in position.

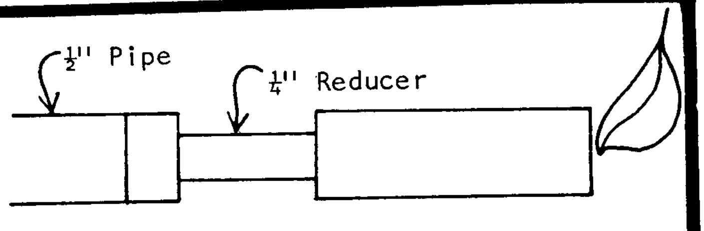


FIG.30 Simple Burner

XII. Temperature

Methane bacteria only work their best when kept warm. The best temperature is 95°F. Without artificial heating the only areas in which a digester will function is in or near the tropics. Thus, without supplemental heat, this unit is limited to the tropics. Alternatively, if placed in an insulated box and heated by two 100 watt light bulbs in series (this takes very little electricity and the bulbs last a long time), with a thermostat set to 95° in the circuit, it can be operated almost anywhere.

XIII The Bacterial Brew

Add to Manure Contents (See Sump Digester)

XIV. Feeding

1. The daily routine consists of collecting three 1-pound coffee cans full of dry chicken manure. (Almost any kind of manure is suitable, but to avoid excessive scum formation, a finer texture manure is better. Chicken or pig manure is probably the most suitable.)
2. Stir in the slurry bucket with 3/4 gallon of water or urine to form a slurry. If you can use urine instead of water, it will aid fermentation and make the effluent a better fertilizer after digestion.
3. Now raise the bucket high so that the slurry will gravity feed into the digester. It will mix with yesterday's load, which by now has been "seeded" with active, hungry bacteria. The inlet pipe (set at an angle) helps the mixing, by tending to make the incoming raw slurry revolve in the inner tube.
4. Dispose of the feathers, fiber, sand, etc., left in the bottom of the bucket.

The action inside the digester is the same on any scale. The raw material, heavily seeded, tends to skulk along the floor of the digester but as the bacteria work on it, gas is formed and lightens it in relation to surrounding material. Vertical motion begins, throwing up chunks of dung and bubbles of gas. Each load displaces the last, around the circuit round the inner tube. At some stage each and every particle has to pass a point of maximum fermentation where the whole mass seethes and bubbles furiously. Up and down currents mix the contents thoroughly. From there the fermentation slows and stratification begins into the layers of gas, scum, supernatant and sludge...the spent portion of the original solids. Through digestion this sludge will have contracted considerably from the original raw state.

Failure of the bacterial "brew" will occur if excessive loads of manure are used. Keep to 3-1 pound coffee cans daily. If not fed daily for one reason or another and the unit is left without "food" for a week for instance, start it up again with four and one-half coffee cans full the first day and continue as usual afterwards. Do not feed in back coffee cans full for each missed day (21 cans for 7 missed days).

A second reason of failure of the brew is an excess of water, particularly cold water.

XV. Removing Scum and Effluent

A. Scum

1. When the scum collector container feels heavy, remove the filler cap from the bottom of the scum container and let the scum out.
2. Care must be taken that air is not allowed to enter the container at this point.

B. Effluent

3. Effluent is drawn off daily or so to the extent of approximately half of volume of daily input at feeding. The other half of daily input is accounted for as (1) gas and (2) contraction during fermentation.
4. The superior fertilizing value of the effluent is discussed elsewhere. This inner tube digester will produce enough to improve growth of plants on an area of 2,152 sq. ft. per year - a good sized vegetable patch.

XVI. Safety Precautions

PRECAUTIONS IN GAS USAGE

Gas will burn with a hot flame when ignited as it leaves the burner (in contact with air). But if gas and air are mixed together in proportions of 1 part in 4 to 1 in 14 and then ignited in a closed area or container, a violent explosion will ensue.

To avoid any possibility of explosion in this sized unit, the first time the digester produces enough gas to fill the pipes, scum accumulator and storage tanks, this gas should be allowed to disperse to the atmosphere. The second time it fills up will be relatively - almost certainly - safe to light. The flame is so clean and blue that it will be difficult to see in sunlight but clearly visible at night.

The second safety factor is to keep a positive (however slight) pressure of gas in the pipelines and storage, so that air is never drawn into any part of the unit. (Weights on the storage inner tubes, pressure on the main tube when emptying the scum, so the pipes won't collapse).

The third safety factor is to check the unit daily for leaks; there will be a discoloration of the tubing in places where the gas has leaked out.

Finally, smell is important in safety handling. Never light a match in a room with a strong smell of gas - or even a slight smell. Air out the room first.

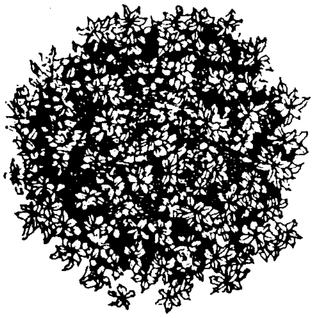
XVII. Lighting the Flame

1. A small gas flame can be lit at the open end, provided the gas flow is held low. If the flow is too strong, the flame will burn inches away from the open end and be difficult to control The adapter on the burner decreases the flow.

XVIII. pH

To keep track of pH values, narrow range litmus paper with a range from 6.5 to 8.5 or 9 can be used to check effluent. In my experience of digesting animal manures, a healthy brew, working at top efficiency will have an effluent pH of around 8.5. This is in contrast to all published literature on digestion of sewage plant solids in which a working range of 7 to 7.6 is considered average. If it should drop to 7.6 or so in this unit, reduce feeding to miss the first day, then half feed until the pH of the effluent rises to 8 at least.

Should the pH drop as low as 7 or 7.2, add a cup of ammonia (the ordinary ammonia bought in a store) to the raw slurry at the next feed in. Reduce the feed in (or loading) slightly from then on.



NECESSITY IS THE MOTHER OF INVENTION

A Brief Personal Account of The First Large-Scale Displacement Digester

by L. John Fry

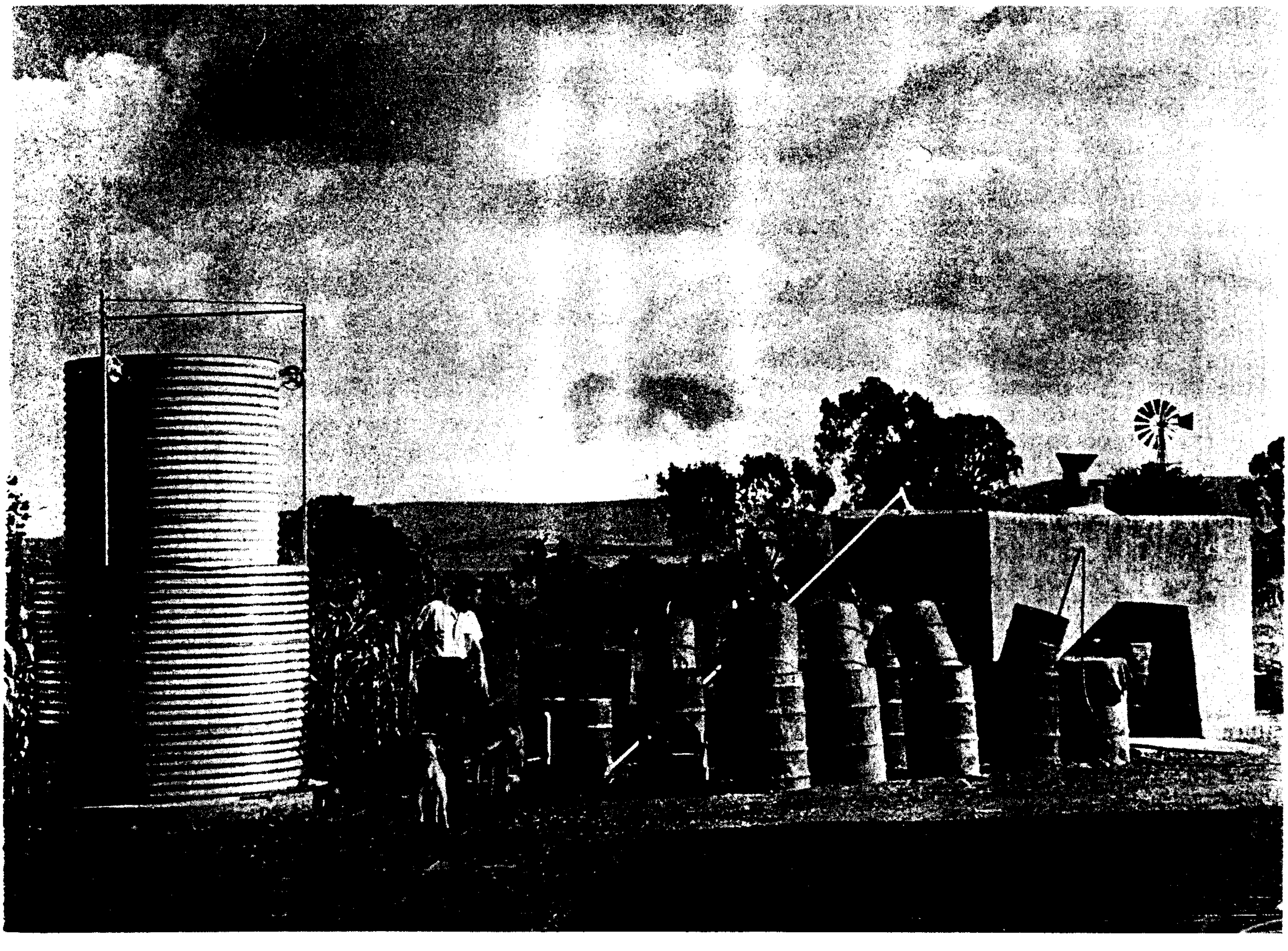


FIG.31 Where it All Began. L.J.Fry's South Africa Farm

I owned and operated a hog farm outside Johannesburg. The average standing population was 1000. It was a model farm on 25 acres and ran most efficiently except for one considerable problem: the two tons (wet weight) of manure produced daily. For years I composted it and spread it inches thick over the farm and used a rotary hoe to chop it into the soil. This required scraping it up, piling it, watering it, and turning the piles twice, at least, then loading it on a truck and finally spreading it more or less evenly. Heavy rains played havoc with it at times. Often drought required using precious water to dampen the compost. It required a lot of labor.

I then read of a suggestion that manure might decompose in the same manner as solids do in most sewage works, namely decomposition in a liquid form by methane bacteria. Would it work on pig manure also?

I went to the main sewage treatment plant in Johannesburg, and was taken round the entire unit. I found the decomposition of solids (called digestion) most interesting. If such solids could undergo a complete metamorphosis as to be unrecognizable from the raw product, then manure solids would presumably do the same. There was one big difference. Municipal waste is washed down the sewer lines with large quantities of water. On the other hand, manure was collected by shovel and carted by wheelbarrow. Water had to be added to turn it into a slurry.

After many months, frequent visits to the sewage works, and long hours in the local University library, I took back to the farm a sample of actively working bacteria in a sealed container as a "starter" to try out on pig manure. I used a series of 50 gallon oil drums, cut the tops off and poured in a slurry of pig manure. Into each drum I then added a measured quantity of "starter," some from the sewage works and some from a sump located at the lowest point below the piggery. Next I fitted 30 gallon drums into the slurry. Some three weeks later the drum with the "sump starter" began to generate gas. The smaller drum filled slowly with gas and rose above the surface of the slurry.

It was then the summer of 1956-1957, days in the low 80°F, nights 20° cooler. It was surprising that the sharp variations of 20°F did not kill the bacterial "brew." The first drum to rise was the one half fresh raw pig slurry and half "brew" from the sump. All the others followed eventually, some weeks later, probably due to insufficient starter "brew."

DESIGN OF THE FIRST FULL SCALE DISPLACEMENT METHANE PLANT

After my success with the sump digester and a great deal of "weighing the options" I decided on a plan of twin digesters with fixed roofs and a series of gas holders to store some of the gas generated. Having twin digesters side by side had the advantages of:

1) Using one as a primary and the other as a secondary digester.
2) Should the primary be overloaded and have a bacterial breakdown, the secondary would then be available to receive at least part of the load. The primary digester would eventually be brought back to use by splitting the load between the two.
3) Different manures could be used for experimentation.

Digester Description

Outside the digester a basin was made 12' x 8' x 2' deep with the floor sloping to a grid made of angle iron 3' x 6' with a steel screen of 3/8" rod with 1" mesh. The very heavy 3/8" rod was found necessary to withstand the suction pull of the sludge pump and for preventing corrosion. A short ramp up to the basin allowed for wheelbarrows of manure to be run up and tipped into the basin. This was done daily and amounted to about 26 wheelbarrow loads of about 2 cubic feet each.

Water (about 250 gallons) was then hosed in and the whole mass raked with a garden rake. When mixed to a slurry, the pump was started and the mass moved to a sand trap. A simple but efficient system was used.

A drum with a tight fitting lid and sturdy clamp had an inlet half way down and an outlet near the top. Sand settled to the bottom. I was inefficient in that the sand had to be cleaned out daily and this could be done only after the top half was cleaned out first.

From there the raw slurry entered the digester through a short straight pipe, the outside portion being 2' above the level of the inside of the digester and the digester end down to 1' from the floor. Thus no air entered the digester.

The digesters were each 50' long and 11' wide, concrete floor flat at the inlet end and sloping down sharply to the far end.

FIG.32 Digester with Storage Tank in Background

At the lowest point was another straight pipe as a digester outlet made of 3" pipe with a gate valve. It is important to note that all pipes in a digester be straight to allow for rodding out. It is necessary from time to time.

Vital statistics to digester design and loading were brought to light by this first unit and will be discussed in detail under the heading of 1) loading rates, 2) displacement 3) scum accumulation and 4) gas yields.

In anticipation of having a serious problem with scum accumulation I set short lengths of pipe into the concrete roof at various angles pointing down to the digester contents, in line with the long sides of the digester. The intention was to recirculate supernatant under pressure with a sludge pump to break the scum layer by getting the whole digester contents to rotate. The scum would then be broken up and forced into the more liquid mass.

In practice all that happened was that the jet of supernatant made a neat hole in the scum and the mass did not move.

As a second measure, I let in a series of pipes through the floor of the digesters and recirculated gas through a compressor to bubble up and crack the scum. This might have been effective if used daily or weekly with absolute regularity. But once the scum became a foot thick it would no longer break up. Also the vent holes in the floor became clogged with sand. Both methods were failures. Scum remained a major problem.

I suspect that many have encountered similar difficulties and have abandoned methane digestion in favor of other methods of treatment, solely because of it. In a small digester it is not too difficult to handle (Inner Tube Digester). In a large scale unit it can build up to 1 foot depth in a year. Scum consists of tightly knit scraps of straw from bedding or animal feed, held together by a dark colored sticky substance thrown up through the supernatant levels in the bubbling zone. It covers the entire surface more or less evenly. Here we come to another advantage of the displacement digester.

Since the scum forms evenly, the larger the surface area it has to form on, the longer it takes before it becomes a thick mat. It takes up so much digester space that the whole digester becomes overloaded due to the slurry being forced through too quickly. It then has to be either broken up and mixed back into the fermentation or physically removed. It is my experience that when it is broken up it merely reforms again within a short time. Little, if any, is decomposed and withdrawn with the effluent. The problem, therefore, resolves itself to a question of physical removal at intervals.

In order to make room in the digester to load in the daily quota of slurry, withdrawals were made from the outlet end from the lowest point, that is, the sludge outlet. I withdrew 3 or 4 days' worth of effluent at a time, of 500 gallons each. To do this I backed my tank truck into a short excavation so that the top of the tanker was about 2 feet below the digester roof level. A 3" plastic connection and two 3" valves completed the withdrawal circuit. On the top of the tank truck was an opening to vent out air when the tanker was being filled. Into this I fitted a tennis ball in a cage so that when sludge rose to the vent joint, the tennis ball shut off when the tank filled. This prevented messy overflows.

The effluent was then spread on fields as a fertilizer. There was also a strong demand for it in Johannesburg where it was used in winter to bring up the grass faster in the spring than any other known method.

Gas yield from the two digesters averaged 8,000 cubic feet per day. The gas was analyzed at the City Gas Works at 711 BTU per cubic foot (sea level value). Sometimes the gas yield went as high as 12,000 ft^3 for weeks at a time, after a digester had recently been returned to work. It was a matter of delayed action of the brew. From the time the digester was half full to the time it was full (about 3 weeks), the bacteria did not generate much gas. At about the time it filled up, the backlog would surge gas production.

To provide the heat to the first displacement digester, I built an engine room adjacent to the digester outlet end. The engine was fueled by 6000 cubic feet of gas daily and the cooling water and exhaust gases were returned to the digester to maintain the optimum temperature. The exhaust gas was led through a series of boulders against one digester wall. The boulders were packed with dry earth covered, in turn, by a layer of conceret as weatherproofing.

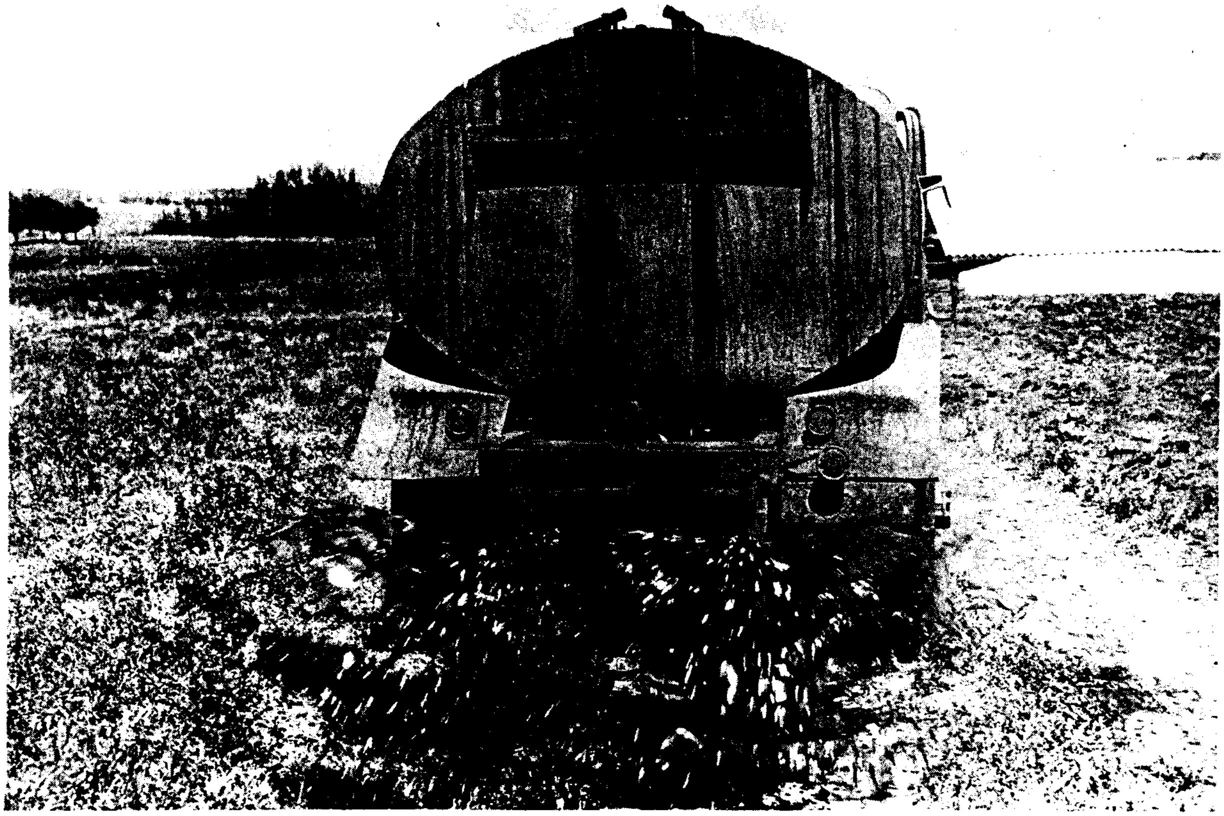


FIG. 33 Spreading the Effluent

The engine design called for a maximum cooling water temperature of 140°F. This coincided exactly with the maximum temperature for pipes laid on the digester floor. If a higher temperature had been used, the sludge would have "caked" on the pipes and prevented the transfer of the heat.

So a small 3/4" pump was installed, driven directly by the engine, and run at slow speed (to improve endurance) to circulate water. In the circuit there was also a 200 gallon header tank to keep the lines full at all times. In winter it was bypassed and in summer the 200 gallon tank was taken into the circuit as a means of cooling the water to prevent the digester temperature from rising over 95°F. The engine and digester combination ran day and night for 6 years, except for occasional stoppages and for repairs.

We are taking the experience gained from this major experiment to draw plans for a series of projects in methane digestion, in a range of sizes. However, it is worth mentioning that the whole methane plant including engine cost about \$10,000 and produced 8000 ft^3 gas daily. At the altitude of 5500 ft above sea level the B.T.U. value was 585 per ft^3. Thus, 4,680 B.T.U.* per day or 46.8 Therms. At the present 1973 price in Santa Barbara this amounts to \$7.57 per day or \$16,578 over the 6 years, in gas alone. The saving in labor in the loading and spreading of manure made for a far faster return on capital. By far the greatest return was neither in gas nor labor saving, but in the value to the soil of the effluent returned as a fertilizing material.

* $\times 10^3$

FIG.34 13 HP Diesel Engine Converted to Run on Methane Gas

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Engine room, summer cooling tank and digester on the first full scale methane power plant to operate on the linear displacement principle. Water heating tower on right was abandonned in the first year.

One day's manure production from 1000 pigs, once digested, spread on crops in 5 minutes.

Table of Contents

CHAPTER 1

How It All Started

I HAVE BEEN ASKED many times why I began to experiment with methane gas production from animal manure — what was it that made me start? Looking back I can recall no single impetus, but rather a combination of forces which seemed to make experimentation inevitable.

Although I had built a complete farm, including sties to accommodate over 1,000 hogs, into one of the best in South Africa, I still had not solved one great problem: what to do about the two tons of manure produced daily. A week's accumulation at this rate meant smells and swarms of flies and this, in turn, brought the health inspector with dark hints that the neighbors were quite prepared to take further steps unless something was done, while also intimating that my permit as a pig farmer might be withdrawn.

His only suggestion was that I build what he called an Otway Pit. This consisted of an excavation some fifty feet deep, fifty feet long and thirty feet wide, lined with brick, surfaced with plaster, and eventually roofed with concrete. It had to have a chimney with fly screening to prevent flies from entering while allowing fumes to escape. When I asked what happens when the pit fills up, he answered that I would simply have to build another one! This struck me as a terrible waste of time, material, labor and space, and directly opposed to my lifelong principle of trying to turn disadvantages into advantages.

Mulling the problems over I remembered a French book I had read with great interest. Titled, Gaz de Fumier (Manure Gas), it was written by E. Lesage and P. Abiet in 1952 and described how manure and vegetable matter

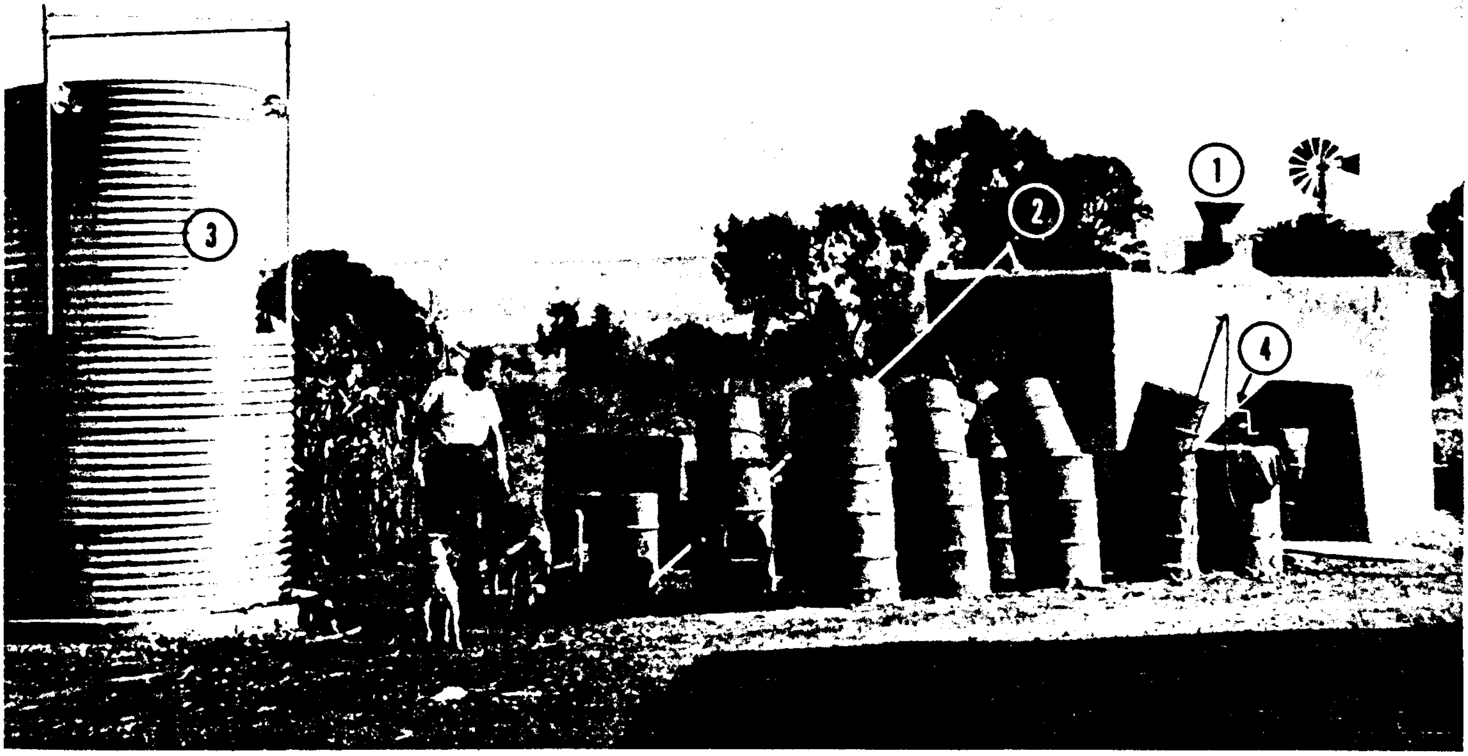


Figure 1: *Vertical drum digesters (foreground) and top loader (right).*
1) *Inlet.* 2) *Gas outlet pipe to holder.* 3) *Gas holder for top loader.* 4) *Scum crank.*

4) The 50-gallon drum is ready to be filled. It should be filled only to the height of the 30-gallon drum with a mixture of half slurry and half starter brew (fig. 2).

5) Make a slurry the thickness of cream by mixing fresh, raw manure with warm or hot water at 90° to 95°F (35°C).

6) To this add an equal amount of starter brew.

7) With the valve open, sink the 30-gallon drum all the way down into the slurry and starter mixture (fig. 2). This must exclude all the air from the 30-gallon drum. Then close the valve.

8) In cool climates, active compost can be packed around the outer drum to maintain a steady temperature of between 80° and 95°F (35°C). After about three weeks, gas should begin to generate. The smaller drum will fill slowly with gas and rise above the surface of the slurry (fig. 3).

9) Safety precaution: A note of warning. When the small drum rises the first time, do not attempt to burn the gas. Rather, let it escape to atmosphere, push the 30-gallon drum completely down into the slurry again, shut off the valve and allow it to rise a second time. This is to insure that no air is mixed with the gas. A gas and air mixture is highly explosive between the range of one part in four to one in 14 if ignited. Even outside this range it could be dangerous. Also the first gas yield will probably not light anyway due to a high proportion of carbon dioxide when fermentation first starts. When burning the gas, open the valve only slightly, press down lightly on the 30-gallon drum to create a positive pressure on the gas. Close the valve before releasing the pressure.

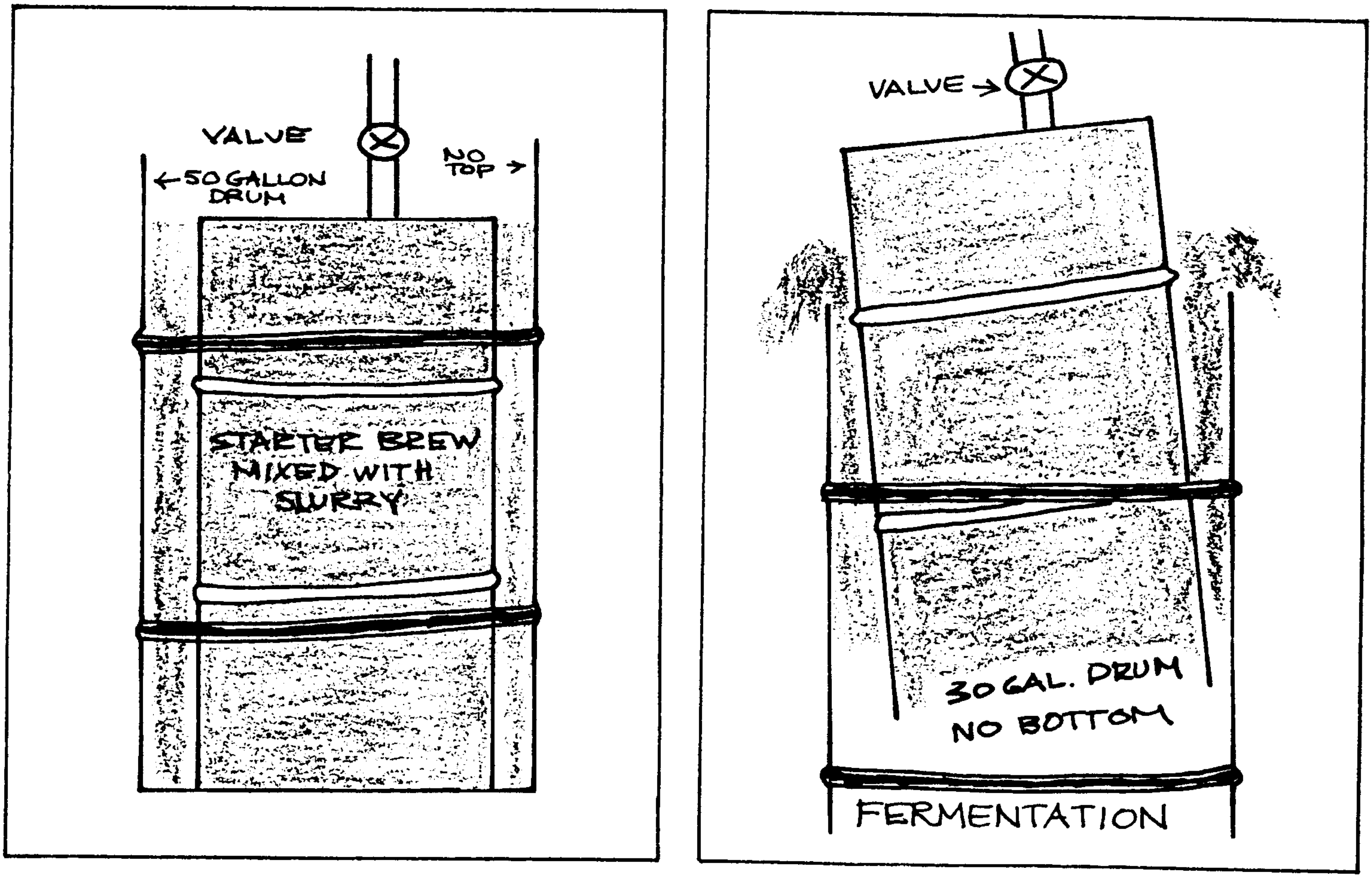
In rare cases there occurs an abundance of gray foamy bubbles at about the time fermentation starts. If this happens leave the digester alone for a few days. Do not feed any raw material. If the digester is heated, reduce the heat.

10) Periodic supplies of fresh raw material should be fed in to keep the digestion going. This can vary from daily feeds to once every three months depending on the requirements of the user and the digester design.

To feed this digester it is necessary to remove the 30-gallon drum, take out about 5 gallons of material and replace it with fresh slurry. Again press down the small drum to exclude air.

Drum designs are particularly good units to learn from since they are so easy to build and maintain.

11) To provide smooth movement of the inner drum, guiding pipes and rollers can be improvised to keep the inner drum vertical.



Figures 2 & 3: Before and after fermentation takes place in vertical drum digester.

CHAPTER 3

Top Loader Digester

Figure 1 depicts two stages in the early development of digesters on my farm. In the center are the oil drums which served during my experiments to "cook up a brew" of methane bacteria, an essential step before operating any size digester.

On the right is the second stage I tried out — the top loader digester. This unit was four feet wide, eight feet long and six feet deep, made of six inch-thick cinder concrete in one continuous pouring, and reinforced by buttress walls on each side of the unit to withstand static pressure. The buttress wall on this side of the digester is visible in the center lower half of the digester. The inlet for the raw hog slurry was located on top and consisted of an eight-inch pipe set into concrete about three feet from one end of the digester and about five feet from the outlet end.

The pipe extended down to two feet from the floor and a large funnel was placed at the mouth to facilitate loading. A one-inch pipe (visible at left) was also set in the roof and led down to a condensation trap, and thence to the gas holder seen at left in the photo.

Three other features characterized this unit:

1) Effluent pipes two inches in diameter were set into the outlet wall (in shade in photo) in a vertical line at about one foot intervals to test the fluidity of the contents and were stoppered off with large tapered corks. The bottom pipe measured four inches in diameter in anticipation of thicker, coarser sludge. This proved to be a useful bit of foresight.

2) The only provision made for insulating the digester was a single-brick wall around the unit and a corrugated iron roof. A space of some six inches was left between the digester, the roof and the walls, respectively. This was packed with straw. In winter, after this photo was taken, the entire unit was painted mat black to absorb whatever warmth it could. Also, water was warmed slightly before mixing with the raw manure.

3) Not seen in this photo was a crank made of one-inch pipe set into the long walls about four feet from the floor, right through from side to side, and fitted into a larger pipe as a bearing. Inside a steel plate 3 ft. x 1 ft. was welded to the pipe at the center of its long side. It could be cranked by a handle from the outside.

Operation

Bacteria were first loaded from the drum digesters and this was followed up with fresh manure added a little at a time until the digester was full. At this point in time methane fermentation was in full swing: Gas was being produced and was flowing through to the gas holder. I had my first sizeable digester working!

Daily loading consisted of one 2 cu. ft. wheelbarrow load of very fresh hog dung and urine made to a sloppy slurry with water. The memory of that regular routine is brought sharply to focus through a sample of the irrepressible sense of humor of my Bantu workers. One would stand on the roof while the other one on the ground would pass up buckets of slurry. Every day the joke was repeated. Before pouring in the slurry they would both groan as if straining. Then the plop-plop of the slurry hitting the previous day's residue was heard. The similarity to another daily function was unmistakeable!

Figure 4: Top loader wall cut open. A failure since the scum had become so dense that this was the only way to remove it.

As I recall, the gas tank of 110 cu. ft. capacity filled in 48 hours — some 55 cu. ft. per day. I used some of the gas for cooking in our kitchen on a two-burner stove, the only alteration needed being to drill the stove jet larger. Another portion of the gas was used to supplement diesel fuel in a 3 BHP 'Petter' engine driving a water pump and a 3 kw alternator which supplied electricity to the entire farm. Before using the gas in that way, I had usually started the engine at four in the afternoon and shut it down at bedtime so as to save fuel. However, my supply of no-cost gas meant such diesel savings that from then on the engine was left on all night.

I found the conversion process to be almost unbelievably simple, as I have since found to be true of all diesel engines. Straight, raw gas flowed directly from the storage tank under pressure generated from the fermentation and kept constant by the weight of the gas storage tank itself at a pressure of 4 in. water gauge through a garden hose stopped off by two valves. The first valve was used for fine tuning of the gas flow and the second, in series with the first, was used for on-off. Just after the two valves the hose led straight into the air intake of the diesel engine. Fine tuning was done by starting the engine on diesel only and warming it up for a few minutes. Then after opening the on-off valve, the fine tuning valve was adjusted slowly.

While adjusting the fine tuning valve one could see the diesel pump governor returning to about the idling, no-load position. The engine was then running mainly on methane gas. I was surprised to find that the black smoke disappeared altogether (white smoke replaced it if too much methane gas was turned on) and that the characteristic knock of the diesel vanished. The latter can be explained by the cushioning effect of the carbon dioxide content of the raw gas. To stop the engine the on/off valve was closed and to start up again, only the on/off valve was opened after starting on diesel. I ran that unit for two years on a mixture of the two fuels and then I used it as a stand-by power unit when the larger 13 BHP gas-only engine was put into use in 1958.

Later I made accurate measurements of diesel fuel consumed in a given time with and without methane gas. The tests showed that, on near full load of the engine, the methane gas supplied 87% of the energy and the diesel fuel 13%. Any lesser quantity of diesel would cause the diesel injector to dribble over a period of time and eventually stop operating properly. Of course the injector supplied the "firing" of the engine and had to be maintained in good running order. It should be mentioned here that when operating a diesel engine as a dual fuel engine at least 20% of the power should be from the diesel fuel in order to avoid any injector trouble.

This little engine not only ran the alternator which provided electricity for household use, but also pumped water which was a very scarce commodity on the farm. The water was pumped to the household supply tank and any overflow automatically ran to a swimming pool. I also installed a switch inside the house to direct the electricity to two floodlights — something which helped prevent thieves from stealing pigs while also drawing night flying insects to the lamp and away from the house.

Further details on how engines can be fueled with methane gas either as a dual-fuel arrangement as with the Petter engine, or as a single-fuel, methane gas powered engine, will be found in the chapter on Uses of Gas.

Lessons learned from this first sizable top-loader digester included:

1) The inlet or loading pipe was incorrectly positioned about midway on the digester roof, thus making a useless pocket of almost ½ the digester capacity. If the pipe had been placed near the end it would have been more efficient and would have more resembled a displacement-type digester discussed in detail later.

2) The stirring crank used to break up the scum layer did not solve the scum accumulation problem. Though it worked well for a few months, it gradually got more difficult to turn until it finally seized up altogether. Before that point cranking did not seem to improve gas production, except momentarily, and the scum layer it was supposed to crack and mix into the digester formed nevertheless. Eventually the digester was broken open and a two-foot deep layer of scum was removed. During the last days of operation, therefore, the digester was only working at ⅔ capacity. Such accumulation is the single greatest problem in any digester system — even more so than in sewage plants.

3) The heating system was inadequate to keep the temperature inside the digester at 95°F (35°C). Hot loading in cold weather would undoubtedly have overcome that problem.

A Note on Safety

This unit had let-off points for testing effluent at various levels and soon after starting up I let off some effluent into a 50-gallon drum. I noticed a curious thing which I have since learned happens about every 20 times digesters are started. Thick, gray, sticky bubbles the size of pudding basins formed on the surface of the effluent when exposed to atmosphere. I filled the drum half full and there were the large bubbles. I left for a few hours and when I returned the drum had filled to the top. It was obvious to me that the bubbles were full of gas only and were not a mixture of gas and air. I bent right over so that my head was below the top of the drum and cautiously applied a match to the top bubble. The reaction was immediate and potentially very dangerous: The methane gas didn't explode but it burnt very fast.

I mention this incident to dramatize that one should always be careful around effluent in a container. Please study the safety precautions given in this publication and, above all, apply them.

This whole section on the top-loader digester has been dealt with specifically for one main reason: I wanted to show that here were lessons I learned the hard way. Following a few months of good results, scum had accumulated to the extent of shutting down ⅓ of the digester's capacity. The only way to remove the scum was to break the walls of the digester (see fig. 4).

The unit had cost me considerable time, effort and money, but the experience was worthwhile in terms of the knowledge gained that could be applied to the building of the full-scale digester described next. The fact cannot be emphasized too strongly to the reader that a workable provision must be made for the removal of the scum and, to a lesser extent, the sand, grit and inert materials that settle to the bottom of the digester. Any shape digester will work for at least a short time. A hole in the ground covered with concrete will produce methane, as will a fancy tank lying horizontally or standing vertically. However, to design and construct one that will operate for years on end is quite another thing.

CHAPTER 4

First Full-Scale Displacement Digester

After my success with the vertical drum digesters and the not-so-happy but instructive experiment with the top-loader, I spent a great deal of time weighing the options and decided on a plan to build twin digesters with fixed roofs and a series of gas holders to store some of the gas generated. Having twin digesters side by side had the advantage of greater flexibility. Should one unit become overloaded and have a bacterial breakdown, the second one would be available to receive at least part of the load. The first one would be eventually brought back to use by splitting the load between the two.

Site

The next step was the selection of a suitable site. I had two separate and distinct piggeries on the farm. One housed boars and sows and included "maternity sties" where litters were raised until weaned. The second piggery consisted of a series of larger sties where the hogs that were weaned graduated to become baconers. I found the different types of feeding easier to control in this way, and I also felt that if a fatal disease should strike in one section I might be able to save the hogs in the other.

Between the two was a piece of land with a slight slope conveniently close to a three-inch water pipe used for irrigation which ran the entire length of the farm and from which overhead spraying equipment was used. The piece of land also ran close to a borehole delivering approximately 150 gallons of water per hour. The site was visible from the house so that I could check on the gas supply first thing in the morning and last thing at night, and yet was far enough away for an engine to be barely audible.

Construction

Once I had selected the site I prepared the foundations by excavating approximately two feet down. Below that level I found a layer of boulders tightly packed in earth and so hard to move that I decided they would make an ideal foundation for the digester and I would not need to pour a heavy concrete foundation. The ground had a very slight gradient of one in fifty and I took advantage of this to allow for the extra depth I wanted toward the outlet end of the digester. The floor was constructed of cinder concrete — a form of burnt coal used in an electricity supply furnace and then washed in water. The cement ratio was one to eight. This proved strong enough for the purpose, besides being a good insulating material.

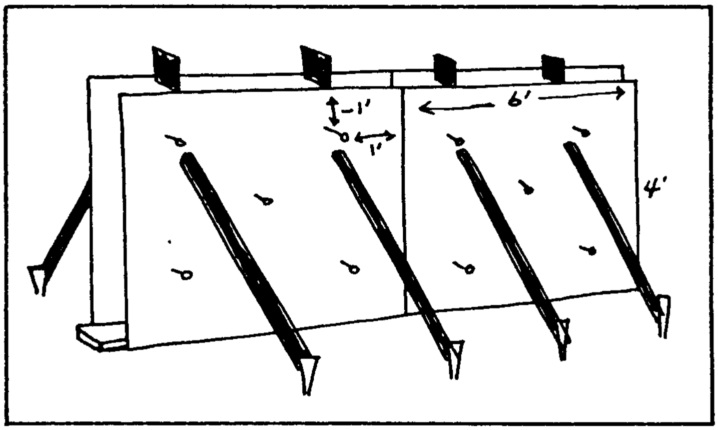


Figure 5: Shutters used in building.

To build the walls I felt I could use the same construction techniques I had used to build the sties, but with some additional strengthening. I set two shutters opposite each other, each drilled through at the spot shown in figure 5. A long bolt was passed through and spacers were placed between the shutters which were then propped in place, making sure they were held exactly vertical with the use of a spirit level.

Whatever mixture was to be used was then poured between the shutters. As the cavity filled to the top the spacers were removed. After the mixture had set, the shutters were taken down and the wall was completed. A strong two to one mix of sand to cement was then brushed on as plastering and sealant.

To add strength to the digester walls, two strands of very heavy cable used in deep well drilling machinery were placed between the shutters at distances of about one and two-and-a-half feet from the bottom. The cables were pre-tensed by tying one end to an implement on a tractor, while the other was imbedded in concrete, and driving the tractor forward until the front wheels were off the ground. Also, short lengths of metal rod were set in the top section of the wall so that, when the concrete wall was eventually positioned, the whole top and sides would be bound firmly together.

To withstand the static pressure of the contents of the digester, bastion walls were built at intervals of approximately eight feet. The base of the bastions were also pegged with steel stakes which went into the ground to hold the walls from being pushed outwards by the weight of the contents of the digester (see fig. 6).

A center wall dividing the two digesters was made with solid concrete over 14 inches across at the base and tapering off to about 5 inches at the top. It was also heavily reinforced with the same pretensed steel cable used on the outside walls. It had to be very strong in order to hold the contents of one digester if the other digester was being cleaned or was out of action for some reason. Potential collapse would endanger lives if the wall was not strong enough to withstand the static pressure of the contents of the other digester. I might note here that the digesters stood the test of time and proved that those measures were quite adequate.

The roof itself was a real headache in construction. I solved the problem by purchasing a large number of used wooden crates, dismantling them into sections, and laying them as a wooden platform supported by poles inside the digester, and extending approximately halfway down the digester length. I did not have enough crates to lay more than one half at a time. In the first half, for reasons explained under "scum problems," provision was made in each digester for a gas outlet, which also doubled as an access hole (see fig. 6).

The use of concrete for the roof was the one big mistake of the whole full-scale digester plan. Laying the concrete for an area of 25 feet square in one continuous mixing and laying operation was a considerable task for the small number of unskilled employees I had. The mixing of the chip stone, sand, cement and water which was required to make a perfect mixture of concrete had to be done by hand. After placing steel reinforcement laterally and longitudinally, according to directions from the concrete association, we began to pour the roof.

I supervised the first mixing but, as laying went on, I had to watch that the concrete was put on exactly the way I wanted and was therefore unable to supervise further mixings. Unfortunately one batch of concrete was mixed with too much water. I noticed this but there was no time to alter it so I noted the particular area it covered. Later on, when the digester was in actual use, I checked that portion with soapy water and the whole area had very fine bubbles of gas coming through as a result of the poracity of that particular mixture of concrete.

When it came time to laying the second half of the roof a few weeks after the first half had set I made the platform and this time, with our added experience, we finished off that portion of the roof without any trouble. To make sure of a good seal between the two layers of concrete I took all precautions recommended by the concrete association and, in addition, left a small groove in which to pour hot asphalt to seal off the last possible leakage points. When laying the second half of the roof a short slit on each side was left open to allow wooden shuttering to be taken out, and then eventually the slit was sealed off.

Over the top of this concrete roof I constructed a second roof of asbestos cement in order to protect the top of the digester and prevent expansion and contraction of the concrete in heat or cold.

As an amusing sidelight to this, after the digesters were in operation, I discovered that the workers on the farm found that sleeping on top of the digester under the hip roof was an extremely warm and cozy way of spending a winter's night, and it became a communal bedroom for many of them.

Outside the digester a basin was made 12 ft. x 8 ft. x 2 ft. deep with the floor sloping to a grid made of angle iron 3 ft. x 6 ft. with a steel screen of ⅜ in. rod with 1 in. mesh. The heavy ⅜ in. rod was found necessary to withstand the suction pull of the sludge pump and for delaying corrosion. A short ramp up to the basin permitted wheelbarrows of manure to be run up and tipped into the basin (fig. 7).

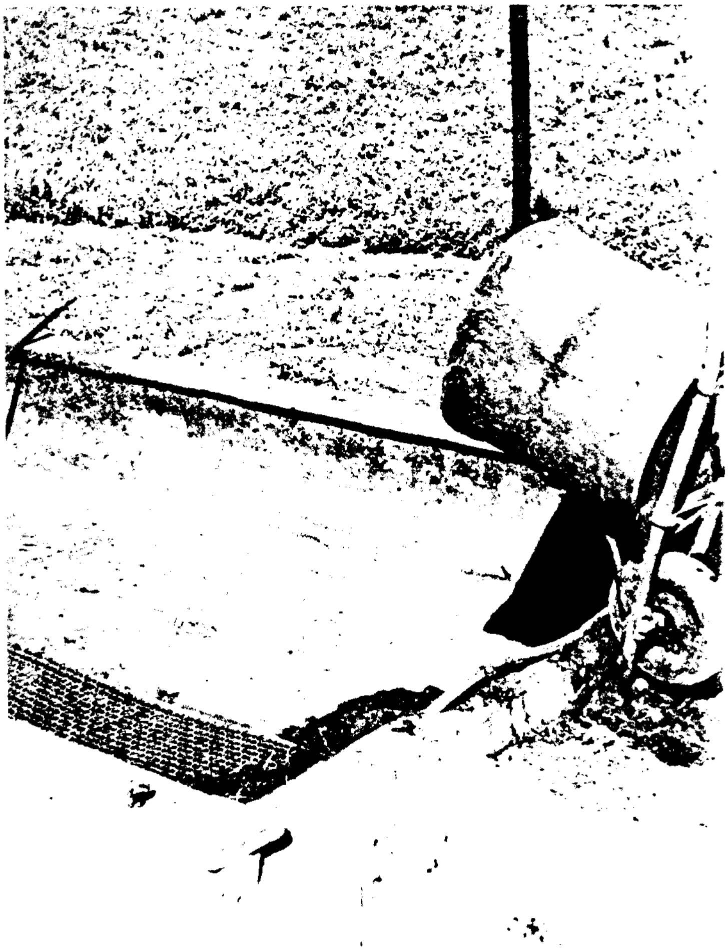


Figure 7: 8 ft. x 12 ft. and 2 ft. deep mixing and loading basin with ramp for wheelbarrows.

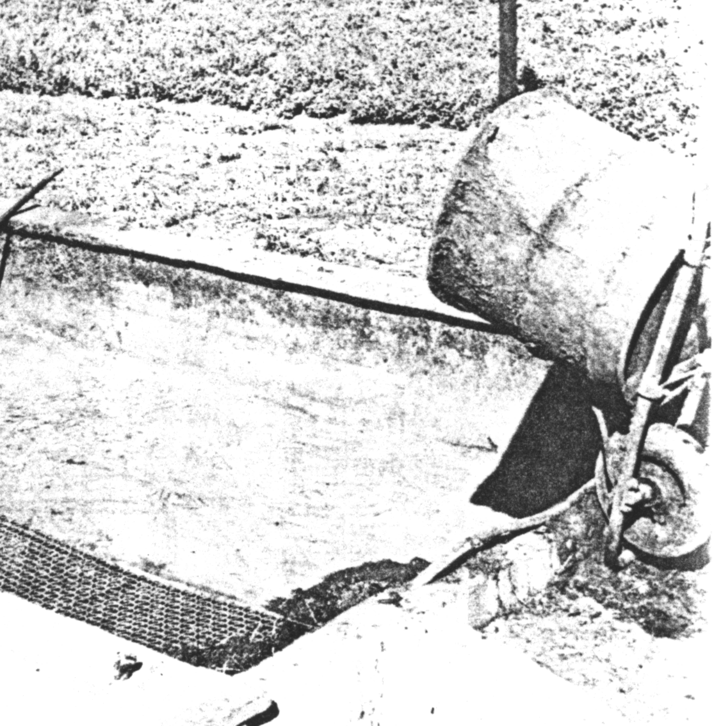
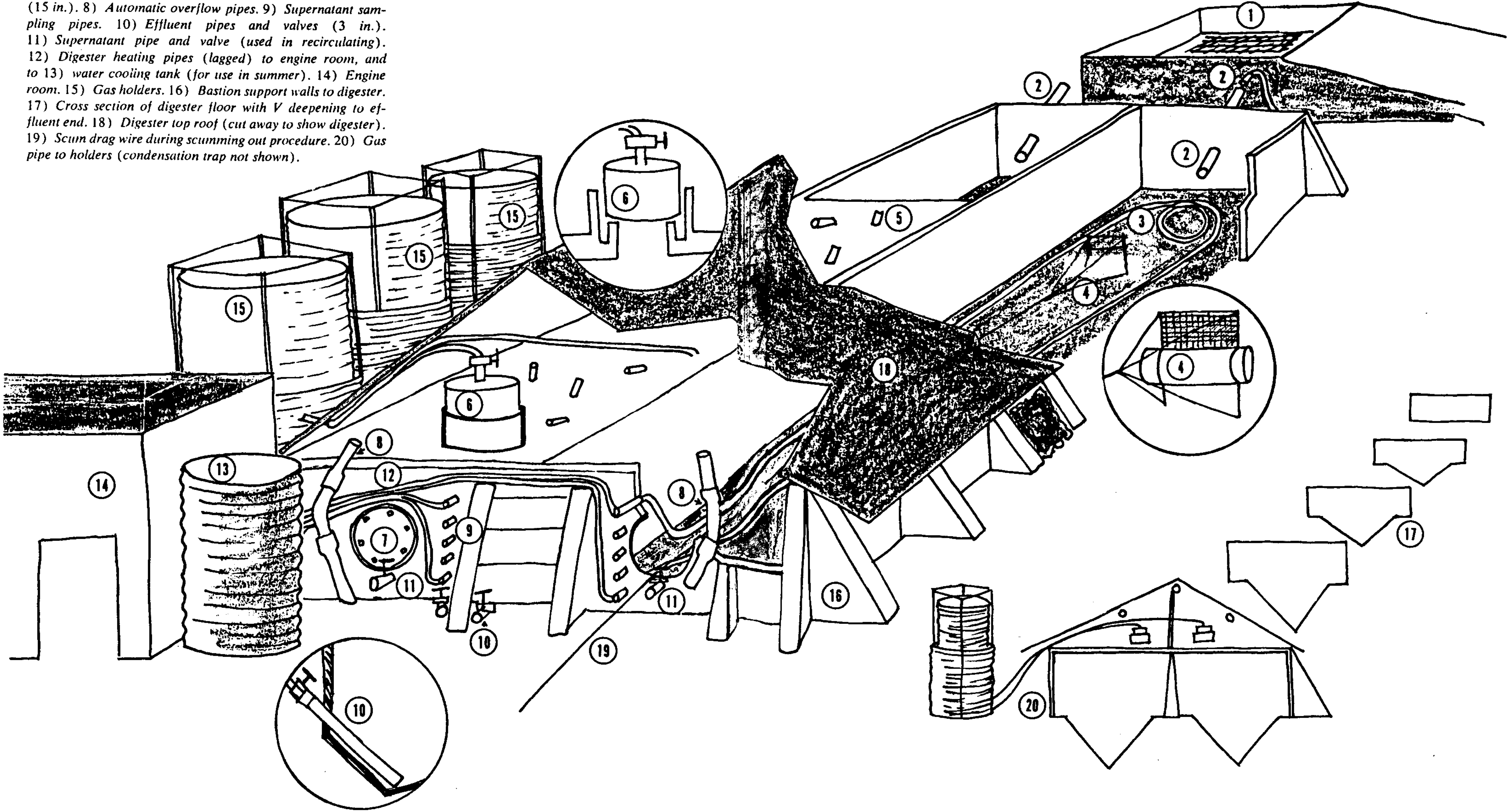


Figure 6: First displacement digester. 1) *Mixing and loading basin.* 2) *Inlet pipe.* 3) *Heating pipe.* 4) *Scum drag.* 5) *Pipes through digester roof intended for scum breaking.* 6) *Gas dome and access point to digester interior.* 7) *Scum port* (15 *in.*). 8) *Automatic overflow pipes.* 9) *Supernatant sampling pipes.* 10) *Effluent pipes and valves* (3 *in.*). 11) *Supernatant pipe and valve* (*used in recirculating*). 12) *Digester heating pipes* (*lagged*) *to engine room, and to* 13) *water cooling tank* (*for use in summer*). 14) *Engine room.* 15) *Gas holders.* 16) *Bastion support walls to digester.* 17) *Cross section of digester floor with V deepening to effluent end.* 18) *Digester top roof* (*cut away to show digester*). 19) *Scum drag wire during scumming out procedure.* 20) *Gas pipe to holders* (*condensation trap not shown*).



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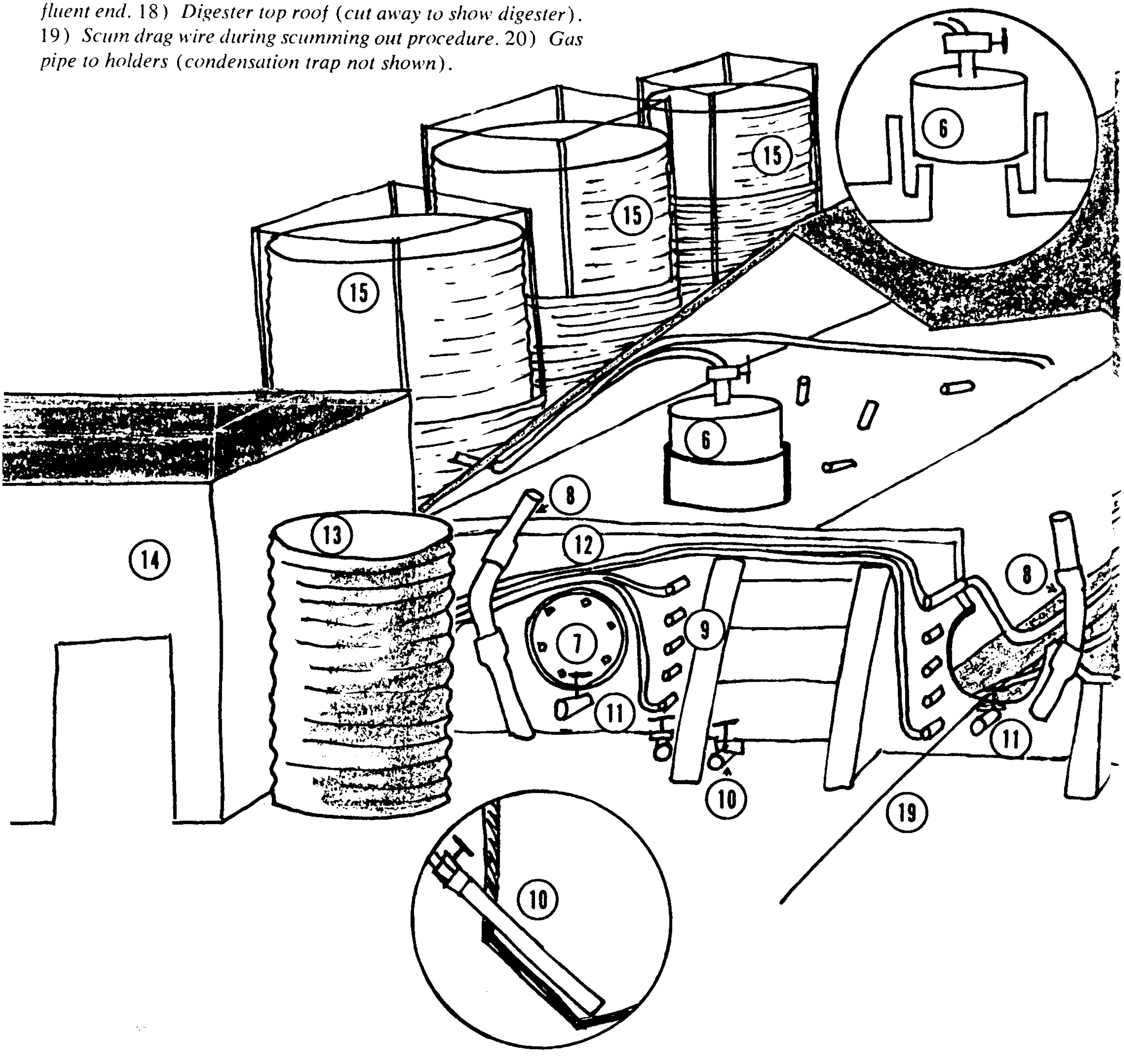

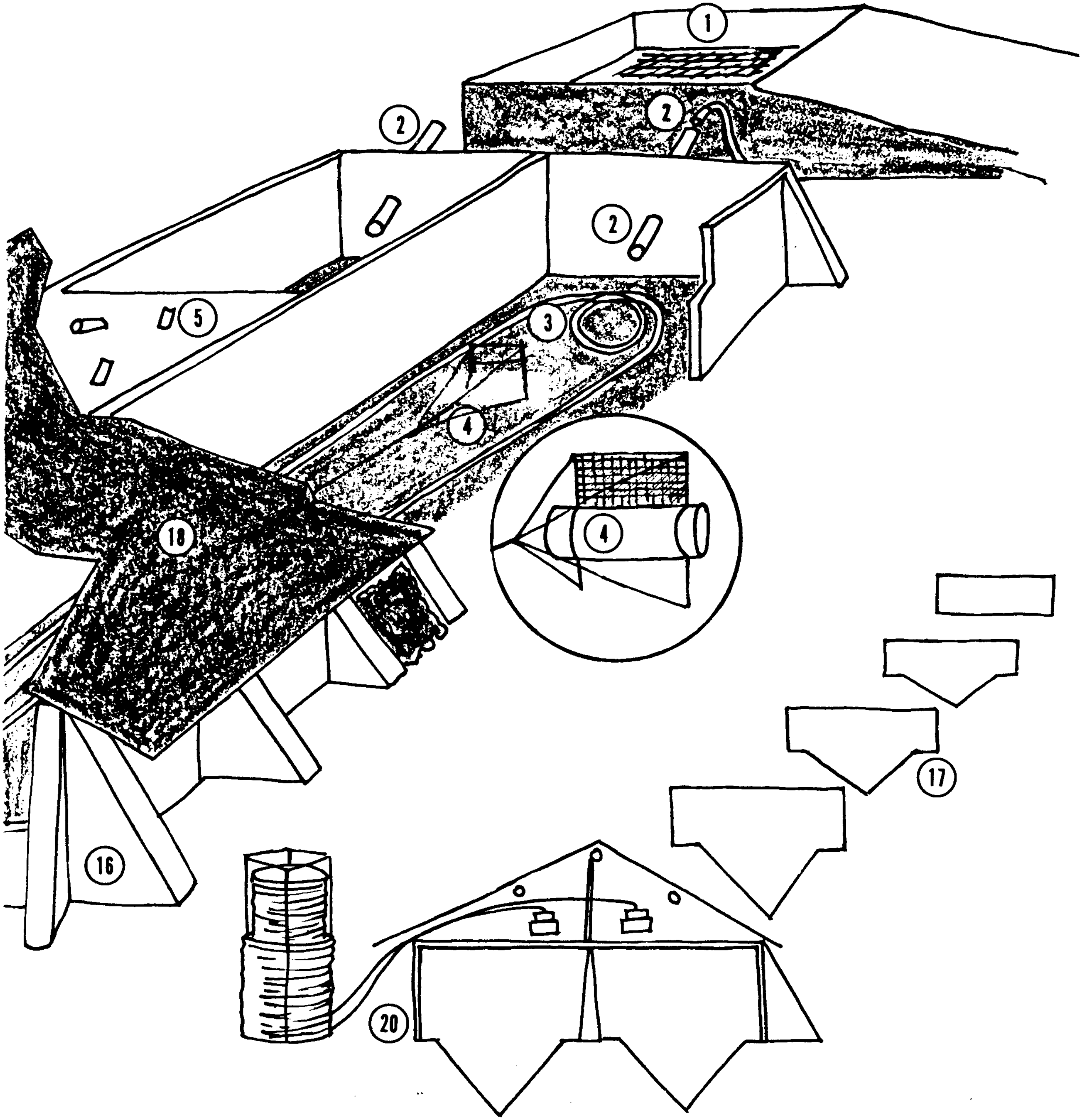

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When it came time at last to start up one of the digesters by seeding it with bacteria, I picked a particularly warm day and loaded the tank truck with the fluid portion of the top-loader digester. Five hundred U.S. gallons were taken to the new digester and offloaded with a sludge pump into the digester itself (fig. 8). After months of planning, painstaking attention to every detail of construction, the time had arrived to 'start up' with seeding bacteria. To a methane plant operator this is quite a moment. I was somewhat disappointed to see that the 500 gallons merely formed a puddle on the floor of the digester. It didn't even reach the walls, but it was enough.

Fresh manure was introduced daily in small quantities until the first digester was approximately one quarter full. At that point, larger loads of raw material were fed in through the basin and, of course, a lot of experimenting went on with the method of feeding it in. The manure had to be mixed with water to exactly the right proportions so as to permit the pump to load it in. I had an open impeller type centrifugal pump, claimed to be unchokeable. However the first time it was used, it choked up with alfalfa stalks and quite some effort was needed to free it. After that I took the precaution of first removing stalks, straw and other floating material by raking the slurry with an ordinary garden rake.

Daily Loading

As a test, the raw manure from my 1,000 hogs was weighed daily in wheelbarrows and the weight of the empty barrows deducted. This was repeated for one week and I found the average daily production of collected dung amounted to 3,980 lbs. per day, in 26 wheelbarrow loads of two cubic feet each. A few sizeable samples of this naturally damp dung were then dried out in conditions similar to an oven at 200°F for several hours. The samples were again weighed and the average taken. It was found that the original damp weight total of 3,980 lbs. was reduced to 1,340 lbs. dry weight. This ratio cannot be applied to all manures as the manure in this case had been collected after a period of natural drying in open sties and conditions of low humidity. Exact statistics were impossible to obtain since rainfall, the conscientiousness of the collectors, and hogfeed variations all contributed to wide fluctuations in quantities and weights. In round figures $^2/_3$ of the weight was moisture, $^1/_3$ dry dung.

The approximately 26 wheelbarrow loads of manure were tipped into the basin daily. Water (about 250 gallons) was then hosed in and the whole mass sifted with a garden rake. When mixed to a slurry, the mass was pumped to a sand trap which was a simple but effective arrangement consisting of a drum with a tight-fitting lid and sturdy clamp, and with an inlet half way down and an outlet near the top. Sand simply settled to the bottom of the drum. The only drawback was that the sand had to be cleaned out daily and this could be done only after the top half was cleaned out first.

From the sand trap the raw slurry entered the digester through a straight pipe, the outside end of which was two feet above the level of the contents inside the digester while the inside end reached down to one foot from the floor. Thus no air entered the digester.

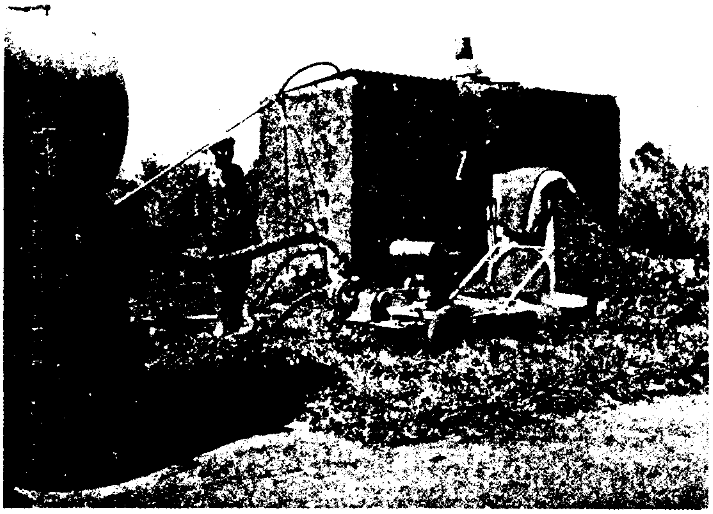


Figure 8: *Effluent from top loader being transported as starter for the first full-scale displacement digester* (1957).

During most of the six years the two digesters were in operation on my farm, the daily load of 1,340 lbs. dry weight was divided equally between each digester. Thus the loading rate was 670 lbs. to 3,000 cu. ft. or, otherwise expressed, .223 lbs/cu. ft./day. If one of the digesters was out of operation, the other received the full daily load, raising the rate to .446lbs/cu. ft./day. Once I maintained this very high loading rate for four months. Towards the end of this time the pH of the effluent dropped slowly from 8 to 7, giving me ample warning of impending failure of the methane generating bacteria, a process otherwise known as souring.

The action I took to restore a strong bacterial "buffer" was to recycle effluent through pipes back into the digester at various points. When the second digester was ready, a few thousand gallons of effluent from the working digester was pumped in and a little fresh slurry was also loaded. It should be noted that the drop in level in the working digester had to be limited by the gas held in the storage tanks, since air must never be mixed with gas. Thus, gas was made to flow back to the working digester to replace the volume of effluent removed.

When the second digester started producing, the initial batch of gas yielded was allowed to escape to atmosphere so as to flush out all air that had been trapped in the digester and pipes. After several days a sample of gas was stored in an inner tube, removed over 200 yards away, and checked for correct smell and burning quality.

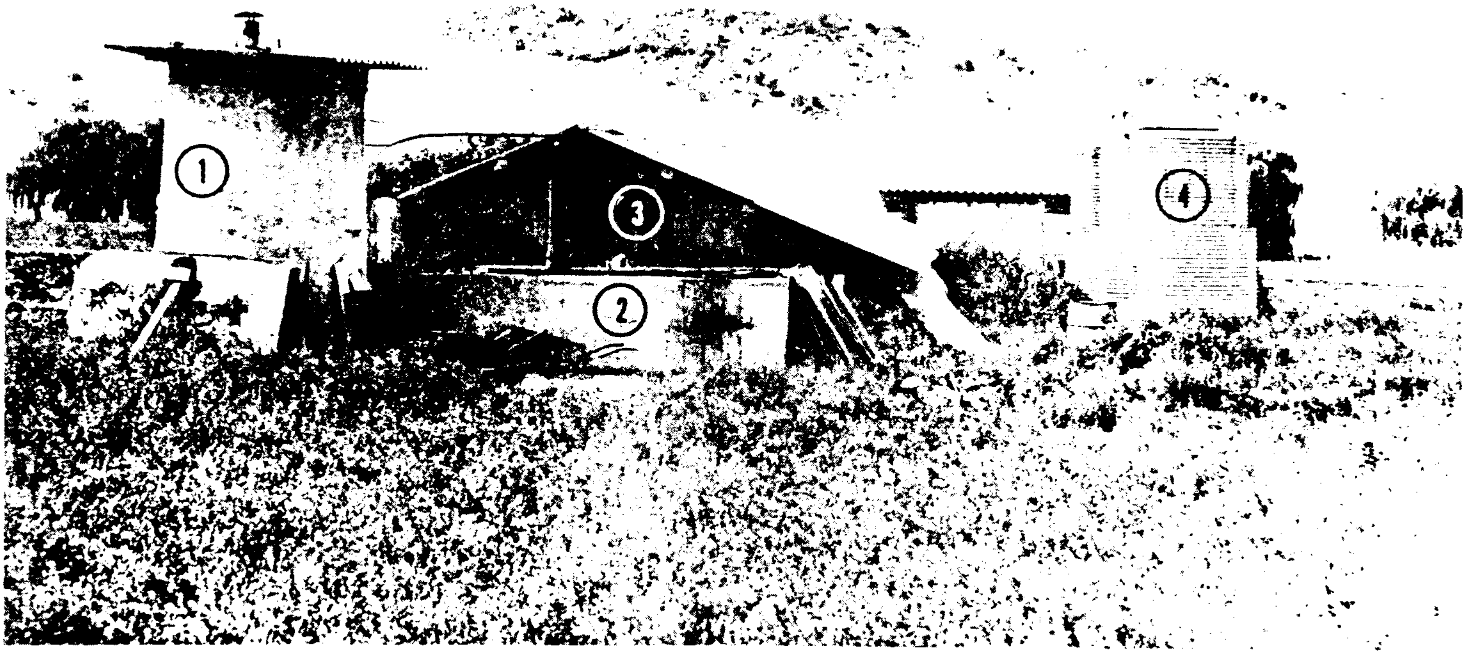


Figure 9: Displacement digester inlet end. 1) *Hot water heating tower.* 2) *Mixing and loading basin.* 3) *Access door to space between digester roof and top roof.* 4) *Gas holders (a third was added later).*

Heating

To provide heat for the digester I built a tower of cinder concrete (at left in fig. 9) to house a 750-gallon (U.S.) corrugated iron water tank. It stood on bricks laid in a zig-zag pattern to expose the maximum area of the bottom of the water tank to the heat from a gas burner. This was the first method used to raise the digester temperature. Boiling water was mixed into the raw manure in the basin to form a slurry. At 120°F it was pumped into the digester which was then at 70°F. And although this method was first tried in the late fall of 1958, with temperatures at night of 20° to 30°F, the temperature in the digesters rose 1°F per day up to 78°F and remained there for the winter. This was sufficient to maintain fermentation at a medium rate.

Later in the year I built an engine room adjacent to the digester outlet end. The engine was fuelled by 6,000 cu. ft. of methane gas daily and the cooling water and exhaust gases were returned to the digester to maintain the optimum temperature in winter. The exhaust gas discharged against the outside of one digester wall. Boulders were packed against this wall then covered with dry earth. A layer of cement plastering used as weatherproofing covered the whole (see fig. 9).

The engine design called for a maximum cooling water temperature of 140°F. This coincided exactly with the maximum temperature for pipes laid on the digester floor. If a higher temperature had been used, the sludge would have "caked" on the pipes and prevented the transfer of heat.

Thus a small ¾-in. pump was installed driven directly by the engine, and run at slow speed (to improve endurance) to circulate water. In the cicuit there was also a 200 gallon header tank to keep the lines full at all times (see fig. 10). In winter it was bypassed and in summer the 200 gallon tank was taken into the circuit as a means of cooling the water to prevent the digester temperature from rising above 95°F. The engine and digester combination ran day and night for six years, except for rare stoppages and repairs.

The original tower and 750 gallon water tank were dismantled, being no longer required for heating. Though raw manure slurry at 120°F in an open basin is an unpleasant material to have to handle, if it is mixed by pump in a container with a lid this remains an efficient method for introducing heat to a digester.

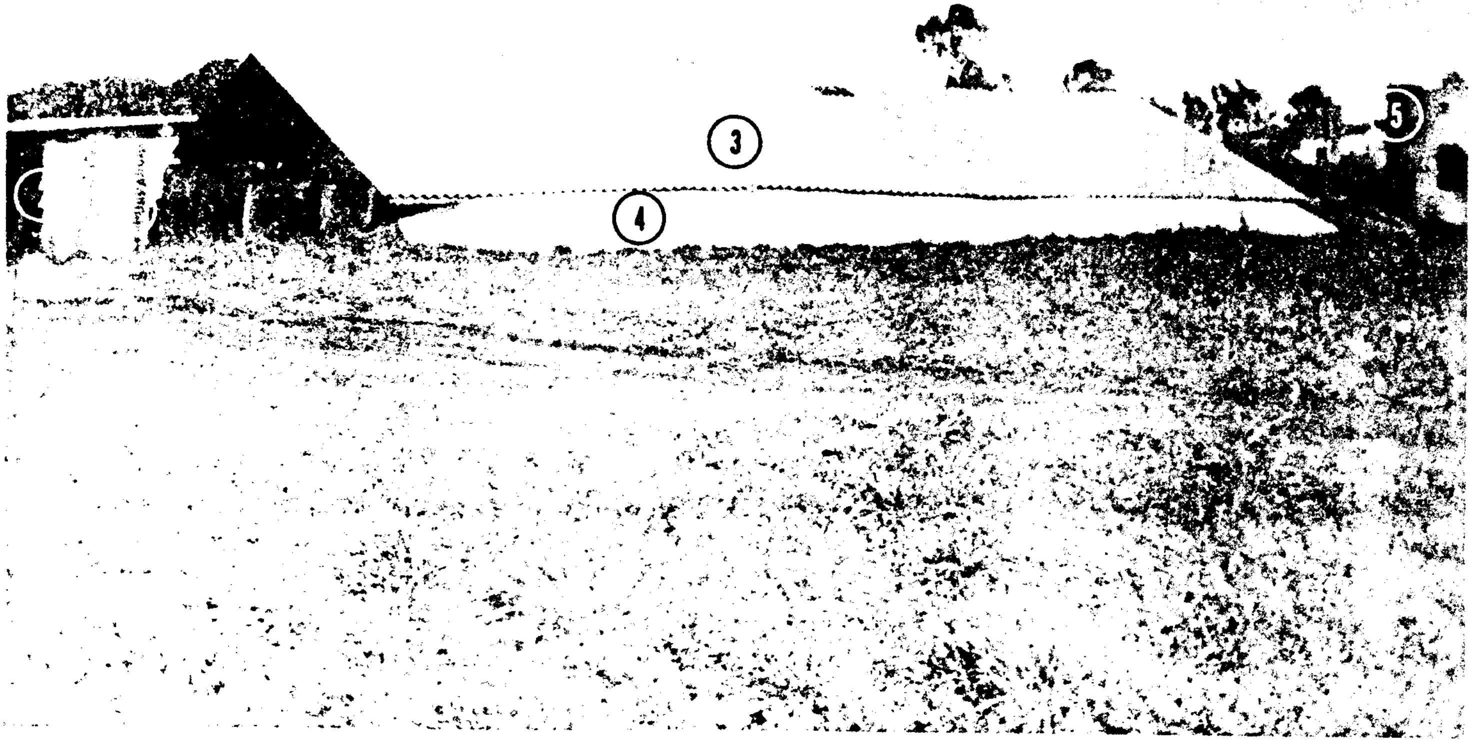


Figure 10: *Displacement digester.* 1) *Header and cooling water (summer) tank.* 2) *Engine room.* 3) *Top roof* 60 *ft. long.* 4) *Earth bank over bastion walls protected with cement layer.* 5) *Hot water heating tower (out of use at this time).*

Withdrawal of Sludge

At the lowest point of each digester was a straight pipe to be used as a sludge outlet, and consisting of a 3 in. pipe with a gate valve. It is important to note that all pipes in a digester must be straight to allow the rodding out which is necessary from time to time. In order to make room in the digester for the daily quota of fresh slurry, withdrawals were made from the sludge outlet. I withdrew three or four days' worth of effluent at a time (some 600 gallons each) about twice a week. As effluent was withdrawn gas flowed back from the gas holders to replace the volume of effluent, since a digester has a fixed capacity and any liquid removed has to be replaced by gas and not air.

To withdraw effluent I backed my tank truck into a short excavation so that the top of the tanker was about two feet below the digester roof level. A three-inch plastic connection and two three-inch valves completed the withdrawal circuit. On the top of the tank truck was an opening to vent out air when the tanker was being filled and into this I fitted a tennis ball in a cage so positioned that when the sludge rose to the vent point, the ball blocked off the opening. This prevented messy overflows. The effluent was then spread on fields as a fertilizer.

Gas

Gas yielded from the two digesters averaged 8,000 cu. ft. per day. The gas was analyzed at Johannesburg City Gas Works at 711 BTU per cu. ft. (sea level value). Sometimes for weeks at a time the gas yield went as high as 12,000 cu. ft. per day after a digester had recently been returned to work. This was due to the delayed action of the brew. From the time the digester was half full to when it was full (about 3 weeks), the bacteria did not generate much gas. Then, as it filled up, the backlog would surge gas production.

Scum

In anticipation of having serious problems with scum accumulation I set short lengths of pipe into the concrete roof at various angles pointing down into the digester contents, most of them in line with the long sides of the digester. The intention was to recirculate supernatant under pressure with a sludge pump to break the scum layer by getting the whole digester contents to rotate. The scum would then be broken up and forced into the more liquid mass. In practice, all that happened was that the jet of supernatant made a neat hole in the scum and the mass did not move.

As a second measure I introduced a series of pipes through the floor of the digester and recirculated gas through a compressor so as to bubble up and crack the scum. This might have been effective if used daily or weekly with absolute regularity, but once the scum became more than a few inches thick it would no longer break up. This routine took too much time for me to recommend it to a busy farmer. Also the vent holes in the floor became clogged with sand. Both methods were thus failures, and scum remained a major problem.

A third provision I made was to equip the digester at the outlet end with a foot and a half of 15 in. pipe (see fig. 6). Each digester had this pipe in it and was sealed off on the outside with a steel plate held in with bolts set into concrete, and with a rubber gasket. Normal gas level was above this point so there was no risk of gas escaping through any small leakage there might have been.

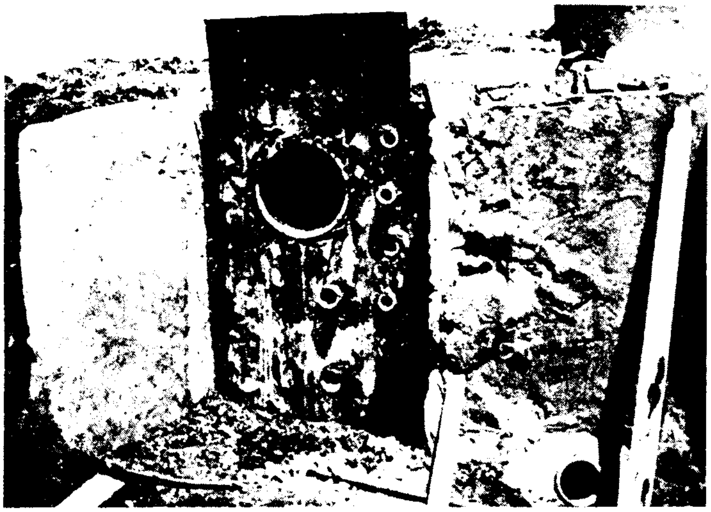


Figure 10 *A*: *Shuttering used during construction for scum ports and supernatant pipes.*

I suspect that many have encountered similar difficulties and have abandoned methane digesters simply and solely because of this scum problem. With small digesters, such as the inner tube digester, the problem is not too difficult to solve. With a large scale unit, scum can build up to one foot and a half in depth in a year. In vertical digesters, the buildup can come to several feet in a short time. Scum consists of tightly knit scraps of straw from bedding or animal feed, animal hair, feathers, etc., all held together by a dark-colored sticky substance thrown up through the supernatant levels in the bubbling zone. It covers the entire surface more or less evenly. I might note that here we find another advantage of the displacement digester. Since the scum forms evenly, the larger the surface area it has to form on, the longer it takes before it becomes a thick mat.

Scum eventually takes up so much digester space that the whole digester becomes overloaded due to the slurry being forced through the process too quickly. It is my experience that when it is broken up scum merely reforms again within a short time. Little if any is decomposed and withdrawn with the effluent. The problem therefore resolves itself to a question of periodic physical removal, a process described later.

Another problem is the light foam or froth that sometimes rises to the surface of fermenting material, thus blocking the gas outlet and causing damage by the pressure thus generated. To overcome this problem the gas outlet was attached to the top of an inverted dome, an asbestos cement bin 2½ feet in diameter, set into a water seal built into the roof itself (see fig. 6). Since the dome had a depth of two feet the foam fell back under simple gravity. When the digester was out of operation, a person could remove the dome, drop a short ladder to the digester floor and climb down inside through the two foot wide opening.

Dimensions

I have previously revealed that the full-scale twin digesters were the first displacement, continuously-operated units known, and that each was 50 feet long and 11½ feet wide. But I have never revealed to anyone until now the other key dimension of depth. I have already stated that the digester floor followed the natural slope of the land it was built on. At the inlet end the depth was four feet and at the outlet, five feet. The floor was flat at the inlet changing to a V of 90°. Each side and outlet portion was 45° from the horizontal at the outlet end (see fig. 6). The effluent pipe led down to within inches of the lowest point in the V. On each side of the digesters remained a narrow, horizontal ledge some 18 in. wide and enough to walk on so as to permit access to the far end. The average depth was thus 5¼ feet and each digester therefore measured 50 x 11½ x 5¼ cu. ft., which converts to 3,000 cu. ft., or 22,440 U.S. gallons. At the specific gravity of water, the digester contents when full to the top weighed 93.6 short tons.

The experience gained from this first major experiment in the production of methane gas has enabled me to work widely in the field of methane digestion and to see many of my designs come into being. Many more ideas are in the drawing phase including my "Power Plant of the Future" described later, and to measure 100 feet in length, 25 feet in diameter and yielding 50,000 cu. ft. of gas daily from 5 tons of manure (dry weight).

This original methane power plant, including engine, cost me 10,000 and produced 8,000 cu. ft. of gas daily. At an altitude of 5,500 feet above sea level the BTU value was 585 per cu. ft., or 46.8 Therms per day. At present prices for natural gas in Santa Barbara this amounts to $7.57 per day or $16,578 over 6 years in gas alone. The savings in labor in the loading and spreading of

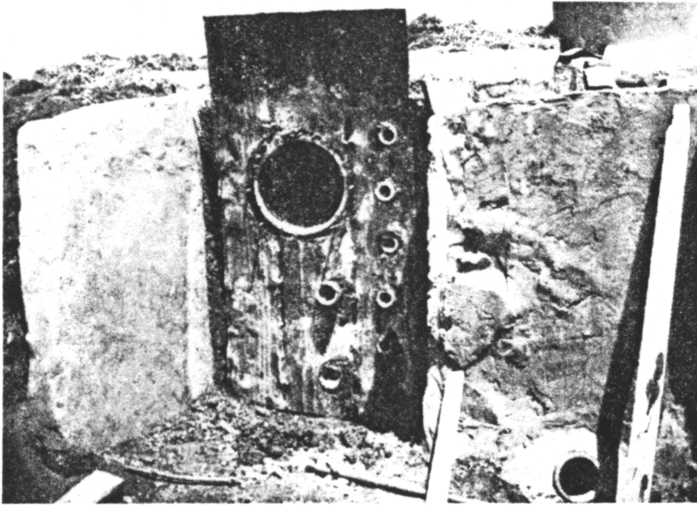


Figure 10 *B*: *Author.* 1) *Gas recirculation pipes.* 2) *Opened sheet for loading in hay as insulation.* 3) *Cement-covered earth bank.*

manure meant a reduction from 8 man/days per week to 1 man/day. However, perhaps the greatest return was neither in methane gas nor in labor saving, but in the value of the effluent returned to the soil as an outstanding fertilizing material. In chemical terms, therefore, the methane power plant also provided me with five tons of nitrogen, 4½ tons of phosphates and 1 ton of potash per year in liquid end products. Professor Gotaas claims that since these chemical elements are in natural form their value as nutrients are a great deal more than the equivalent weights of N, P, and K in fertilizers from mineral or other sources.

A Few Dates in a Scan of the Past

Messrs. Abiet and Lesage in their book, Gaz de Fumier, pinpoint the year 1776 as being the date when a Monsieur Volta first found that gas, rising spontaneously from immersed vegetable waste, contained methane. It was then the term "marsh gas" was coined. In 1808 Humphrey Davy trapped gas from a mixture of manure and water. Almost eighty years later Louis Pasteur corresponded with Ulysse Gayon on the subject of anaerobic decomposition. Gayon experimented and derived gas which he burned in a demonstration before a gathering of the Society of Physical and Natural Sciences in Bordeaux in 1888. At the turn of the century anaerobic decomposition with methane bacteria began to be harnessed as a means of treating human wastes in sewage works. One of the first experiments was in a leper colony in Bombay in 1900. The first known published work on methane gas from animal dung was done in Algiers in 1938 by M. Ducellier and M. Isman who inspired the practical work later of Abiet and Lesage. After World War II, the experiments were turned to practical use in China, India and Europe. In the mid-1950's Mr. Ram Bux Singh and I, quite independently, began to test out larger-scale working units, using different shapes of digesters.

CHAPTER 5

Working Solution to Scum Accumulation

Figure 11: *Farm.* 1) *Digester.* 2) *Breeding sties.* 3) *Fattening sties.* 4) *Main house.* 5) *Manager's house.* 6) *Pump near river* (*electric motor driven by DC current from digester*).

After about a year's operation, one of the twin digesters began to drop in efficiency. The gas yield dropped, the pH was at a low 7.1 and the effluent when loaded in the tank truck showed more gas activity than usual. What was happening was that methane decomposition was taking place outside the digester, which was, in effect, being overloaded due to a reduction in available space within the unit caused by the build up of scum.

After trying to recycle the effluent back to the central strata in an attempt to break the scum (unsuccessfully since the effluent merely bored a neat hole through the crusty layer) and after trying to recycle gas through a compressor and through pipes in the floor, also unsuccessfully, I decided to clean out the digester physically. This was the point in time when the true facts of methane plant operation using animal wastes could be seen and the problems noted and corrected. So far as I know no one had ever done this before in a displacement digester.

First the gas line to this digester was shut. The gas dome was removed and air was allowed to enter. An important note: Here is one time when extreme care must be taken not to have any naked lights about, and to avoid causing sparks. I took the added precaution of not wearing nylon clothes, hob nail boots, and especially of not having an ordinary electric light anywhere near the area. Remember that a mixture of gas and air, particularly in a closed or semiclosed container, plus ignition, spell out EXPLOSION. A word to the wise.

The liquid portion of the effluent was pumped out until the sludge pump ceased to deliver. The level was down to about the half-full mark. Either the material was too thick to pump or the suction pull was too much for the pump to handle. As air entered the digester (replacing the removed effluent) strong fumes of ammonia came off the digester contents. It was obviously impossible to go inside at this stage. Since no more could be pumped out, the only solution was to flush

Figure 11: *Farm.* 1) *Digester.* 2) *Breeding sties.* 3) *Fattening sties.* 4) *Main house.* 5) *Manager's house.* 6) *Pump near river* (*electric motor driven by DC current from digester*).

out the digester with clean water. The unit was filled up using water passed in through the roof inlets, down the raw material inlet and out through the gas outlet manhole, in an attempt to wash out the semisolid material. When the unit filled the liquid portion was again flushed out. The whole operation was repeated three or four times until the fumes became weak enough to permit safe access.

I preferred to go in myself first since I did not wish to ask anyone to do something which might be hazardous. As an added precaution I used a compressor to pump fresh air through a hose pipe and took that down through the manhole with me. The 15 in. scum removal panel had been removed and thus allowed some light inside. A large mirror held by a man outside the digester was also used to reflect sunlight in a beam the length of the digester.

The air seemed safe to breathe although it smelled strongly of ammonia. I discarded the hose pipe as unnecessary. On the floor of the unit was a layer of spongey scum about 18 in. deep. The narrow 18 in. ledges along the sides of the digester were difficult to walk on since sandy debris above the heating pipes had made the ledges into steep slopes. The roof was slippery with dark slime and could not be used to steady myself.

After this thorough initial check, a suitably clothed team of workers began the laborious task of shovelling scum out through the 15 in. scum hole. After the scum was removed I was surprised to find a considerable deposit of chip stone grit and sand. I concluded these materials had obviously come from the pig sty floors where elements in the hog feed had corroded parts of the concrete area over a long period of time, thus allowing sand and stone to be swept up with the manure. Since the digester had been in use for a year, and well over 350 tons (damp weight) of manure had passed through it, I wasn't surprised that some particles had passed the sand trap. What was surprising was the quantity. Over four tons of that deposit was shovelled out.

It stood to reason that the sand trap was either inefficient, or was not being cleaned out regularly. The latter proved to be the case but at the same time I thought about a better method of dealing with this problem (solutions are outlined later in this book).

The chip stone had gathered near the inlet end of the digester and the size of the particles decreased to fine sand. Some mineral deposits accumulated towards the effluent end. The progressive V-ing of the floor from horizontal at the inlet end to a 5° slope at the effluent outlet point had been constructed with the intention of concentrating grit to the effluent outlet and thus passing it through with the effluent. Occasional blockages when withdrawing effluent were proof of the fact that most did, in fact, pass out. But it was also found that larger pieces of chip stone had accumulated

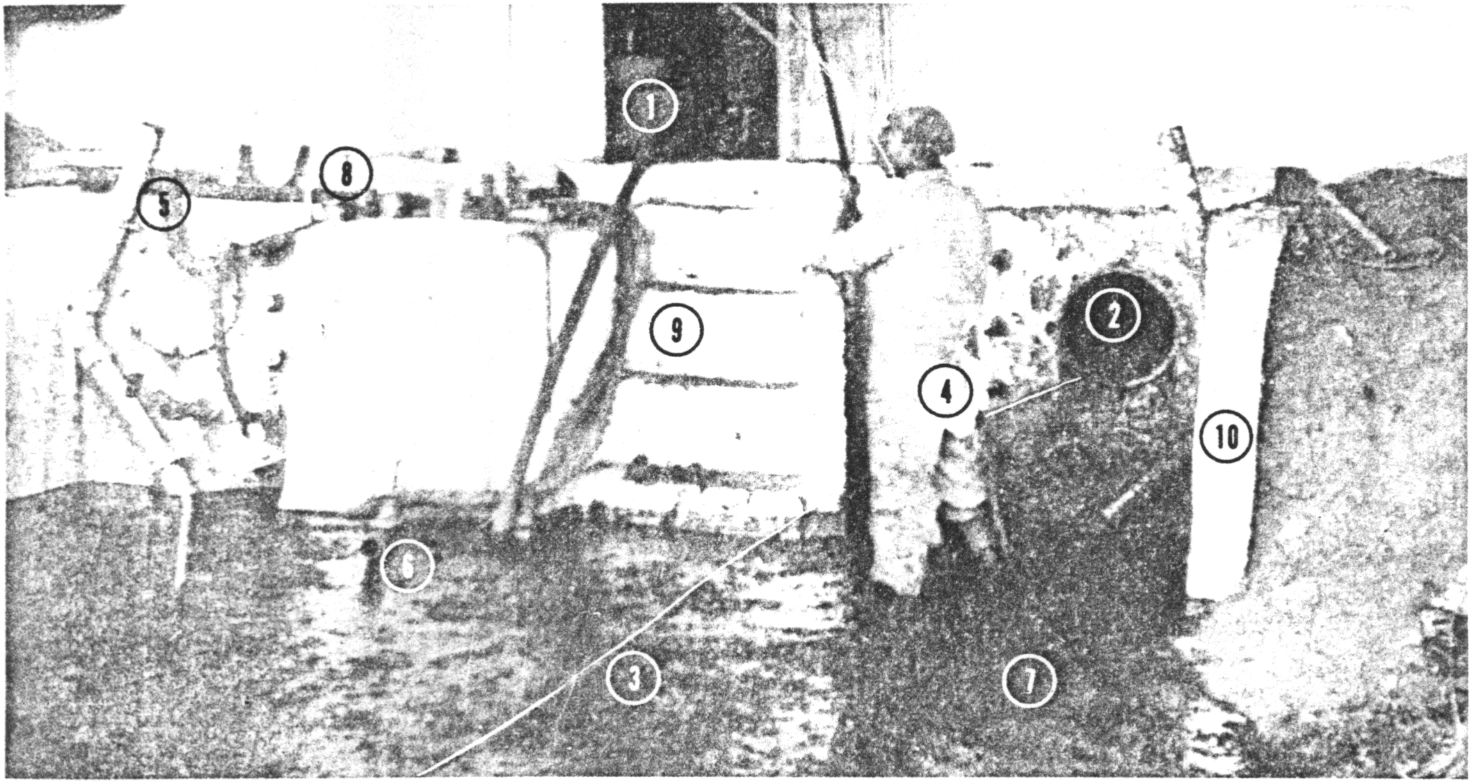


Figure 12: Digester during scumming out procedure. 1) *Gas dome of digester in use.* 2) *Scum port open.* 3) *Scum drag wire.* 4) *Sunlight reflected by mirror (behind camera) for illunimating digester contents (intercepted by figure).* 5) *Automatic overflow pipe.* 6) *Effluent outlet.* 7) *Scum after removal.* 8) *Level indicator plastic pipe.* 9) *Hot water pipes disconnected from digester being worked upon.* 10) *A bastion wall.*

near the inlet pipe and for a short distance only. The four tons removed represented a waste of approximately 3% of the total digester space. In comparison the scum layer of over 18 in. depth had wasted about 30% of the working space in the digester.

When all these materials were shovelled out the engine cooling pipes were seen. One of the pipes was made of steel and the other of plastic. Both, however, were covered on top with a hard, brittle crust of mineral deposits similar to the "furring" in a kettle. The material broke off easily at the touch. An anaysis was not made since this did not present a problem. This topic will be dealt with later but it might be mentioned here that the problem can be overcome very simply by burying the pipes in the concrete floor. This would also get the pipes out of the way when scumming out, keep them from kinking, as well as preserving them. The transfer of heat through the concrete would be no problem.

Scum Problem Solution

It was obvious that since recirculation of effluent and/or gas would not break the scum layer so that it could be pumped out with the effluent, the scum would have to be physically dragged out at intervals of about 12 months. The methods tried until then required far too much labor and attention. The obvious logical answer was for a device to be left inside the digester — a mechanism that would float at the scum level with drag wires holding the drag in place. The end of the drag wire would be secured on a hook accessible from the outside through the 15 in. collar at the outlet end.

One device was made for each digester and assembled inside each unit. They were used effectively when the time came a year or so later and continued to be of great use over the years to come (see fig. 13).

Three minor problems remained:

1) The scum outlet opening was so narrow that when the scum was dragged to the outlet end, it had to be hoed out from each side and the middle, through the 15″ collar.

2) The bottom of the drag got entangled with the heating pipes and had to be jerked free.

3) The drag was not equipped to be pulled to and fro. It had to be pushed with a long pipe, tipped with a hook, from the outlet end and all the way back to the inlet end, a distance of 50 feet.

The scumming out procedure was to close off the gas and drop the digester contents level (as seen on the level indicator) to the lowest point on the 15 in. scum outlet. Then the plate was removed and the drag wire

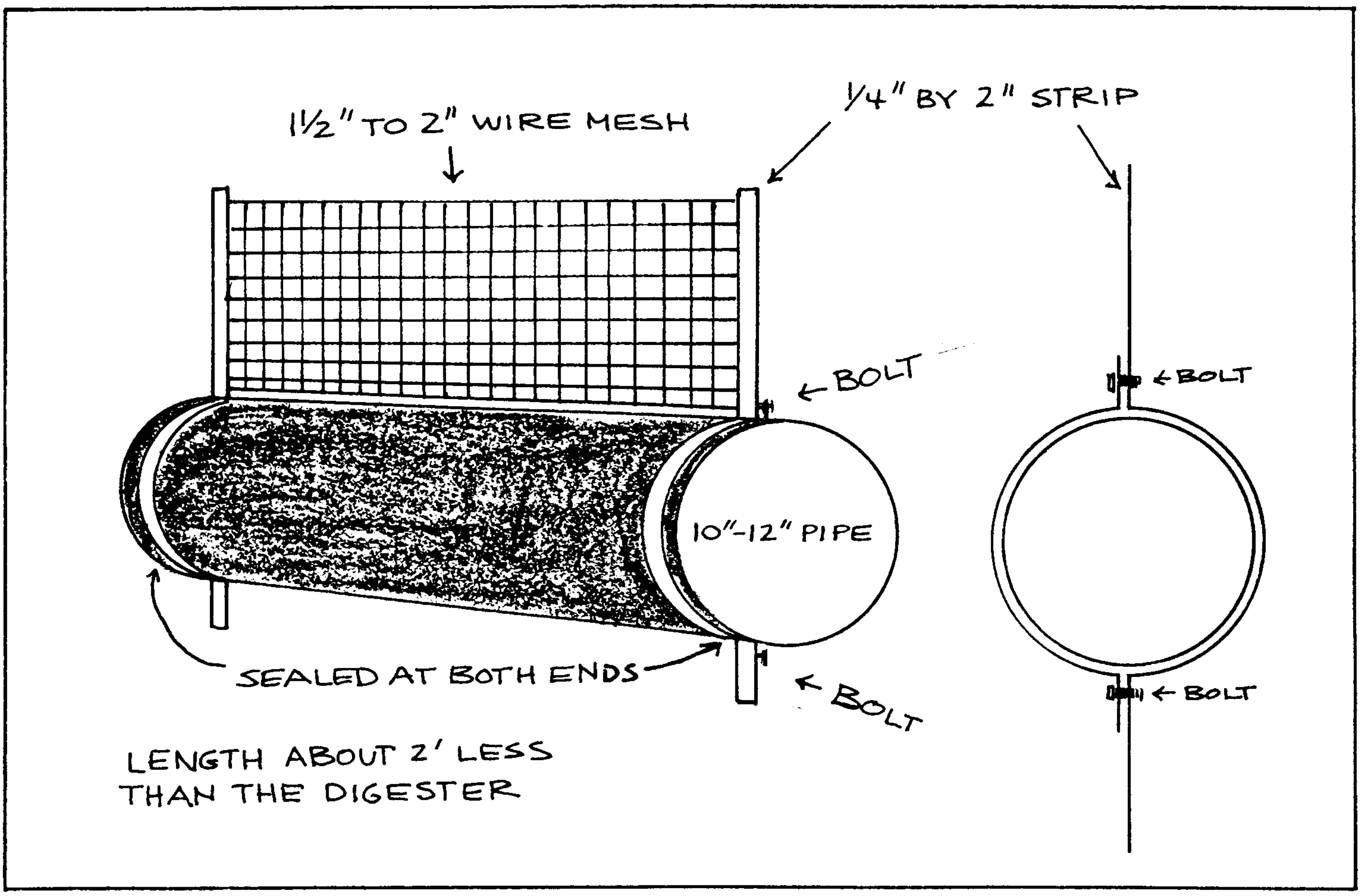


Figure 13: *Scum drag.*

inside the scum port collar located and pulled slowly. The scum now floating on the digester contents was hoed out onto the concrete apron and later removed. The plate was then secured, the digester fed the normal load and air flushed from the digester and pipes in the normal procedure for starting up. Within two weeks, and often within a few days, the digester was back into normal operation.

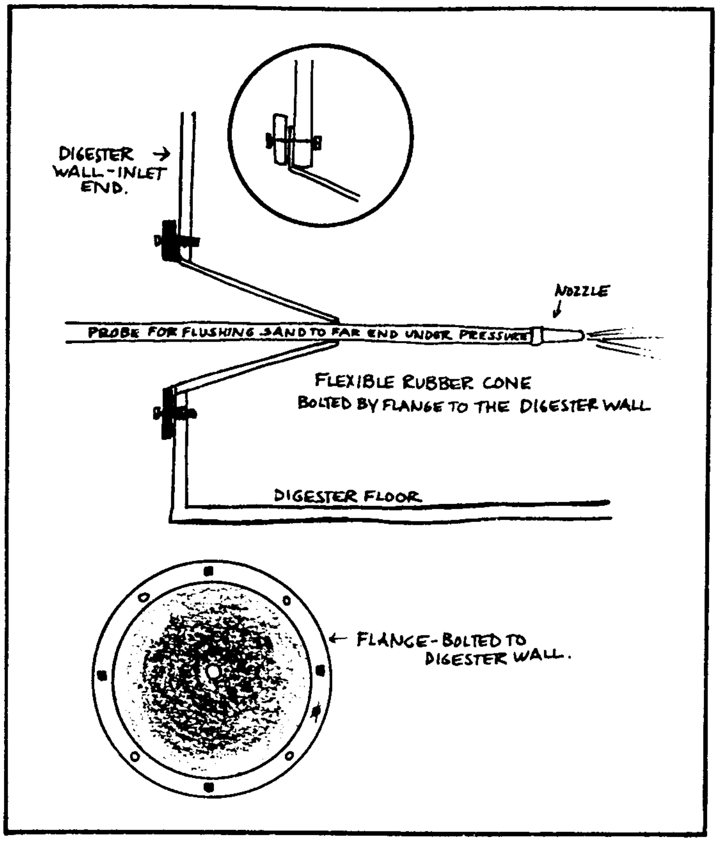


Figure 13A: Sand probe for inlet end of digester.

Summary

1) Digestion on a large scale can indeed be achieved. In fact, the larger the digester unit, the higher the overall efficiency.

2) Concrete is not a good material to use for the roof of a digester in that it contracts and often cracks right from the time it begins to set and even for years afterward. If not mixed in exactly the right proportions of water, cement, sand, stone and reinforcing metal the roof will also be porous.

3) Whatever material is used for the roof precautions must be taken to seal off thoroughly against leakage.

4) It is preferable to shape the roof in the form of a half cylinder. By keeping the digester contents at about one foot from the top, the scum accumulates on a large, broad surface and therefore not as fast or deep as it does in a vertical digester. Accumulation is slower and is also confined to a width narrower than the width of the digester itself after the level is dropped to the scumming out position.

5) To accommodate the drag, the scum removal doors should be almost as wide as the widest part of the digester, and well below the normal working level of the digester contents so as the avoid any possibility of gas leakage through faulty gaskets on the scum doors. Fluid leaks can be dealt with far more easily than gas leaks.

6) An easy to clean, efficient form of sand trap must be adopted for processing raw slurry before it enters the digester. However, should such a system be impossible to operate at top efficiency, some provision should be made to the digester design to insert a probe at the inlet end, through which fluid supernatant could be pumped under pressure to shift sand down to the effluent outlet where it can be withdrawn along with the effluent and disposed of in the same manner. Both effluent removal and recirculation could be done at the same time to avoid accumulation of sand around the effluent outlet in unmanageable quantities.

7) Heating pipes should be laid into the concrete floor.

8) Access points should be made at a number of points along the side of the digester to a) withdraw samples for testing pH, etc., b) recirculate effluent to restore bacterial activity, c) inject ammonia or other chemicals to restore more favorable conditions for the methane bacteria to work efficiently in case of a possible fall-off in gas yield. Since the gas yielded is directly proportional to the rate of decomposition, every effort must be directed to maximum gas production but not to the point of overloading the digester.

Note: Since the first printing in 1974, a patent No. 3954619 has been granted for the scum drag. This does not apply to any other country than the U.S.A. or dependencies. The description and method of operation are adequately demonstrated in Fig. 13 and on pages 86, 87. A license to construct and use this device may be obtained from the owner of the patent and author of this book.

CHAPTER 6

Gas Holders Used on My Farm

Gas holders are necessary with any shaped digester having a fixed roof for these reasons:

1) To allow gas to escape from the fixed volume of the digester without causing changes in pressure in the digester.

2) To permit storage at low pressure.

3) To act as an automatic pressure release mechanism. Should the gas holder fill completely, any further inflow will safely escape from under the gas holder tank, through the water in the lower tank, and out to atmosphere. In practice, this procedure causes a loud rumbling when batches of gas escape sporadically.

4) For the return of gas to the digester should effluent be withdrawn. (Air must never penetrate a digester except when cleaning or scumming out.)

5) As a means of measuring the gas output over a given period of time by the rise of the inner tank.

For my South African plant I had three holders: two of about 350 cu. ft. (about 10 cu. meters) and one of 300 cu. ft., making a total storage of 1,000 cu. ft. (28.5 cu. meters). Since production was 8,000 cu. ft. (226 cu. meters) per day all three filled in three hours. Expressed another way, daily gas production totalled eight fillings of all three tanks. The size of one of the larger tanks can be seen in fig. 14 being transported on a three-ton truck.

One of my chief frustrations ever since this unit was put into operation in 1958 has been to convey orally or in writing just how much gas was produced. To the vast majority of people cubic feet or meters of gas mean very little. Most know what a gas bill is but few take the trouble to check how many cubic feet of gas of what BTU value they have consumed.

I was pleased with a surprise visit by a team of six scientists who arrived one lunchtime to ask if I would demonstrate exactly how I had arrived at the claim of 8,000 cu. ft. per day. A part-empty tank was carefully measured in diameter and the gas production from the digesters was led into this tank only. The rise of the tank over a short period of time (about 15 minutes) provided the data to measure production, and the scientists checked all figures themselves in detail. My claim was found to be in error. Production at that time was not 8,000 cu. ft. per day as I had claimed but 12,000 cu. ft. My claim had been correct but I had not bothered to count the peaks of production since I could not store or use the excesses. Gas escaped to atmosphere (as it has for billions of years in nature through anaerobically decaying vegetation), but in terms of air pollution this represented about the same effect as a pebble thrown into the ocean.

The only solutions to the "problems" of creating what at first appeared to be vast surpluses of energy were to: 1) Burn it for cooking (150 cu. ft. per day) or refrigeration (only about 40 cu. ft. per day); or 2) To combust it as a fuel in an engine. But what sort of engine? I had previously been using the gas to supply up to 87% of the power in my 3-HP Petter diesel engine as the gas could be used more efficiently in a high compression engine such as a diesel than in a low to medium compression gasoline engine (see section on Gas Uses).

I was not prepared at this time to consider the expense of compressing gas into cylinders for storage and later use. There was no technical reason why this should not have been done but it seemed to me logical at the

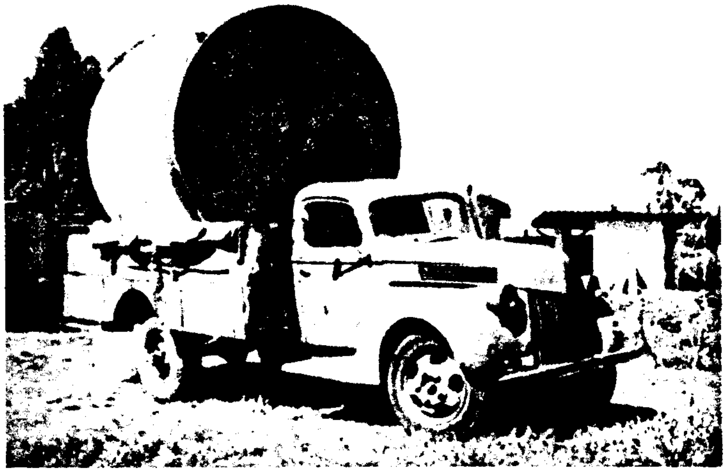


Figure 14: A gas holder tank being transported. Compare size with the 1941 3-ton army truck.

time to confine the gas plant to a stationary power supply unit for farm electricity and mechanical energy and not to extend the experiment to the complications of scrubbing gas of carbon dioxide and hydrogen sulphide prior to compressing for use on mobile farm machinery and trucks.

I did branch out a little experimentally, however:

1) An ingenious young man drove down to my farm and showed me his device to convert his car to run on compressed gas. He had a cylinder in the trunk, a regulator to reduce pressure from 100 p.s.i. to much lower, and a variable jet into the air intake. Would my methane gas be suitable? I had plenty of it and a compressor nearby. We connected up and compressed raw (unscrubbed) gas straight into the cylinder. When the gas was up to his tank's working pressure (100 p.s.i.) we tried it out. He started on gasoline and then switched over to methane gas. The engine ran well in a steady fashion, but it had a marked lack of power in acceleration. It was "sluggish". Also I noticed a rapid drop in the volume of gas. In only 20 minutes of driving the gas was nearly used up, despite the fact that this was a small car. While being driven I thought about a bumper slogan "Power to the Pigs" but discarded it immediately when it became obvious we were not going far on this novel form of fuel, used in this form.

2) From time to time a Ford V-8 gasoline engine of 100 HP was fueled by methane gas to operate a hammer mill which absorbed 50 HP. Consumption of gas at the rate of about 20 cu. ft. per HP per hour, or 1,000 cu. ft. per hour to fuel the engine was so great that all other engines had to be stopped when milling. The three gas holders when full only contained enough for one hour, plus the gas generated from the digesters in one hour (another 350 cu. ft.).

The engine was started on gasoline. When running smoothly the gasoline was shut off and after a measured period of time (about 30 seconds) when the engine began to falter, methane gas was turned on at the on-off valve. A second valve adjusted the finer tuning of the gas flow to power the engine and mill. In this case, I used a one-inch pipe to provide sufficient flow at low pressure (6-in. water gauge). After one hour and 20 minutes gas was shut off for three hours to store enough gas to continue milling.

Construction Components

Gas holders were made inexpensively from galvanized corrugated iron tanks. Aluminum could also have been used but was more expensive. All fittings for the gas pipes, guides and bracing were standard plumbing items with the exception of a roller mounted on a bracket. The base of the bracket was wide enough to be bolted on the crests of two adjoining corrugations. The concave roller fitted loosely around a one-inch pipe.

An important feature of a gas holder is that it should move up and down freely, without undue friction. If a series of holders are used, each can have weights placed on it in a succession so that the first to fill will be the lightest. As this one reaches its capacity the upward movement can be stopped by the top pressing up against the top bracing. Gas will then flow to the next lighter tank and so on to the last holder where it can finally escape through the water when that holder is full.

Pieces of paving weighing a total of about 330 lbs. (150 kg.) were placed on all three holders to increase pressure to six inches water gauge (0.21 psi.) so that enough gas would flow through the pipes for the engine consumption needs and household cooking purposes. The houses were 800 and 1,100 feet away, respectively, and were amply supplied with gas through one-inch, plastic, irrigation-type piping.

The weights required to raise pressure is directly proportional to the diameter of the gas holder. The larger the diameter the greater the weights needed to provide the pressure required. If heavy gas holders are used it may be necessary to provide rollers and counter weights, depending on the diameter. Even the huge city type gas holders weighing thousands of tons usually float on water seals on only a pressure of 16 inches water gauge.

Figure 14 shows an example of the dimensions involved. This was the inner gas holder tank. The outer tank (not shown here) was larger to the extent that the guide pipes and rollers bolted to the inner tank were located inside the outer tank. The distance from the base of the roller bracket to the outside of the one-inch pipe was 4½ inches. Therefore the inner tank of 8 ft. 9 in. required the outer tank to be at least 9 in. larger in diameter, or 9 ft. 6 in. In practice, and to allow for slight errors in construction, it was 9 ft. 8 in.

Two tanks were made for me in a tank factory:

1) The gas holder tank of 8 ft. 9 in. diamter, 6 ft. in height of 24 gauge, commonly-used, thin, galvanized iron. One end (the top when used as a holder) was 22 gauge. The extra strength prevented it from ballooning out when in use. The bottom (seen in fig. 14) was the end that floated constantly in water. Since this end moved through the water when gas entered or exited, large holes were made to reduce friction to the water. The whole bottom end was not removed in order to provide some lateral strength and thus keep the rollers positioned firmly in relation to the guide pipes. The gas pipe passed through the largest of these apertures.

2) The water tank of 9 ft. 8 in. open both ends, 6 ft. long.

Construction Sequence

1) The gas tank was carefully measured and the eight rollers bolted on, each of the four top ones one quarter of the distance around the circumference. The other four were bolted at the bottom and directly in line with the top ones. The tank was then positioned on levelled

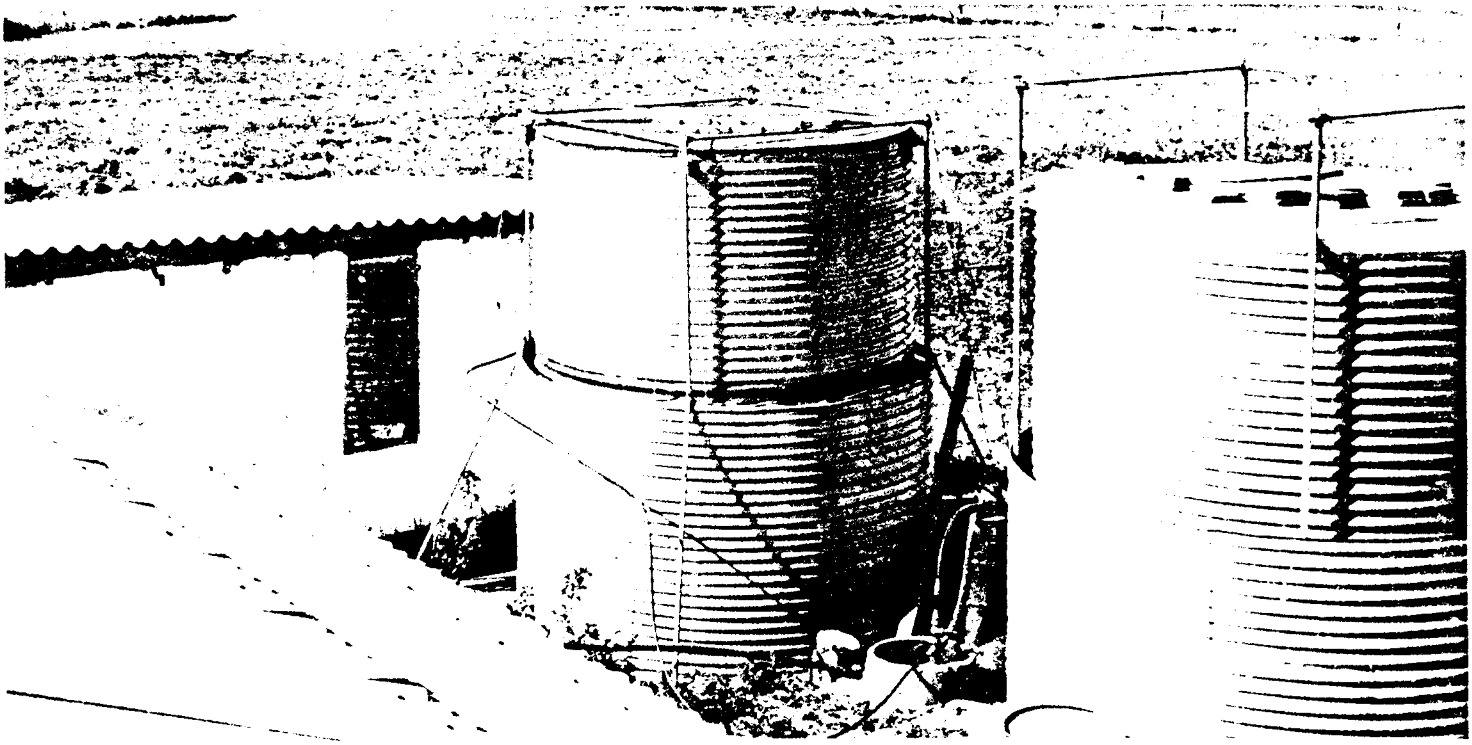


Figure 15: Gas holder on left is full. The one on the right is nearly full. Note weights on top and cross bracing.

ground exactly where it was to be installed, but raised off the ground for convenience in digging (explained later).

2) The four guide pipes were cut and threaded both ends. The length was calculated as follows: a) Since the tanks were each 6 ft., the length was kept under 12 ft., b) from this was deducted 6 in. for the inner tank to float. This 6 in. represented the water gauge pressure of the gas both in the holder and therefore in the digester, c) if the gas holder was to be any but the last holder of a series, I deducted a further 2 in. Assuming this was the only gas holder (or the last of a series) then the length was 11 ft. 6 in. Four more pieces of pipe each of 14 in. length were then cut off and threaded at one end. The other end of the pipe was cut longitudinally for 2 in. and in two cuts at right angles to each other. Each of the four pieces were then splayed out to form a footing for holding firmly in concrete (see fig. 17). A coupling (sometimes called a socket) was then screwed firmly onto the short pieces and loosely to the long guide pipes.

3) The four one-inch guide pipes were then placed against the rollers and held in place by a piece of wire drawn around all four and the tank. The wire was placed midway between the rollers and slight tension was applied. The tension was such as to bend the pipe inward by only about ⅛ to ¼ in. Later on when construction was finished this slight misalignment would provide enough play so that the rollers would not press too hard against the guide pipes.

4) Making sure the gas holder tank was dead vertical, the four guide pipes with couplings and the short lengths screwed on then rested on the ground. A small hole was dug around each splayed foot to a depth of 6 in. below ground level and a little concrete was then poured around each. In areas where lightning might strike gas holders it is strongly recommended, at this point in construction, to drive a metal stake deep into the ground near one of the feet and bond them together to make a good electrical contact. I did this on my farm and one of the tanks was indeed struck by lightning. No damage or fire occurred.

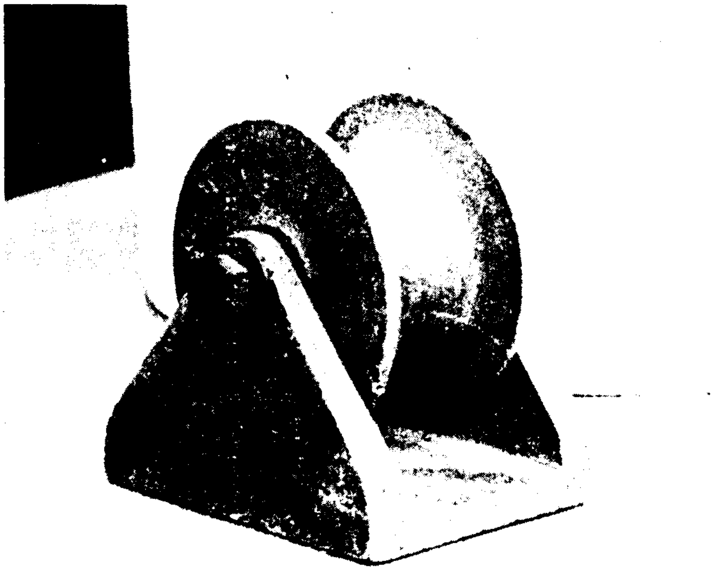


Figure 16: Gas holder roller, the only item not available as standard equipment.

5) With the inner gas tank in position the gas pipe was then installed. The size of the gas pipe had to be proportional to the size of both the effluent and loading pipes of the digester for the simple reason that if the digester was loaded gas would be displaced into the gas holder rapidly. If effluent was withdrawn through the 3-in. outlet, gas to replace it had to flow back to the digester. Since gas flows more easily than liquids a pipe size of two inches for the gas proved adequate. The 2-in. pipe was to be set in the concrete base with a 90° bend leading up to the same height as the outer water holding tank. The piping consisted of a threaded length leading in from outside laid in a shallow (2-in.) excavation, a slow bend of 90° (not an elbow), and a vertical length to bring the pipe level with the top of the outer tank, a distance of about 6 ft. 4 in. from ground level. The end of the pipe was kept from damaging the gas holder and also from shutting off the gas flow when in the down position, by welding a small plate at right angles to it ½ in. off the opening (see fig. 18).

The final positioning of the gas pipe consisted of laying it in the shallow trench so that the vertical portion passed freely through the largest of the apertures cut in the bottom of the gas tank, without being in line to touch it at any point of its travel up or down. The gas pipe in the trench was checked with a spirit level to make sure that it was slightly off the level, thus ensuring that condensation would lead away from the tank, to the outside. Later, a little concrete was laid around the gas pipe to keep it in position until the concrete in the base was poured to hold it firmly in this position.

6) When the concrete was set the guide pipes were unscrewed at the couplings, but gently to avoid moving the concrete. The pipes were marked for their respective final positions and laid on the ground. The gas holder tank was removed and the exterior painted to delay corrosion by the weather. The interior was painted with asphalt emulsion to prevent the galvanizing from being stripped off by the gas, thus causing eventual corrosion.

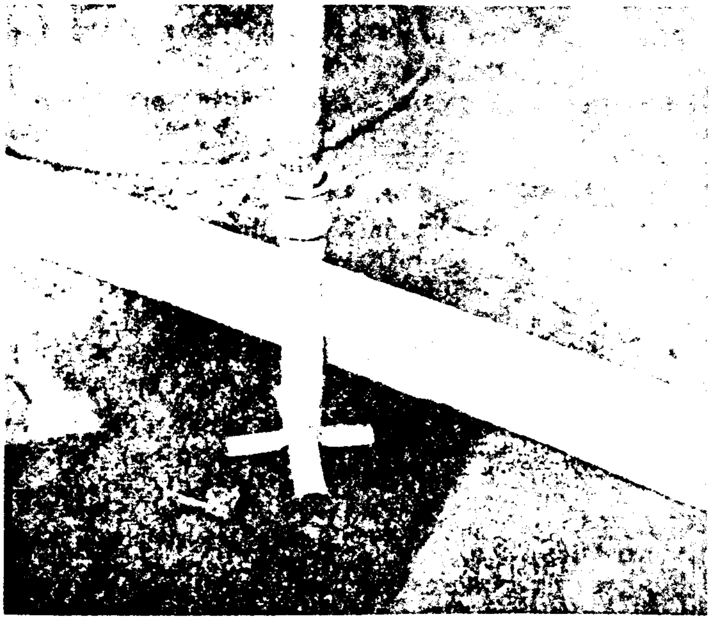


Figure 17: Splayed pipe in dug-out hole as base to guide pipes.

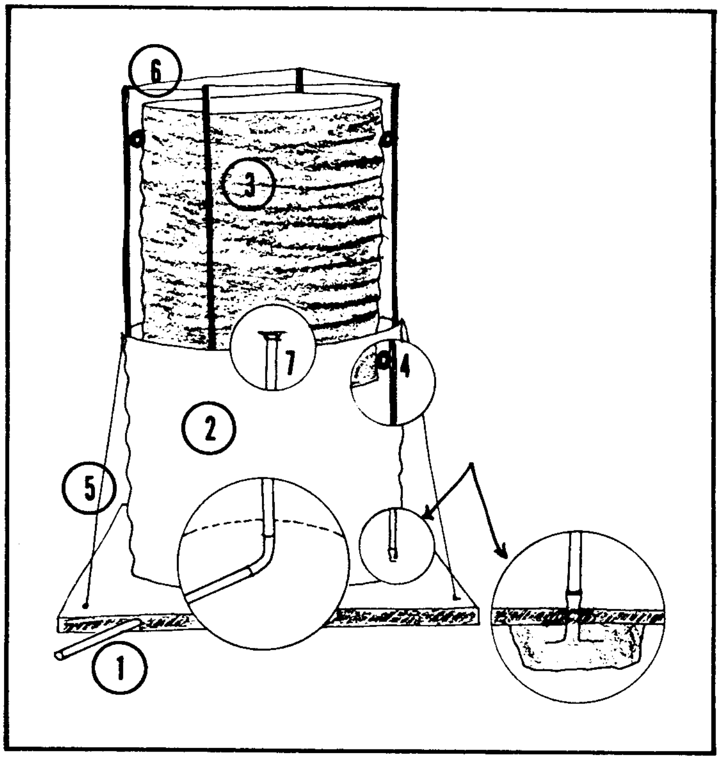


Figure 18: Gas holder. 1) Gas flow in and out. 2) Water tank. 3) Gas holder tank. 4) Roller on guide pipe. 5) Stay wires on guide pipe. 6) Cross bracing. 7) Top of gas pipe with protective plate.

One tank was not treated on the inside and was in use for over four years before repairs had to be made. The repairs consisted of stopping leaks of water from the outer, larger tank and it was only at this time that coating the inside of the smaller gas holder was done as a precaution. The galvanizing had been entirely removed, leaving bright steel which yellowed with rust within minutes of being exposed to air. This was further reason for coating. Asphalt emulsion was used because of its relative cheapness and because no harmful fumes were let off while painting inside. A rule to remember is that corrosion is greatest at the line where water and air meet. Hence the lower tank holding water always corrodes first.

7) With the site now clear except for the four short pieces of pipe with couplings standing vertically and the gas pipe in position, the outer cylinder was tested for fit by placing outside the four pipes, resting on the ground. Boxing for concrete 6 in. deep was then made on all four sides, and the cylinder removed.

8) Concrete was then poured in the box 6 in. deep. Only the four couplings and gas pipe protruded (see fig. 19). With the concrete wet, the outer cylinder was immediately placed in position and vibrated so as to sink 2 in. into the concrete. A true vertical position

was checked with a spirit level and the cylinder propped with timber as necessary to hold this position while the concrete set. It should be noted that the water holding tank need not be of corrugated iron. Any structure that will hold water is suitable, i.e., reinforced brickwork, concrete, or any other strong enough material to withstand the static pressure of the water inside.

9) After a few days to allow setting, work was begun on coating the inside of the water holding tank. A thorough job is essential to the long life of this tank as in any tank destined to hold water.

10) Final assembly: Three of the guide pipes were screwed into their respective couplings. The water tank was filled to the brim. Planks of timber were laid across the top on which the gas tank was placed above its designated position. The fourth guide pipe was then screwed into the coupling. The four guide pipes were linked and cross braced using ordinary pipe fitting and ½ in. pipe, or railing fittings as used in pipe scaffolding. To ensure strength where high winds could damage the gas holder, I also guyed the guide pipe structure to concrete blocks a few feet out from the base of the water tank. By levering at a number of points the planks were removed and the gas tank lowered to float in the water.

By fitting a valve to the 2 in. gas outlet pipe and closing it off, the gas holder could then be left for 24 hours or more to check for leaks. When the valve was opened air escaped and the gas holder sank slowly to its lowest point. After this the water level in the outer tank sank slightly since the weight of the gas holder was removed from it. It was topped with water.

11) When first put into use as a gas holder, gas displaced the water in the topping up, causing it to overflow until the gas holder began to float. After this no more overflowed and the holder rose and fell according to the flow of gas.

Figure 19: Base to water tank being made of concrete. 1) Gas pipe in position. 2) One of the four guide pipe couplings held in position. Once the 6-in. layer of concrete was laid the water holding tank was positioned vertically and around the four couplings.

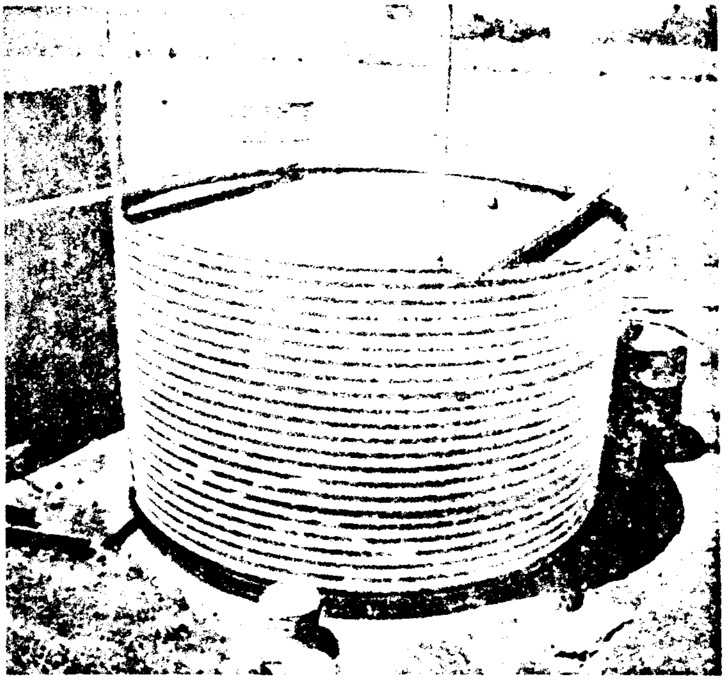


Figure 20: Water tank filled and ready for the gas holder (in background) to be lifted into position along planks (later removed). Note gas pipe protruding above water.

After four to five years of operation I was puzzled one day to find that the automatic overflow of supernatant from both digesters was pouring out, when I switched the gas to one particular gas holder. The only cause of this problem was that the gas was not flowing into this holder. I switched the flow to another holder and dismantled the piping to the faulty one. I found the gas pipe completely blocked with a black "fur". It could be removed easily in the straight portion of pipe by rodding out, but this pipe had an elbow which prevented further cleaning out and a "snake" drain cleaner had to be used to finish the job. Caution: In the dismantling of sludge gas piping within a gas holder or digester under repair the rapid oxidation of iron sulphide deposits within such piping may create heat or flame.

Condensation Trap

The gas holders were connected to the digesters through a condensation trap. Since the raw gas from a digester is saturated with moisture, this moisture condenses to water when cooled. The 2-in. pipes leading from the

Figure 21: The gas holder being positioned with one guide pipe resting in shallow hole.

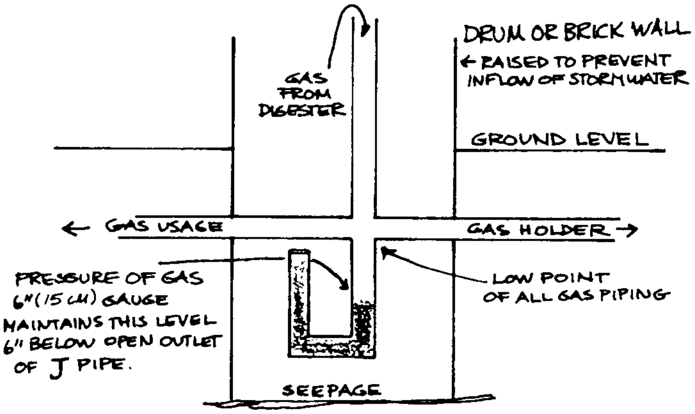


Figure 22: Condensation trap principle.

digesters were nearly always cooler than 95°F. Condensation from 8,000 cu. ft. per day amounted to a fast steady drip. Provision should be made to protect the trap from storm waters since the filling of the trap well with water would seal off the gas flow.

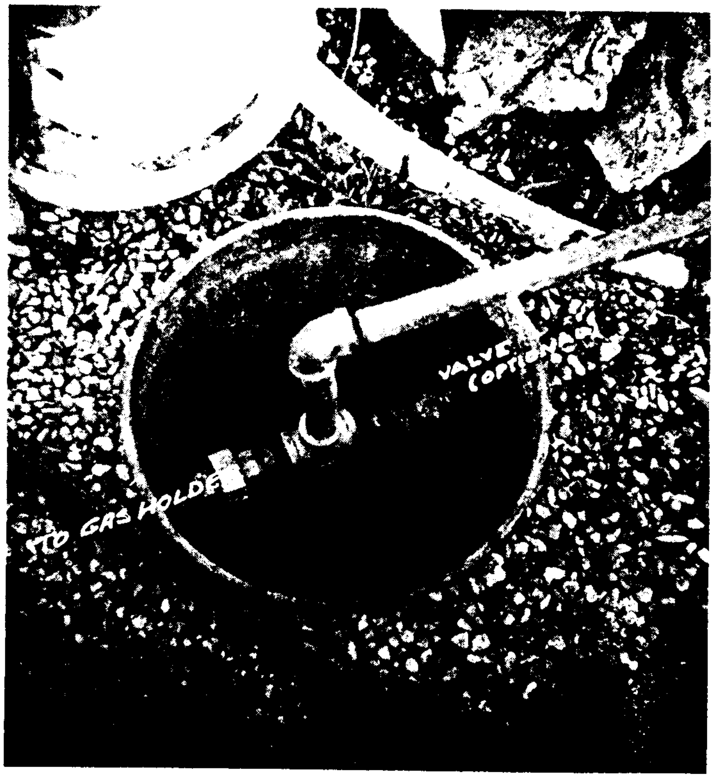
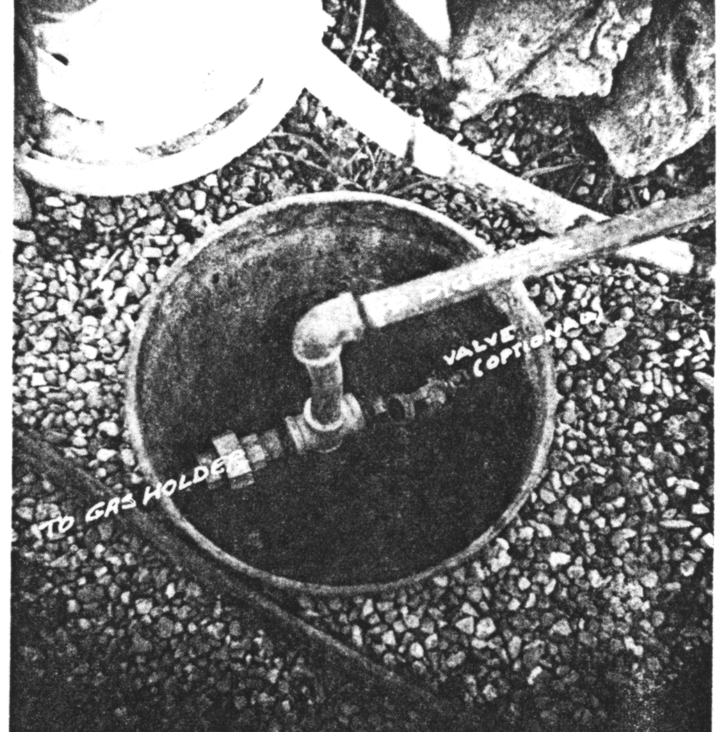


Figure 22A: Top view of trap. A valve is optional.

Raw gas can be led any distance, according to the size and length of pipe in any volume required, but since the gas is saturated with moisture, condensation will effectively block off the flow if the pipe is laid dead level. If it is uphill or downhill the flow will not be impeded provided a condensation trap is installed at the lowest point in the line. If a gas line is to be laid across a valley it can be laid in a decline and then an incline up the other side, but a trap is needed at the low point. Metal pipes are not recommended. Plastic pipes are preferable and cheaper. On large installations it might prove economical to clean and dry the gas. The gas would then be in all ways similar to natural gas, and traps would not be needed. Gas holders, the water tanks beneath them, and the condensation traps must be protected against freezing in order to function.

Further methods of gas storage are mentioned in the section on Gas Uses.

If a methane plant is sited in a low lying area prone to flooding (such as Bangladesh), provision must be made for gas to escape should the entire methane plant, including gas holders, be submerged. Failure to do so could result in either or both floating upwards. An inverted T piece should be placed at the highest vertical point in the gas pipe line above the outlet from the digester. A vertical pipe should then be joined to the inverted T long enough to rise above any potential flood level. A valve must be provided, to be opened only when flooding is likely.


TO DIG
VALVE
(OPTIONAL)
TO GAS HOLDER

CHAPTER 7

Digester Types and Scum Removal

For millions of years nature has decomposed the organic matter that falls to the earth's surface. On the ground that matter decomposes by the aerobic (compost) process, given the proper conditions of moisture and air. Under water or where there is no air, the anaerobic process takes over, culminating in decomposition by methane bacteria and the generation of a gas that not only burns like natural gas but suits this century admirably as a 120 octane fuel. The significance here is that the methane gas can power an internal combustion engine and, being of a relatively high octane rating, it's efficiency as a fuel rises as the compression ratio of the engine is higher — within limits. It can also be used efficiently in a gas turbine engine.

It is possible to imitate this natural process, to harness the resultant power and to accelerate the rate of decomposition with controlled conditions of temperature, fluidity, and with regular "feeding" of bacteria. The airtight tank in which all this is done is called a digester.

Digesters are of three types:

1) **Batch-Load Digesters.** These are completely filled all at one time with mixtures of coarse and/or finely ground vegetable matter, including even paper. The units are sealed up to exclude air and left to generate methane gas. The process can be speeded up by introducing quantities of an active methane bacterial slurry from a previously working digester. Many such units are being used in Europe. However, the disadvantage of these units is that when decomposition ceases, and hence the generation of gas, the entire digester must be emptied and cleaned out, requiring considerable labor. See Chapter 10.

A recent manifestation of this batch principle is seen in the sinking of gas wells at old garbage dumps and land fills. This process is simple and yields gas in quantity. A number of factors limit widespread use, however, such as suitable terrain, moisture, and seeding material.

The principle of a batch load digester should not be discarded as impractical, although the face of Europe is said to be dotted with disused methane plants of this "primitive" design. One singular advantage of these units is that coarse farm vegetable wastes can be digested with efficiency, and when a batch-load digester is used in combination with a displacement-type, continuously-operated digester on a farm, each could be fed different raw materials and produce the same end products. I hope to build an efficient, modern batch digester and outline my plans along these lines in a sequel to this book in due course.

2) **Vertical Digesters.** These are circular tanks, often of millions of gallons capacity, used in sewage treatment plants, or as much smaller units such as are built in India by Ram Bux Singh who has spent many years researching and writing about his designs and their practical applications.

The advantage of the circular tank is that construction is cheaper since the static pressure of the contents can be withstood easily and cheaply by reinforcing the concrete. The disadvantage is that the natural fermentation with methane bacteria make the contents surge vertically with considerable force. Consequently fresh material deposited in the digester may be removed as early as the next day when decomposed effluent is withdrawn to make room for the fresh input. The roof may be fixed, in which case gas is piped to a gas holder for expansion and storage, or the roof may float either in a water seal or in the contents of the digester itself. Either way heat losses through the top cover in cold weather are high to the point of being excessive. Most sewage treatment plants are of this general design. but some are more efficient than others in their properties of thermal insulation.

3) **Displacement-Type, Continuously-Operated Digesters.** These are digesters fed relatively small amounts frequently so that gas and fertilizer are produced continuously.

Finely ground, colloidal waste matter is mixed with urine and water to form a slurry. Dung is ideal for this purpose since the animal has ground up its original feed and chopped it up in advance, as well as having provided the needed minerals from the dead cells of its body. When mixed to the right consistency (between 10% and possibly as high as 14% dry solids to moisture content) and after eliminating much of the sand, grit, chip stones and other inorganic materials, the slurry is gravitated or pumped into the inlet end of the digester. Each load "displaces" or pushes along previous loads in such a way that the digester, at full working capacity, is in effect a succession of loads of slurry. Each load is seeded with methane bacteria from the previous load, which in turn is seeded by the previous one.

In other words, the microscopic methane and other bacteria backtrack to the inlet end during the intervals between loadings and set the anaerobic process in motion. Methane decomposition is admirably suited to a continuous endless-belt type fermentation unlike most others. With yeast and suitable feeds, for instance, only the batch process would apply.

Down the length of the digester each load goes through a series of natural biological changes. In simple language one could say that the whole process could be likened to a factory line where one group of workers takes the raw material and conditions it for a second group who convert it for the specialized work of turning out the end products. In this case those products are a versatile flue gas, plus a fertilizer.

Since the methane bacteria have to backtrack to the inlet end over a given period of time, it is logical that the width and length of a digester be to certain proportions.

My first thoughts of a digester for hog manure was to have been a 3-ft. pipe of over 800 ft. length. The manure was to be loaded daily at one end and an equal volume allowed to flow out the far end. With a loading of 160 cu. ft. of raw slurry per day, this would have displaced 23 ft. of pipe. Clearly the methane bacteria could not backtrack such a distance. The thought was abandoned in favor of a shorter and wider digester. However, an alternative would have been to seed the raw material, but to do this the volume of effluent (used as seeding) must be at least equal to the raw material volume. Even with a 50-50 mixture there is no certainty that each and every loading would have been thoroughly seeded. Failure could result in foul odors and of course no gas. It would also mean that each daily loading would occupy 46 ft. instead of the intended 23 ft., thus wasting half the working space in the digester.

Each load of slurry goes through biological changes, described later, but the changes in the physical state of the mass is abundantly clear. At some point in the progression down the digester the methane bacteria work actively on the mass, create methane gas in it and force a mass to well up in a volcanic movement which is repeated endlessly. This section of the digester is like a witch's cauldron of seething, bubbling vertical currents. The shearing action of clumps of material passing each other creates even more mixing and, in turn, more gas. The effect of this action is to mix the materials thoroughly into homogeneous similarity (fig. 23).

Violent activity slows down in the succession down the digester to the far end where the materials separate into the following strata, or layers:

a) **Gas as a Vapor.** As the gas is generated, pressure to escape from the digester is also generated. There is no known limit to the pressure that is self-generated, but I have read of a pressure as high as 8 lbs. per sq. in. (562 grams per sq. cm.).

This is not of any particular significance to the operator of a methane plant except that the pressure is sufficient to raise a weighted gas holder with a back pressure of six inches (15 cm.) water gauge. Any higher pressure might retard gas yields and be difficult to handle in a digester, as explained later under "design."

b) **Scum.** Since this is such a problem to methane digestion of animal manures I will deal with it in every detail known to me on the principle that it is better to know your enemy and strike his weak point rather than flail around blindly hoping to hit him.

"Foam" is sometimes mistaken for scum. The trap described later in the section on the inner tube digester is designed to allow foam to escape harmlessly. Foam has some of the characteristics of scum and is neither liquid, gas, nor solid, but an intimate mixture of all three. In the trap, foam settles into a liquid with a small solid content. In the inner tube digester the true scum accumulates nevertheless after a year or so of continuous operation, despite agitation which can be applied readily by thumping rhythmically on the flexible material. If the scum is broken it merely reforms in a different pattern. The same would be true of large scale flexible digesters, one of the digester designs proposed on a farm or feedlot scale.

"Froth" is also mistaken for scum. For some reason not explained in any text book that I have read, a froth of large, grey sticky-surfaced bubbles is sometimes generated in the first few days of starting up a digester. In about one case in twenty, when the digester is first filled to somewhere between 10% and 70% of capacity, large grey bubbles will suddenly appear though the

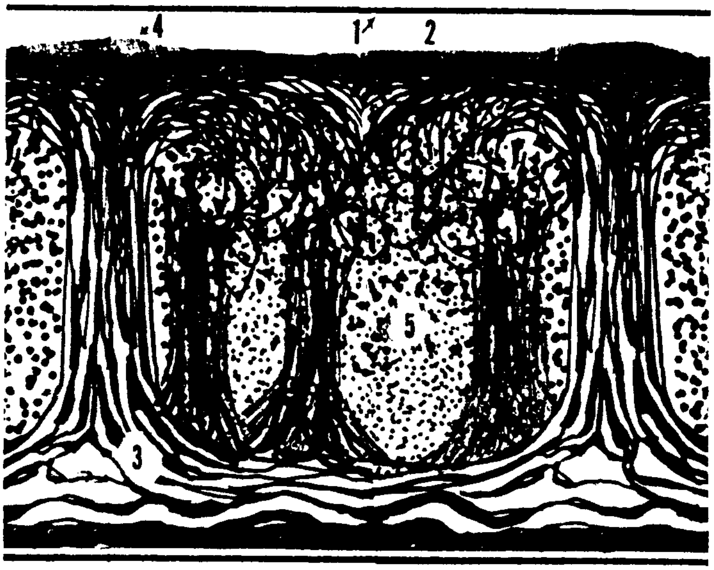


Figure 23: Volcanic type movement in a digester. 1) Digester roof. 2) Gas layer. 3) Gas being generated in layer of raw material. 4) Gas lifts layer to surface. 5) Layer broken up and falling as particles to reform into another layer.

regular procedure of seeding, adding water, and loading of fresh slurry is followed. These bubbles even fill the gas outlet pipe and ooze from the condensation trap, or from any opening to the outside.

This froth is no problem at all. Simply leave the digester alone without loading any raw slurry for a few days and it will disappear. Then continue loading.

There is a third type of material which is often mistaken for true scum. Cattle dung (and possibly that of other ruminants) has the extraordinary property of not absorbing moisture once dried out, even when made to soak in water or urine. Thus the specific gravity of the dung slurry remains less than water and it floats. This dung may be in the form of cow pats or it may be in small pieces, as with steer manure sold in stores. Whatever its form the material will float and be as much a problem as true scum, filling the digester with material that floats in the upper layers and will not pass through the normal process of digestion, which is to sink to the bottom when decomposed as sludge.

True scum is a mixture of animal hairs, skin particles rubbed off in scratching, straw or wood shavings from animal bedding, feathers and generally anything that will float. When removed and dried it is so light that a piece 6 ft. x 6 ft. x 1 ft. thick can be lifted with one finger. Yet it is so bound in a layer that it can only be broken from the digester's working surface by a hoe.

This is a problem to human sewage plant operators but I think it is a far more severe one in animal manure digestion.

Scum is bound together in matted form by fine particles of sticky material brought up in the volcanic action of the bubbling fermentation. It spreads evenly over the entire surface area of the digester contents and not, as one would surmise, in one particular area. In a displacement digester scum forms relatively slowly due to the large surface area. In vertical digesters formation is more rapid due to the small surface area in relation to capacity of digester, thus aggravating the problem many fold.

Scum in vertical digesters with a floating gas holder on top may well present an added problem: the scum is considerably lighter in weight than the liquid beneath it. Since it is not liquid and since it has gas locked in between the fibres, it is porous to gas. If the scum layer is forced into the gas dome portion of the floating roof it will eventually spread to the water seal that the floating roof rests on. If enough spreads to the water seal, it will cease to be a seal and gas will escape to atmosphere. Not only will gas escape but a smelly, ugly ooze of material will drain down the outside of the digester. This is also highly corrosive to steel when air is mixed with it.

Supernatant. This is that strata of the digester contents which lies above the dormant level, i.e., sludge. Supernatant is the spent liquid of the original slurry. Fermentation causes the original slurry solids to release liquids and thus the supernatant "liquor" (as it is called in sewage plant operations) occupies by far the greatest depth in the digester at the outlet end. No special measures need be taken with supernatant since it is withdrawn with the other effluent to make space for fresh, raw slurry. Sludge and inorganic solids, being at the lowest point in the digester, are drawn off first. The effluent at that point is thick and sometimes a little difficult to get to flow initially. Later it flows readily and that is the supernatant.

Sludge. This is the spent solids in mulch form carried by supernatant liquor, reduced in volume by about 50% from the original raw state. Many have asked if sludge could be dehydrated and turned into a dry packaged fertilizer. The answer is a very qualified yes. Dehydration can be done on drying beds by allowing the liquid portion to filter through a medium of sand and gravel, or through other types of filters. However, in so doing most of the valuable nutrients are leached away on the drying beds and only the mulch remains. Digestion changes the structure of sticky colloidal material in which moisture is bound, into a granular state for the solids through which liquid percolates readily. The difference is comparable to that between clay and sand. The material left is then heated, causing nearly all the remaining nutrients to be driven off. The end product, although concentrated in dry form is of poor value in comparison to the considerable fertilizing value of the effluent withdrawn.

The lowest layer in the digester is inorganic sand grit and minerals. Occasionally it tends to block the outlet from the digester but usually flows out easily with the sludge and supernatant.

Only one single advantage exists for the vertical digester with a floating roof, compared to such disadvantages as heat losses through lack of thermal insulation, fast developing scum, gas leaks, corrosion, unsightliness, and its basic design which allows raw slurry to be withdrawn with the sludge after only a day or two detention due to the vertical motion of anaerobic decomposition. That advantage is that the floating roof can be lifted off with a winch or other mechanism, and the scum can be shovelled off the top by hand. This is a somewhat doubtful advantage to a busy modern farmer seeking efficiency in the short time he can spare to maintain the methane plant on his farm. Logically it would appear preferable to have separate gas holders and digesters so that all the potentially offensive stages of decomposition are locked away in a sealed container — the digester itself.

Various solutions to the scum problem have been attempted:

1) A patent exists for a chain that can be turned from outside the digester and is meant to flail the scum. My reaction is that though this might work temporarily,

the scum would soon reform in another pattern and only a very small area could be flailed in this manner.

2) There is also a theory that if liquid is pumped through the roof from the most fluid portion of the digester (the supernatant level) that liquid will break the whole scum layer and move the entire mass causing portions to shear against each other and break up like a layer of ice in a turbulent sea. My observation is that the jet of liquid merely bores a neat hole through the scum. And again, even if the scum layer did break up it would form again in another pattern.

3) A system to force compressed gas through pipes laid in the digester floor has also been suggested. My view, again, is that this may work in the early stages of scum formation, provided a daily or weekly routine is adhered to meticulously to recirculate the gas. However, if forgotten for a time the scum will become so dense that gas will not break it up and, in any case, will reform again.

4) Agitation. Many suggest beating the scum in any feasible way. Propellers on long shafts have been tried in sewage plants. Paddles that can be turned from outside either by hand (as in the top loader described) or mechanically by some device not specified or even invented yet. The problem is the same: break up the scum and it will reform in another pattern. Not only that, but anaerobic digestion is not improved by continuous agitation. Sporadic movement, or the mixing of one part of the digester succession with another is an excellent way to improve decomposition and hence to improve gas yield. In fact, agitation could be called essential to full activity, if performed periodically, but could not be offered as a solution to the scum problem. Certain elements in the scum, feathers and hair to name only two, which do not decompose in this process will continue to rise and float.

5) Also suggested have been systems complete with scum doors and mechanical devices with spikes or rollers that will drag, push, or suction the scum out. These ideas have not been put into practical application yet but are nearer the mark in solving the problem.

6) The solution to the problem that I offer is not ultimate perfection but is a simple, near-complete one. The first requirement is for scum doors which are positioned below the normal level of the digester contents to prevent any possible leaks through faulty gaskets which would be the case if the doors were positioned at the high level where the scum accumulates.

Scumming-Out Procedure

The procedure for scumming out is as follows:

a) Shut off the gas line to gas storage and open the digester gas pipe to allow air in. (Note: Read the section on safety.)

b) Draw off sludge and supernatant until the level indicator shows the contents level to be about three inches (7 cm.) above the bottom line of the scum door.

c) Open the scum doors at both ends, but starting with the outlet end.

d) Feel around inside the digester for the drag line hooked to its securing position. Draw the drag slowly to the outlet end. At this point there are two alternative procedures: 1) Drop the scum onto a concrete apron outside, let it dry and then remove it, or front load it with a tractor and remove as is. 2) Excavate a pathway for a truck to reverse close up to the scum doors, with the loading deck level or below the scum doors. Design a chute of any suitable material to form a bridge between the scum door and the truck. Pull the drag wire and spill the scum directly into the truck.

This method could be improved upon to the point where scumming out would not be the messy, sloshy, rubber-booted ordeal it was for me on the first displacement digesters I built in South Africa. I am glad I had the foresight to install even 15-in. scum ports, though these proved inadequate for quick and easy removal. However, both digesters were indeed scummed out several times over the six years of continuous operation.

e) Return the drag to its position and attach the end of the drag line to its securing point.

f) Close and seal the scum doors.

g) Load raw slurry and flush air from the digester as described in "starting up". The methane bacteria will again be in full production within a week or so. The expectation among readers might be that production should return almost immediately, i.e., within a few hours. The fact that this cannot be is explained by two factors: 1) The air allowed into the digester is somewhat detrimental since anaerobic bacteria can only live and thrive in an environment devoid of oxygen. However, the almost motionless state of the digester contents during and after scumming out preclude penetration of oxygen to any appreciable depth. 2) The very absence of the scum layer is likely to be detrimental to the physical and biological activity of the fermentation itself for a few days. A layer of some slight depth may well be desirable and necessary. The other useful aspect of scum is as a thermal insulator.

In a vertical digester with a floating gas holder the cold from the outside would be conducted by the roof right down into the digester contents so that scum and its insulating properties would be useless. This would apply even more when the gas holder is in the down position.

In a displacement digester the entire unit and its contents must be insulated from extreme cold and heat. That includes the scum layer, whatever its thickness or insulating properties.

Frequency

That leads me to the frequency of scum removal. On my farm in South Africa my pigs were fed grain, protein concentrate, waste food, and alfalfa (called lucerne in

British countries). Hog hairs and alfalfa were the chief culprits in forming scum which built up to a layer one and half feet deep (45 cm.) in a year. However, each digester had by then processed 350 tons (damp weight) of manure and all factors considered that did not amount to a very deep layer when considering the total volume digested.

By scheduling the scumming out process during the warm summer weather I insured the least possible disruption of the fermentation process and it was also an advantage to have two digesters so that I could stagger the routine.

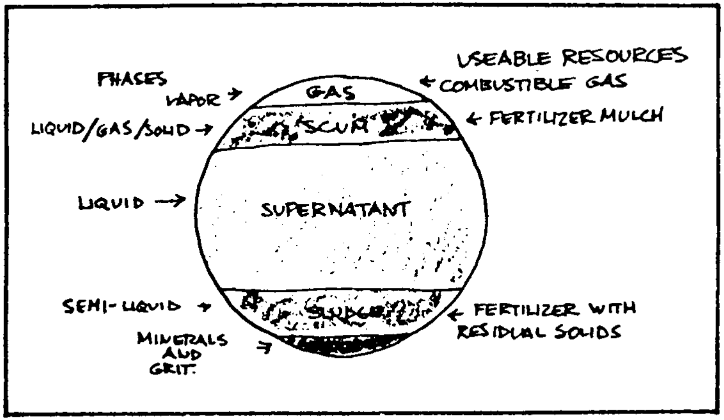


Figure 23A: Stratified layers of end products of digestion.

I offer the above solutions to the scum problem a the result of much hard-gained experience. I am abou to seek patent protection in the U.S. for my scu removal system, but this need not affect those for who this book is written such as homesteaders, farmers o livestock breeders who desire to build digesters of thei own. My patent protection is meant to apply to thos whose business it is to build methane power plant for others to use.

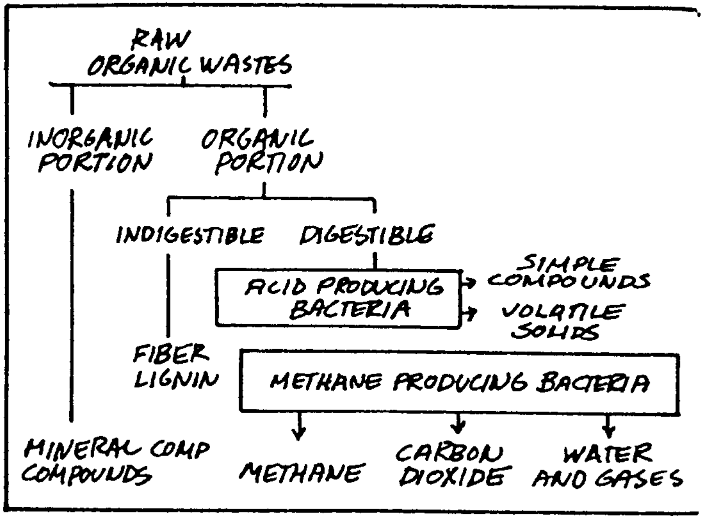


Figure 24: Biological breakdown of material in a digester.

CHAPTER 8

Biology of Digestion

Bio-Succession in the Digester *

Perhaps the most important thing to remember here is that digestion is a biological process. At the same time as the raw slurry proceeds through a physical displacement down the length of a digester, it also follows a biological succession, along somewhat parallel lines, but by no means in the same sequence.

The anaerobic bacteria responsible for digestion cannot survive with even the slightest trace of oxygen. Thus, because of the oxygen present in the manure mixture fed to the digester a period of time passes after loading before actual digestion takes place. During this initial aerobic period, traces of oxygen are used up by oxygen-loving bacteria.

After oxygen has disappeared, the digestion process can begin. That process involves a series of reactions by several kinds of anaerobic bacteria feeding on the raw organic matter. As these different kinds of bacteria become active, the by-products of the first bacteria provide the food for the other (fig. 24). In the first stages of digestion, organic material which is digestible (fats, proteins and most starches) are broken down by acid producing bacteria into simple compounds. The acid bacteria are capable of rapid reproduction and are not very sensitive to changes in their environment. Their role is to excrete enzymes, liquefy the raw materials and convert the complex materials into simpler substances, especially volatile acids which are low molecular weight organic acids. The most important volatile acid is acetic acid (table vinegar is dilute acetic acid), a very common by-product of all fat, starch and protein digestion. About 70% of the methane produced during fermentation comes from acetic acid.

Once the raw material has been liquefied by the acid producing bacteria, methane producing bacteria convert the volatile acids into methane gas. Unlike the acid bacteria, methane bacteria reproduce slowly and are very sensitive to changes in the conditions of their environment.

Biologically, then, successful digestion depends upon achieving and (for continuous-load digesters) maintaining a balance between those bacteria which produce organic acids and those bacteria which produce methane gas from the organic acids. This balance is achieved by a regular feeding with enough liquid and by maintaining the proper pH temperature and quality of raw materials in the digester.

pH and the Well-Buffered Digester

To measure the acid or alkaline condition of a raw material, the symbol "pH" is used. A neutral solution has a pH of 7, an acid solution has a pH below 7, and an alkaline (basic) solution has a pH above 7. The pH has a profound effect on biological activity, and the maintenance of a stable pH is essential to all life. Most living processes take place in the range of pH 5 to 9. The pH requirements of a digester are in a narrower range of 7 to 8.5. If digestion is not started by seeding with methane rich bacteria, such as a load of manure swept into a pond by storm water, the buffered condition will not be there and a different succession will ensue, as follows:

During the initial phase of digestion which may last about two weeks, the pH may drop to 6 or lower, while a great deal of carbon dioxide is given off. This is followed by about three months of slow decrease in acidity (or even six months in cold weather) during which time volatile acids and nitrogen compounds are formed. As digestion proceeds, carbon dioxide and more methane is produced and the pH rises slowly to about 7. As the mixture becomes less acid methane fermentation takes over. The pH then rises above the neutral point (pH 7), to between pH 7.5 and 8.5. After this point the mixture becomes well buffered; that is, even when large amounts of acid or alkali are added the mixture will adjust to stabilize itself at pH 7.5 to 8.5.

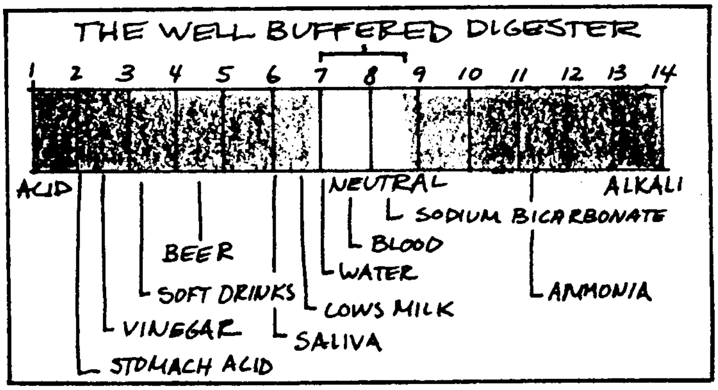


Figure 24A: The well-buffered digester.

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* By arrangement with Richard M. Merrill, M.A., my coauthor of Newsletter No. 3 on Methane Digesters published by the New Alchemy Institute, I am extracting here sections of the work on the Biology of Digestion.

Once the mixture has become well buffered, it is possible to add small amounts of raw material periodically and maintain a constant supply of gas and sludge (in continuous-load digesters). If you don't feed a digester regularly (batch-load digesters), enzymes begin to accumulate, organic solids become exhausted and methane production ceases.

After digestion has stabilized, the pH should remain around 8.0 to 8.5. The ideal pH values of effluent in sewage treatment plants is 7 to 7.5, and these values are usually given as the best pH ranges for digesters in general. From my experience, a slightly more alkaline mixture is best for digesters using raw animal or plant wastes.

In practice, the stages of acid formation and acid regression should be evident only in starting up digestion units. Once good alkaline digestion is established, the acid stages are not apparent unless the normal digestion becomes upset through over-loading, poisonous chemicals, or for other reasons.

While all stages of digestion may be taking place at the same time in the digester, with the acids produced in the first stage being neutralized by the ammonia produced in subsequent stages, best and quickest results are obtained when the over-all pH value of the last stage (7 to 8) predominates.

You can measure the pH of your digester with narrow gauge litmus paper available from a number of chemical laboratories, in a range of from say 6 to 8 or 6.4 to 8.4. It is important to read the directions carefully in order to obtain accurate readings. Dispensers and refills are available at reasonable cost. Meters are also available. The initial cost is far higher but worthwhile with large, multiple-digester methane plants where frequent checks are to be made. Checks are particularly important where digesters are loaded near or over their maximum rate for short periods.

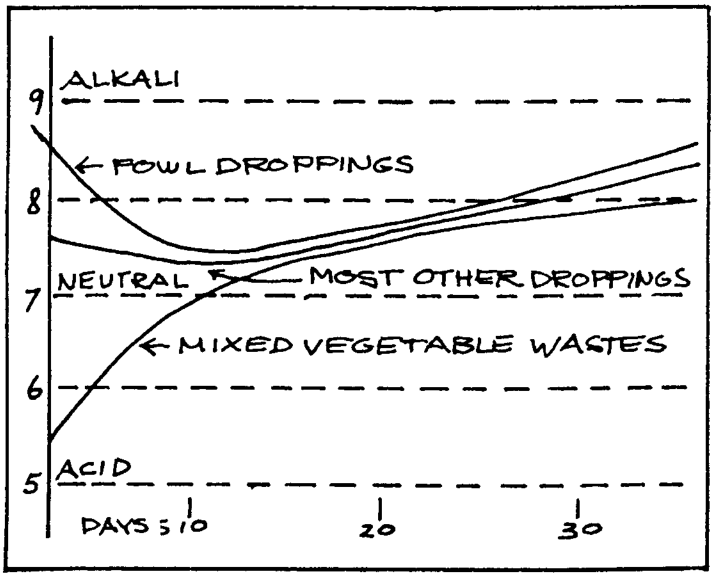


Figure 25: Typical pH succession in a displacement digester.

If the pH in a displacement continuous-load digeste becomes too acidic, the digester design allows considerable flexibility in correcting the problem:

1) The mixture can be brought back to normal by recirculating supernatant from the outlet end to the inlet end in quantities equivalent to the normal quantity of daily fresh slurry. This would be the remedial action for a drop of .5 in pH in one day. On large-scale digesters incorporating sampling points at intervals along the digester side, it would be preferable to recirculate supernatant back to about the center of the digeste to restore the buffered condition.

2) The mixture can also be brought back to norma by reducing the amount of raw material fed to the digester to allow time for the methane producing bacteria to restore a balance. Unfortunately the ga production will drop off considerably and the surging bubbling action and natural physical agitation wil temporarily slow down with it. It is better not to hav reached the over-acidic condition to start with but i it does exist remedial action is a must, or the digeste contents may turn sour and have to be removed entirel from the digester. It is a condition I have not yet me in the operation of over 25 methane plants, but is know to have had to be a last resort action in some sewag plants up to a few years ago. Since then it wa discovered that the addition of a little (in relation t digester size) ammonia restores the pH balance.

3) As a last resort, the addition of one part ammoni (in 40 parts warm water) to 10,000 parts digester content (one gallon of ammonia in 40 gallons of water to a 10,00 gallon digester) can be added as in 1) above. Thi can be repeated, along with a reduced amount of ra slurry, for three or four days, by which time the balanc should be restored. If it is not, look for other reason

If the effluent becomes too alkaline, more carbo dioxide will be produced, and that will have the effe of making the mixture more acidic, thus correctin itself. Patience is the best cure in both cases. Neve add acid to a digester. This will only increase th production of hydrogen sulphide.

Temperature

For the digesting bacteria to work at the greate efficiency, a temperature of 95°F (35°C) is bes Gas production can best proceed in two ranges of temperature: 85° - 105° and 120° - 140°F. Different sets o acid-producing and methane-producing bacteria thriv in each of these different temperature ranges. Thos active in the higher range are called heat-loving o "thermophilic" bacteria. Digesters are not commonl operated at this high range because: a) most material digest well at the lower range, b) the thermophili bacteria are very sensitive to any changes in th digester, c) the sludge thermophilic bacteria produc is of poor fertilizer quality, and d) because it is difficu to maintain such a high temperature, especially i temperate climates.

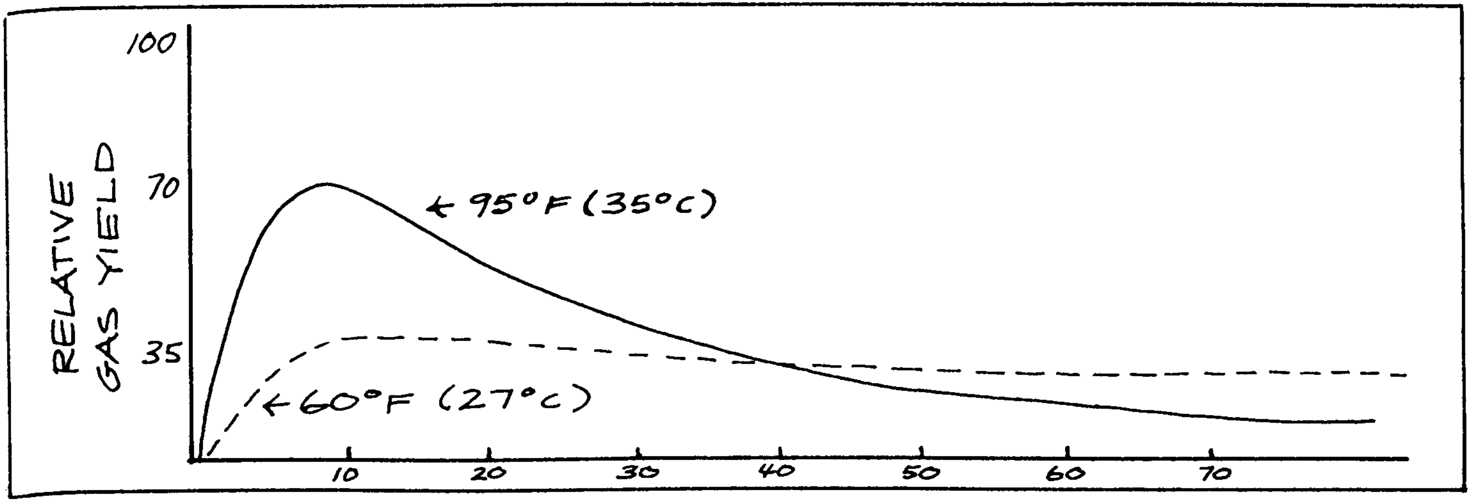


Figure 26: *Gas yield in relation to time and temperature.*

The bacteria that produce methane in the normal range of 90° - 95°F are more stable and produce a high quality sludge. It is not difficult to maintain a digester temperature of 95°F.

As seen in fig. 26, the mesophilic (medium range) bacteria still operate, but only very slowly, at temperatures down to 42°F (5.5°C). Effluent sludge and/or supernatant stored at low ambient temperatures in containers after withdrawal from a digester, continue the process for a considerable time, even when exposed to air, if not otherwise disposed of. (See Chapter 10).

A very few types of bacteria find their optimum conditions at low temperatures of 32° to 40°F (0° to 5°C). These are known as psychrophylic bacteria. Little is known at present about the usefulness of these bacteria in the practical application of methane power plants. This is just one of the questions on digestion worthy of research. Can active effluent in the mesophylic range continue fermenting in the psychrophylic range?

CHAPTER 9

Raw Materials

The chief constituent of organic wastes is cellulose. This matter continuously made by photosynthesis from water and atmospheric carbon dioxide, is the most renewable raw material in the world. It is the chief basis of all fossil fuels which are, in turn, only a small fraction of the living material formed over the ages. As a result of special conditions of entrapment, coal, oil, shale, petroleum, gas and bitumous sands have been preserved and are now being consumed in one form or another at an accelerated rate. Most of the organic materials that formed in past ages have long since been converted by oxidation back to carbon dioxide and water.

Oxidation, by definition, is the breaking down of organic material in the presence of oxygen in the air, or aerobic decomposition. Different bacteria (anaerobes) and particularly methane bacteria decompose cellulose material when confined in a container with no air (or under water). Rather fortunately for our sense of smell the whole process of putrescence and decay can be solidly locked into a container — the digester. As a result it is not only possible but entirely feasible to create a fuel, a fertilizer and save labor doing it all, by using selected raw materials. Coarser, more fibrous materials (such as crop wastes) not suitable for digestion in a linear displacement digester can be treated in a batch-type digester to be described in a sequel to this book.

Speaking in broad terms, cellulose is harvested through plants of endless variety, either as food for animals, fowl or fish which are themselves eaten, or directly as food for humans. This concentration of food is conveniently ground to a pulp in animals' or humans' own private digestive systems and passed out, of course, in the form of excrement. Here it might be noted that though at first thought the energy crisis would appear to having nothing in common with intestinal rumblings, there is in fact a connection. Those rumblings are a reminder that a 120 octane vapor fuel is common within ourselves through the digestion of wastes.

All we need to know is how to emulate the same principle on a large scale: How to concentrate the action harness and accelerate it, and thus at least replac part of the dwindling fossil fuels of the world.

It is my pet argument that since food is harveste from far and wide, consumed by humans and animals and the wastes treated by methane decomposition reducing those wastes to bottom dead center of th cycle of living things, it would then be logical and sensible to return the decomposed material back to th earth in a form wherein the recreation of cellulose ca take place again. Ideally that material would be thi spread back to the earth in proportion to the harves that was removed from it originally.

By arrangement with Richard M. Merrill, my coautho of Newsletter No. 3 on Methane Digesters, I am reproducing here extracts of the section on raw materials.

The amount and characteristics of organic materials (both plant and animal waste) available for digestion vary widely. In rural areas the digestible material will depend upon the climate, the type of agriculture practiced, the animals used and their degree of confinement the methods of collecting wastes, etc. There are also degrees of quality and availability unique to urban wastes. Because of all these things, it is practically impossible to devise or use any formula or rule-of-thumb method for determining the amount and quality of organic wastes to be expected from any given source There is, however, some basic information which is useful when you start wondering how much waste you can feed your digester.

Digestible Properties of Organic Matter

When raw materials are digested in a container, only part of the waste is actually converted into methane and sludge. Some of it is indigestible to varying degrees and accumulates in the digester or passes out wit the effluent and scum. The "digestibility" and other basic properties of organic matter are usually expressed in the following terms (ref. 1):

Moisture. The weight of water lost upon drying at 220°F until no more weight is lost.

Total Solids (TS). The weight of dry material remaining after drying as above. TS weight is usually equivalent to "dry weight." However, if you dry your material in the sun, assume that it will still contain around 30% moisture. TS is composed of digestible organic or "Volatile Solids" (VS), and indigestible residues or "Fixed Solids" (FS).

Volatile Solids (VS). The weight of organic solids burned off when dry material is "ignited" (heated to around 1,000°F or 600°C). This is a handy property of organic matter to know since VS can be considered as the amount of solids actually converted by the bacteria.

Fixed Solids (FS). Weight remaining after ignition. This is biologically inert material.

Since most farmers do not have access to an oven in which to test samples, two practical solutions are offered:

1) An oven can be made from a 50-gal. oil drum by welding a shelf near the center on which to place a container full of the sample. However, care must be taken to prevent flames entering the drum and igniting the sample.

2) As a shortcut to give only an approximation of the Volatile Solids Weight, take two equal representative samples of raw damp dung and determine the Total Solids weight of the first sample. Place the other sample in a large container, pound it to a slurry, and wash the slurry away, leaving only inert materials and grit. After repeating the washings several times, weigh the grit. The difference in weight between the two samples will then determine the approximate Volatile Solids weight.

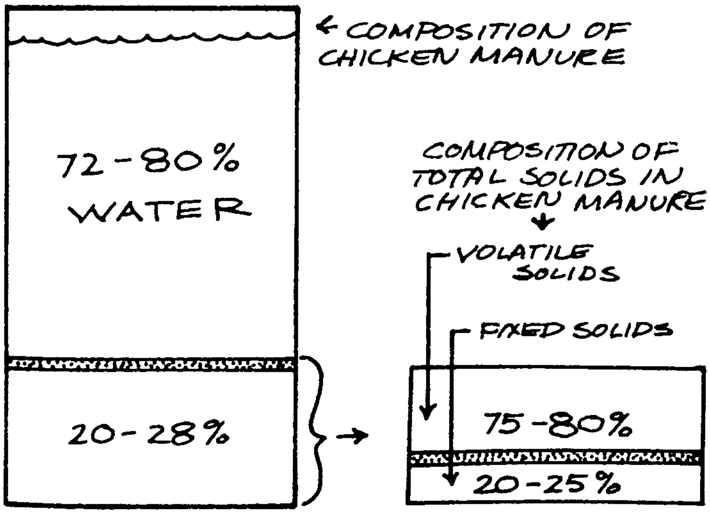


Figure 27: Properties of chicken manure.

As an example of these weight determinations, consider the make-up of fresh chicken manure (ref. 2). If we had 100 lbs. of fresh chicken manure, 72 to 80 lbs. of this would be water, and only 15 to 24 lbs. (75 - 80% VS of the 20 - 28% TS) would be available for actual digestion (fig. 27).

Amount of Manure Collectable. When you see a table which shows the amount of manure produced by different kinds of livestock, it is important to know that the amount on the table may not be the amount that is actually available from your animals. There are three major reasons for this:

1) The size (age) of the animal. Consider the total wet manure production of different sized pigs:

Hog Weight	Total Manure Lbs/Day	Feces	Urine	Ratio Manure/ Hog Wt.
40-80	5.6	2.7	2.9	1:11
80-120	11.5	5.4	6.1	1:9
120-160	14.6	6.5	8.1	1:10
160-200	17.6	8.5	9.1	1:10

Table 1. (Ref. 20)

So the size of your livestock has a lot to do with the amount of manure produced. Notice that the ratio of total wet manure production to the weight of the pig is fairly constant. It is likely that similar ratios could be worked out for other kinds of livestock, enabling you to estimate the production of manure from the size of the livestock.

2) The degree of livestock confinement. Often the values given are for commercial animals which are totally confined. All of their manure can be collected. On the homestead or small farm, total confinement of the livestock is not always possible or desirable. (Foraging and uncrowded livestock are less likely to contract diseases and more likely to increase the quality of their diet with naturally occurring foods.) Because of this, a large proportion of the manure is deposited in fields and thus hard to collect. For example, the fresh manure production of commercial chickens in total confinement is about 0.4 lbs. per chicken per day. (Ref. 2 & 3). However, for small-scale operations like homesteads and small farms, where preference tends to favor the well-being of the chickens rather than the economics of egg production, chickens are often allowed to forage all day and are confined only at night. In such cases, only manure dropped during the night from roosts can be conveniently collected. In our experience, this may amount to only 0.1 to 0.2 lbs. of fresh manure per day per adult chicken. Similar reasoning holds for other livestock.

3) The kind of manure that is collected. Included here are all the fresh excrement (feces and urine), all the fresh excrement plus the bedding material, the wet feces only, and the dry feces only.

Manure Production and the Livestock Unit

Keeping in mind all the factors that can affect the type and amount of manure that can be collected, we can assemble a general manure production table. The table only shows rough average values obtained from many sources (ref. 2 - 22). Values are expressed as the amount in pounds of wet manure, dry manure and volatile solids that could be expected from various adult livestock per day. For the table, average adult animal weights are: cows - 1,000 lbs; horses - 850 lbs.; swine - 160 lbs.; humans - 150 lbs.; sheep - 67 lbs.; goats - 170 lbs.; turkeys - 15 lbs.; ducks - 6 lbs.; and chickens - 3½ lbs.

Table 2 enables us to get some idea of the production of readily digestible material (Volatile Solids) from different animals. Only the feces are considered for cows, horses, swine and sheep, since their urine is difficult to collect. However, for humans and fowl, both urine and feces are given since they are conveniently collected together.

The relative values of digestible wastes produced are not given in pounds of manure per animal per day, but in a more convenient relative unit called the "Livestock Unit." The table shows that on the average one medium horse would produce as much digestible manure as four large pigs, 12½ ewes, 20 adult humans or 100 chickens.

Toxic Materials

The methane bacteria did not appear to be affected by antibiotics placed in the feed of the younger pigs. Copper sulphate dissolved in water was coated over pens used by breeding stock to stop an outbreak of foot rot caused by a fungus. It killed the fungus but manure scraped from these pens had high concentrations of copper sulphate. The effect was to slow down and almost stop gas production for three weeks until the effect wore off. All heavy metals in solution have adverse effects on digestion as do disinfectants and detergents.

Carbon to Nitrogen Ratio (C/N)

From a biological point of view, digesters can be considered as a culture of bacteria feeding upon and converting organic wastes. The elements of carbon (in the form of carbohydrates) and nitrogen (as protein,

Table 2. Manure and the Livestock Unit.

Average Adult Animal		lbs/day/animal		Total Solids/ Day 20% of Feces	Volatile Solids/Day 80% of TS - 85% for Swine	Livestock Units
		Urine	Feces			
BOVINE (1000 lbs.)		20	52	10	8.0	
	Bulls					130-150
	Dairy cow					120
	Under 2 yrs.					50
	Calves					10
HORSES (850 lbs.)		8	36	7	5.5	
	Heavy					130-150
	Medium					100
	Pony					50-70
SWINE (160 lbs.)		4.0	7.5	1.5	1.3	
	Boar, sow					25
	Pig >160 lbs.					20
	Pig <160 lbs.					10
	Weaners					2
SHEEP (67 lbs.)		1.5	3	0.5	0.4	
	Ewes, rams					8
	Lambs					4

	Portion	Amount	%TS	TS/Day	%VS	VS/Day	
HUMANS (150 lbs.)	Urine	2 pints, 2.2 lbs	6%	.13	75%	.10	5
	Feces	0.5 lbs	27%	.14	92%	.13	
	Both	2.7 lbs	11%	.3	84%	.25	
FOWL	Geese, Turkey (15 lbs.)	0.5 lbs					2
	Ducks (6 lbs.)						1.5
	Layer Chicken (3½ lbs.)	0.3 lbs	35%	.1	65%	.06	1.5
	Broiler Chicken	0.1 lbs					

nitrates, ammonia, etc.) are the chief foods of anaerobic bacteria. Carbon is utilized for energy and the nitrogen for the building of the cell structures. These bacteria use up carbon about 30 times faster than they use nitrogen.

Anaerobic digestion proceeds best when raw material fed to the bacteria contains a certain amount of carbon and nitrogen together. The carbon to nitrogen ratio (C/N) represents the proportion of the two elements. A material with 15 times more carbon than nitrogen would have a C/N ratio of 15 to 1.

A C/N ratio of 30 (C/N = 30/1 or 30 times as much carbon as nitrogen) will permit digestion to proceed at an optimum rate, if other conditions are favorable. If there is too much carbon in the raw wastes, nitrogen will be used up first, with carbon left over. This will make the digester slow down. On the other hand if there is too much nitrogen (low C/N ratio; 30/15 for example), the carbon soon becomes exhausted and fermentation stops.

There are many standard tables listing the C/N ratios of various organic materials but they can be very misleading for at least two reasons:

1) The ratio of carbon to nitrogen measured chemically in the laboratory is often not the same as the ratio of carbon and nitrogen available to the bacteria as food (some of the food could be indigestible to the bacteria, such as straw, lignin, etc.).

2) The nitrogen and carbon contents of even a specific kind of plant or animal waste can vary tremendously according to the age and growing conditions of the plant, and the diet, age, degree of confinement, etc., of the animal.

Nitrogen. Because nitrogen exists in so many chemical forms in nature (ammonia, NH3, nitrates, NO3, proteins, etc.), there are no reliable quick tests for measuring the total amounts of nitrogen in a given material. One kind of test might measure the organic and ammonia nitrogen (the Kjeldahl test), while another might measure the nitrate/nitrite nitrogen. Also, nitrogen can be measured in terms of wet weight, dry weight or volatile solids content of the material — all of which will give different values for the proportion of nitrogen. Finally, the nitrogen content of a specific kind of manure or plant waste can vary, depending on the growing conditions, age, diet, etc.

For example, one study reported on a field of barley which contained 39% protein on the 21st day of growth, 12% protein on the 49th day (bloom stage), and only 4% protein on the 86th day (ref. 23). One can see how much the protein nitrogen depends on the age of the plant.

The nitrogen contents of manure also vary a great deal. Generally, manures consist of feces, urine and any bedding material (straw, corn stalks, hay) that may be used in the livestock shelters. Because urine is the animal's way of getting rid of excess nitrogen, the nitrogen content of manures is strongly affected by how much urine is collected with the feces.

For example, birds naturally excrete feces and urine in the same load so that the nitrogen content of chicken, turkey, duck and pigeon manure is highest in nitrogen content. Next in nitrogen content, because of their varied diets or grazing habits are humans, pigs, sheep and then horses. Cattle and other ruminants (cud chewers) which rely on bacteria in their gut to digest plant foods, have a low content of manure nitrogen because much of their available nitrogen is used to feed their intestinal bacteria (fig. 28).

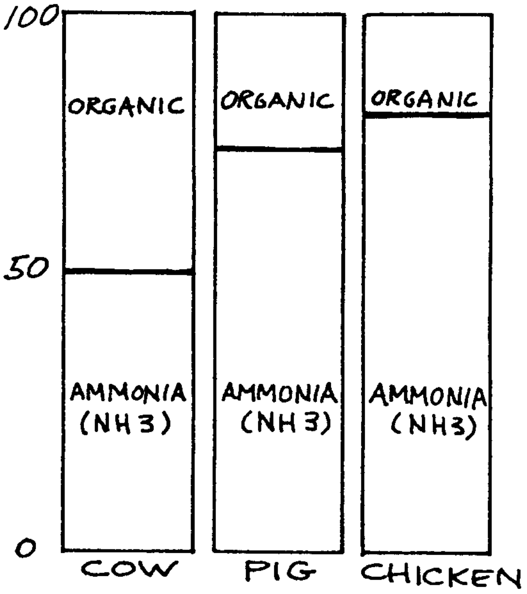


Figure 28: Types of nitrogen found in different kinds of manure.

Even with the same kind of animal there are big differences in the amount of manure-nitrogen. For example, manure of stabled horses may have more nitrogen than pasture manure because feces and urine are excreted and collected in the same small place.

Since there are so many variables, and because anaerobic bacteria can use most forms of nitrogen, the available nitrogen content of organic materials can best be generalized and presented as total nitrogen (percent of dry weight).

Carbon. Unlike nitrogen, carbon exists in many forms which are not directly useable by bacteria. The most common indigestible form of carbon is lignin, a complex plant compound which makes land plants rigid and decay-resistant. Lignin can enter a digester either directly with plant wastes themselves or indirectly as bedding or undigested plant food in manure. Thus, a more accurate picture of the C part of the C/N ratio is obtained when we consider the "non-lignin" carbon content of plant wastes.

Calculating C/N Ratios

Table 3 can be used to calculate roughly the C/N ratios of mixed raw materials. Consider the following examples:

Example 1: Calculate the C/N ratio of 50 lbs. horse manure (C/N = 25) and 50 lbs. dry wheat straw (C/N = 150).

Nitrogen in 50 lbs. horse manure = 2.3% x 50 = 1.2 lbs. Carbon in 50 lbs. horse manure = 25 times more nitrogen = 25 x 1.2 = 30 lbs. Nitrogen in 50 lbs. wheat straw = 0.5 x 50 = .25 lbs. Carbon in 50 lbs. wheat straw = 150 times more than nitrogen = 150 x .25 = 37.5 lbs.

	Manure	Straw	Total
CARBON	30	37.5	67.5 LBS
NITROGEN	1.2	.25	1.45 LBS

C/N ratio = 67.5/1.45 = 46.5

Since the cut-off limit for efficient digestion is a C/N ratio of 30, the combination of these materials in a digester would not be suitable.

Example 2: Calculate the C/N ratio of 8 lbs. grass clippings (C/N = 12) and 2 lbs. of chicken manure (C/N = 15).

Nitrogen in 8 lbs. grass clippings = 4% x 8 = .32 lbs. Carbon in 8 lbs. grass clippings = 12 times more than nitrogen = 3.8 lbs. Nitrogen in 2 lbs. chicken manure = 6.3% x 2 = .13 lbs. Carbon in 2 lbs. chicken manure = 15 times more than nitrogen = 1.9 lbs.

	Manure	Straw	Total
CARBON	3.8	1.9	5.7 LBS
NITROGEN	.32	.13	.45 LBS

C/N ratio = 5.7/.45 = 12.6

The C/N ratio of this mixture is low. We might want to add a higher proportion of chicken manure since it contains more carbon per weight than grass.

The following table is a summary of the important chemical properties of organic materials. Values are averages derived from many sources (ref. 1,3,5-16,23-26) and should be used only for approximation.

	Total Nitrogen % Dry Weight	C/N Ratio
ANIMAL WASTES		
Urine	16	0.8
Blood	12	3.5
Bone Meal		3.5
Animal Tankage		4.1*
Dry Fish Scraps		5.1*
MANURE		
Human, feces	6	6-10
Human, urine	18	
Chicken	6.3	15
Sheep	3.8	
Pig	3.8	
Horse	2.3	25*
Cow	1.7	18*
SLUDGE		
Milorganite		5.4*
Activated	5	6
Fresh Sewage		11*
PLANT MEALS		
Soybean		5
Cottonseed		5*
Peanut Hull		36*
PLANT WASTES		
Hay, Young Grass	4	12
Hay, Alfalfa	2.8	17*
Hay, Blue Grass	2.5	19
Seaweed	1.9	19
Non-Legume Vegetables	2.5-4	11-19
Red Clover	1.8	27
Straw, Oat	1.1	48
Straw, Wheat	0.5	150
Sawdust	0.1	200-500

Nitrogen is total nitrogen dry weight and carbon is either total carbon (dry weight) or (*) non-lignin carbon (dry weight).

Table 3. Carbon & Nitrogen Values of Wastes

The above passages extracted from Newsletter No. 3 were assembled from a large number of sources and condensed to form a survey on a wide variety of raw materials to be used in all types of digesters. However, in a displacement-type digester there are a number of specific restrictions on the physical state of raw materials to be used. Some raw materials such as sawdust, hay, straw bran, dried out steer manure, and grass clippings are totally unsuitable to a displacement digester but could be used as part of the loading of a batch digester.

It cannot be emphasized too strongly that the raw materials should not have a specific gravity less than water. That is, the materials should not float on water. This requirement immediately eliminates sawdust, hay, straw and grass clippings. The reason is very simple. If they float in water they will almost certainly float as scum in the digester and not mix with the heavier elements.

Scum is the single greatest problem in a digester and must be avoided at all costs. Even with materials that are suitable for displacement digesters there will be traces of materials that float when released by the agitation of the fermentation and thus slowly form a scum. As described elsewhere, the slower the scum forms the better. Thus, for instance, horse dung derived from hay and grass, and coarse in texture, would very likely not be a suitable material.

Ruminant manure (cow and steer) is unique in one unusual characteristic. If allowed to dry the manure will not absorb water again and will float. Even milling the dry pats will not make the material absorbent. It is thus an unavoidable restriction with ruminant dung that it must be collected in a naturally wet state or kept wet until loaded into a digester. This is a simple matter in a dairy where droppings are swept away frequently. The suggested method is to use a high-pressure water spray to move the materials into a channel leading eventually to the digester.

Other animal manures will readily absorb moisture to form a slurry with or without the urine that normally goes with it. Urine will increase the nitrogen content of the final effluent and raise the pH of the slurry, thus accelerating fermentation. Sewage plant textbooks stipulate that water is an essential element in digestion. Even if a slurry of the correct consistency could be obtained with dung and urine alone, the addition of at least some water would appear to be a necessity.

Slurry consistency is hard to prescribe precisely. If too wet, space is wasted in a digester. If too thick the natural agitation and movement of the fermentation will be restricted. One prescription is that slurry should be the consistency of cream, neither too thick nor too thin. In that state the slurry will be thin enough to allow such inorganic solids as grit, sand, etc., to separate and fall by gravity to the lowest point where it is to be collected. As far as it is technically possible these materials must be eliminated from the slurry before it is poured into the digester. A number of different methods are discussed under Digester Operation.

The ideal raw material is finely ground, sticky and can be loaded fresh from the animals, or from food processing plants. Probably it should not be stale or putrid, although my experience is that occasional loads of putrid, stinking material did not affect digestion adversely. A routine I kept to for years on my first displacement digester was to mix water with the raw manure in the mixing basin outside the digester in the afternoon, and pump it into the digester the next morning. Only very occasionally, in hot weather, did it begin to putrefy.

One excellent example of a pure vegetable raw material is a plant called sisal which grows in East Africa where a factory processes this plant in the manufacture of rope twine and sacking. The fibers of the plant are extracted while the other coarse material is removed. All that is left is a jelly, a material which was an encumbrance to the factory owners until advice was sought as to its disposal. The suggestion was to digest it anaerobically. After some successful trials, a full scale digester was built which ultimately yieded 17,000 cu. ft. of methane per ton of raw material and supplied the entire power needs of the factory with some left as surplus.

Hog manure often contains hair rubbed off in scratching and dead flakes of skin which eventually blend into the scum layer, but not so fast as to be a serious problem. Hair of any sort does not decompose anaerobically.

Not enough is known about droppings from other animals but it can confidently be assumed that the collected fresh droppings of all animals in a zoo, for instance, would decompose. This leads to a further point: Different types of manure, or manure and plant residues, can be mixed provided no lignin or coarse fibrous material is used. If liquid from plant wastes can be forced out with a press, it will decompose, even if the pH is as low as 5.8.

There is no reason why plants with a low crop value should not be grown as feed for methane bacteria, which in turn would work as a farmer's microscopic slaves to yield an income immediately measurable with the use of a gas meter. Effluent from the digester would also be of value, particularly in growing certain selected plants. This area is wide open for a fascinating line of new research.

A word of warning: Raw materials for composting are entirely different to those used for digestion. It is easy to think of both systems breaking down wastes and therefore being similar in their raw input. However, this is not the case in a displacement or vertical type digester. Aerobic and anaerobic bacteria cannot thrive in the same environment. I once attempted to enrich a compost heap with effluent from my own digester. All composting (aerobic) activity stopped dead for months and only recovered when I turned the heap over and thus aired it out.

Another experiment was with the raw material stage of the digestion process. I tried composting the raw hog dung, urine and alfalfa until it heated up. It was then mixed with water and fed into the digester. The primary objective was to heat the material before loading. The effect was that whatever heat was generated was of next to no value since the temperature of the water determined 90% of the heat of the eventual slurry. Also, to generate heat, the aerobic bacteria fed on the very material that were meant to feed the anaerobic bacteria. Thus the gas produced was far less than usual. This is not a practical method of generating heat.

Human Waste as a Raw Material

This book is mainly concerned with methane digestion of animal manure and it would be wrong for me to try to crowd into the world of sanitary engineering. It might even be illegal. Before tampering with the existing, official system of sewage disposal, the approval of the area's sanitary engineer must be sought. Pathogens and viruses are carried in human sewage and these can cause disease. The danger is greater in poorly designed and/or operated plants.

Human waste products are similar to those of animals and the raw material certainly does digest anaerobically as is the case in sewage plants around the world. However, getting that material into a digester is a big problem.

Human sewage is normally carried away from houses connected to a sewer line by a flush of water of at least three gallons. The average person consumes another 37 gallons of water per day which also goes down the same drain. The sewage plant thus receives 99.6% clean water plus .4% highly polluting material. Usually the oxygen in the water is just sufficient to prevent the solids from beginning to putrefy before entering a large circular tank (clarifier) which allows most of the undissolved solids to sink to the bottom, from where they are regularly withdrawn and sent to a digester for treatment. Most of the more valuable fertilizing nutrients are leached out when borne down to the plant with the large quantities of water and hence the fertilizing value of human sludge is not even remotely as great as sludge from an animal digester. By contrast animal manure is collected in a concentrated manner along with the valuable urine. A little water (some is essential to digestion) is added to make a slurry which then enters the digester within a few hours, preferably before it begins to putrefy.

Since the main problem with digesting human wastes concerns the difficulty of loading the material into a digester hygienically where it can undergo the near-metamorphosis common to all other manures, this area deserves careful study.

Sewage plant manuals offer the typical figure of one cubic foot per day per human, per hook-up to a sewage line. Since leaching out causes losses of at least half the volatile solids we could logically assume a value of two cubic feet. Dung from a pig of 120 lbs. live weight yields 10 cu. ft. (as on my farm), but a pig's pollutional load has been found to be five times that of a human (ref. 3, 10), so that a figure of 2 cu. ft. is again substantiated. Yet again, exact measurements are impossible since humans are a) away from home at least some of the time, and b) deliver widely varying quantities of wastes depending on their diets and working habits. A laborer doing heavy physical work on a vegetarian diet consumes vastly more than a city worker eating a small amount of food with high calories, and as a result delivers ten times the volume of solids.

The question of whether to make the change from the customary system to a methane plant is governed by:

1) The legality of change according to local laws.
2) The economics of building and particularly, of operating, a methane power plant.
3) Whether the number of persons "on the line" could possibly make the system worthwhile. It would be hard to imagine a unit in a household of three or four persons, but in an institution numbering in the hundreds, the system could well be deemed feasible. Bear in mind that a person burns an average of 60 cu. ft. (about 2 cu. meters) per day for cooking and heating, as compared to a raw material output sufficient to produce one thirtieth that amount of methane gas.
4) Whether special provisions must be made to separate kitchen wastes from human wastes, or to segregate materials that will not float, or whether a grinder must be used (at some expense in energy) to make the material suitable for the digester.

The following suggestions are offered as possible means to providing solutions.

Solution No. 1: A toilet of the type often made for campers or other vehicles of the road. This unit is a slightly smaller version of the ordinary house toilet, but has a different flushing system. In the bowl is a trap door shaped like an inverted lid equipped with a seal. When the lid (or watergate, if you will) is in position a small amount of water (one pint or 400 c.c.) is made to fill in the bowl. The quantity of water can be adjusted at will.

A lever outside the toilet enables one to open the lid and drop the whole contents straight down a drain. Instead of going to a temporary reservoir for later disposal as in a camper, this drain could lead straight into the inlet of a digester. The inlet pipe of at least 3 in. (8 cm.) diameter would have its lowest point in the digester well below the level of the contents so that no gas could escape through the liquid seal. However, some material in the pipe itself would be sure to begin putrefaction and the fumes would be highly obnoxious. The best way to overcome that problem would be to install a small pipe from beside the top of the digester inlet pipe to below the watergate lid and to vent the fumes to atmosphere.

A toilet equipped to be fitted with a plastic container that would decompose in the presence of methane bacteria could also be a solution but such a plastic is not known to be on the market yet.

Solution No. 2: Neighborhood collections with the method mentioned above but using a vacuum tanker or other sanitary means for disposal into a community digester of suitable size.

The addition of household scraps, even though passed through a grinder disposer, or of grass clippings is not possible in a displacement digester due to the scum problem. Disproportionate quantities of water, particularly cold water, would also dilute and cool the digester excessively, thereby preventing fermentation.

Solution No. 3: Using mineral oil as a flushing agent instead of water. The mixture flows to a holding tank where the oil separates from the solids, floats and is pumped back to the header tank for further flushings. Water based liquids and the solids are pumped to a digester of suitable proportions. This solution is only a suggestion and subject to much more research and trials.

Collecting and Preparing Manure for Loading

Collection of raw droppings and/or suitable vegetable wastes is sure to be a problem of considerable magnitude in adapting a methane plant to an existing feedlot or farm. It is a problem that will have to be faced and solved by farmers individually according to their needs and in relation to their existing patterns of collection. The labor savings of a methane power plant begins at the moment the raw slurry is loaded. From then on the effluent can be handled hydraulically (see Sludge Uses).

A factor to consider is that the bacteria require regular feeding to produce a steady flow of gas. Daily or even more frequent feeding is best, using a device that would load the digester automatically when a collection trough is filled to a given level. Worm screw feeders might be another solution.

If a loading is missed for a day (such as Sunday) gas production will dip considerably but return to normal within a few hours after adding the day's load. In fact a temporary rest might even be beneficial. If a day is lost, however, the double load should not be made the following day but should be spread over three or four days.

Future designs of farm buildings will, no doubt, make provisions for methane plants as integral units in the over-all planning so that collecting, preparing the slurry and loading are as simple and efficient as possible. It should be emphasized that any machinery used for this purpose should be simple and easily dismantled since this is the dirty end of a digestion system. This can also be the dangerous end as harmful fumes will concentrate in enclosed, cramped spaces, particularly below floor level.

Another problem for some farmers will be collecting droppings without including earth, sand and grit. It is absolutely essential that every effort be made to keep these inorganic materials from being loaded as they will fill up the digester over a period of time and be extremely difficult to remove with the effluent. Since some is bound to be loaded along with other inert materials, mostly of mineral origin passed out in the manure, a special section of this book is devoted to this particular problem (see Digester Design). The problem is best avoided by not collecting manure where animals are not kept on a hard surface such as concrete.

Cattle manure can be used if collected before it dries and provided it is free of dirt and sand so as to avoid time-consuming separation before loading. It can be confidently expected that gas yields will be at least 5 cu. ft. per pound dry weight of raw dung (.31 cu. meters/kg.). Some or all of the urine may be used to reduce the material to slurry, plus a little water. Since cattle manure is 18% solids when dropped, only a little extra moisture is required to bring it to the right consistency.

Dairy manure can be used as described above, while noting that water used in washing down must, of necessity, be minimal.

Hog manure plus urine is an excellent raw material, with a potential yield of 8 cu. ft. per pound (dry weight) (.45 cu. meter of gas per kg.). Manure in slurry form collected from under slatted floors, or material which has accumulated over more than three days, will not produce the maximum yields since fresh manure is the best for digestion. As more research is done on this point, it may be found that one to three or more days of initial putrefaction (manure in water and urine) may even be beneficial to the operation of a methane plant. Beyond that point the mass may turn too acid for safe loading in a digester if performed as a routine. I loaded putrefying slurry on a number of separate occasions (not on a regular basis) without any detrimental effect.

Another point to bear in mind is that fumes rising from slatted floors carry a considerable risk of affecting the health of hogs and of spreading disease. For instance, an epidemic could spread quite readily under those conditions. It might be found worthwhile to consider both a more efficient and more hygienic method of collection, suited at the same time to efficient loading into a digester. At a number of hog farms I have visited, the floor under the slats has been flat or nearly so. At others the floor had steeply inclined surfaces, forming a V in which the manure collected for easier handling.

Chicken, turkey and other fowl manure will yield about the same amounts of gas as hog manure in similar weight proportions. Points made for hog dung apply equally here. A further point to note in the collection of those manures is that quite often these are allowed to dry under the cages. This will reduce the value of the raw material in the digestion process slightly, but, more important, when the manure is eventually collected for loading there is an added risk to the health of the birds through contaminating dust clouds as well as from fumes which can spread disease. One of the cleanest collection devices I have ever seen consisted of glass panels beneath the cages. Water was "fogged" onto the glass to keep the droppings moist. Then a series of large windscreen wipers swept the mass to the end of the line and out to a collecting pit, in a near-perfect state for loading into a digester.

Other manures and mixtures. I do not have extensive experience with other manures, or have had inconclusive results due to scum accumulation, and thus do not wish to mislead on this point. It can be logically assumed that the droppings of any bird or animal which remains healthy from the food it eats will have a suitable carbon-nitrogen ratio for digestion. It can also be assumed that mixtures of cattle and fowl droppings will be a considerable improvement over the use of one or the other singly.

Preparation of slurry presents two problems.

1) Mixing it to a near-correct consistency.

2) Elimination of inorganic solids such as chip stone, grit and sand, as well as other inert materials, to the greatest extent possible.

The problems are partly interwoven since grit will not settle out by gravity if the consistency is took thick. If too thin, the working space in the digester will be wasted through an excess of water. The temperature of the slurry as it enters the digester can be governed by heating the water before mixing. If a digester is very thoroughly insulated thermally, this heating may be all that is required to maintain the optimum of 95°F (35°C), described later under Design.

Problem No. 1 — Consistency. To define the correct ratio of moisture to solids, a mixture of 80% moisture would be dry enough to stack in a heap without "slumping." This is obviously too thick. At the other end of the scale a 7% solids mix would be too fluid and also carry unwanted quantities of oxygen which require neutralization by bacteria before true methane fermentation can begin.

Fluidity can therefore be fined down to between 10% and 12%, or even possibly as high as 14%, with a consistency that is between thin and average cream in physical appearance (but not color). The formula to find the percent of dry solids is:

$$\frac{\text{Weight Dry Solids}}{\text{Weight Of Wet Solids}} \times 100 = \%\text{-Dry Solids}$$

The formula to find the percent of moisture is:

$$\frac{\text{Wt. Of Wet} - \text{Wt. Of Dry Solids}}{\text{Weight Of Wet Solids}} \times 100 = \%\text{-Moisture}$$

In cold weather the water added to make manure into a slurry can be heated even to boiling point without apparent damage to the manure so as to avoid a drop in temperature of the digester contents. Solar heating and storage could be used, supplemented by gas heating from the digester at times when solar heating is insufficient. Heating the raw slurry may be an excellent method of keeping digestion going in small, well-insulated methane units, but in large plants of 20,000 gal. capacity upwards, other methods of heating would be necessary, such as the cooling water from an engine, plus exhaust gas. These methods are discussed under Design.

Problem No. 2 — Grit. The objective of any grit-removal device is to remove the maximum amount from the slurry, preferably separate it in a clean form, and economize on labor to the maximum (see design and figures).

A very common method for collecting manure is to sweep it into an underground holding tank from whence the top layers of organic material are removed periodically. Eventually, however, the foul and filthy problem will have to be faced when the lower layers have to be removed. As any farmer knows, this chore is one of the worst on any livestock farm and can be dangerous to workers if there is no proper ventilation. If a methane plant is to be integrated in a farm I strongly recommend not using such a pit. Rather, I suggest that manure be dealt with in a continuous movement passed through a grit remover and then loaded. Thus, smells, flies, the spread of worm infestation, and the risk of reinfection by disease can be things of the past.

On p. 41 a C/N ratio of 30 is given as an optimum. An exact ratio is by no means critical to efficient digestion. A ratio of 2, or at the other extreme of 50 or more, will digest but may not be as simple to keep "brewing".

CHAPTER 10

Digester Design

Digesters can be designed either for batch loading or for continuous operation. Although this book is on displacement-type, continuously-operated digesters it is well worth mentioning in passing the basic principles of other digester designs.

Batch Digesters

These are digesters loaded with raw materials which are impossible to reduce to a slurry for loading in continuously-operated digesters. Coarse, fibrous materials such as field crop wastes, certain manures from cattle and other ruminants, garbage of organic origin and even newspapers can be used here.

These materials are mixed, packed together as tightly as possible, and then sealed off from the outside air. Fluid from a previously working unit or from a continuously-operated digester is then pumped in to seed the matter with methane bacteria. The unit is left to ferment as long as gas is produced, depending on the temperature of the contents, for anywhere from about three months at 95°F (35°C) to six months or more at 60°F (15°C). See also Chapter 7.

The disadvantages of batch digesters are that:

1) Loading requires considerable labor and, to a lesser extent, skill in packing the raw materials tightly to save space and seeding fluid. Also, raw materials must be carefully selected to make sure that the C/N ratio of the total load is lower than 30 to 1, by including proper amounts and proportions of hog dung with urine, crop wastes, and even some newspapers, for instance.

2) Only when gas production almost ceases can the digester be opened to atmosphere and unpacked. Again, considerable labor is involved. Although the liquid contents are drained away before unpacking, unpleasantly strong fumes of ammonia remain and could be dangerous to health, particularly in a confined space. The spent, damp material will still be fibrous as digestion does not break down the lignin, the component in plants that makes them stand up, although it does decompose the sap and soft contents of the plant. Composting bacteria (the aerobes) will be inhibited until the anaerobic bacteria die off and the heap is turned over to air out.

3) Gas production is in batches. This can be overcome by building a series of batch digesters and staggering the loading so that the production from one unit will overlap the others. The same gas storage system can be linked to each digester in turn.

The main advantages of batch digesters are:

1) They require little or no daily attention.

2) Cattle manure that has dried out and will not absorb moisture can be used in a batch digester where it cannot be used in a displacement digester.

3) Manures that are collected from open ranges or from feedlots may have earth mixed in and can be used as above.

4) Periodic use. Where the availability of raw material is seasonal (after harvesting, for instance) and the gas is required in quantity for drying other crops, a batch digester serves the purpose.

5) Many diverse raw materials can be used, i.e., corn stalks, pea vines, sugar-cane stalks, leaves, grass clippings, stubble, prunings, bagasse from sugar mills, corn cobs, and milling wastes from wheat, rice and other grains. To supply the required nitrogen content, a host of other ingredients may be added such as slaughterhouse and cannery wastes. Other minor miscellaneous wastes of organic origin could also be used such as antibiotic fermentation residue, fruit and vegetable trimmings and rejects, dog droppings, etc. All would decompose anaerobically and be hygienically sealed in airtight containers while giving off much needed fuel and fertilizing material.

Continuously-Operated Digesters

These units have been in use for over 70 years almost exclusively in the processing of human sewage to render it safe for final disposal. Basically, there are two different designs:

1) **Vertical digesters** which are usually circular since construction is simplified and can withstand the static pressures of the fluid contents. In operation a little raw material is loaded regularly through pipes to a certain point in the unit, usually near the center. This can be varied so that fresh loads are deposited at different points for good seeding with bacteria.

Since the digester contents are fluid and gas is generated within the material, the gasified solids rise abruptly when lighter than the surrounding material to erupt at the surface in a volcanic-type action. This phenomenon can be observed on the surface of manure lagoons or when effluent from a digester is decanted to a container. This action can be quite forceful.

Generally speaking the greater the depth of the digester, the greater is this movement. From the moment gas is released from the solids, particles rain back through the mass, reform on the floor in pockets of gas and repeat the volcanic action. Eventually the particles are stripped of their capacity to generate gas and remain on the floor of the digester as sludge.

In a vertical digester the floor is usually shaped like an inverted cone. The outlet or effluent pipe withdraws sludge at regular intervals to make space for fresh raw materials. The first part of the effluent withdrawn is therefore usually thick with sludge. If the withdrawal is continued, the effluent will thin down to supernatant liquor. Alternatively the supernatant liquor may be withdrawn from a higher level, depending on the design of the digester.

There are a number of variations in the design of a vertical digester:

a) Fixed roof with the gas outlet leading to a gas holder resting in water to afford a seal.

b) Floating roof with the dome portion acting as gas holder and with the unit's skirt being sealed by the contents of the digester itself.

c) Floating roof as in b) with the skirt sealed in a water jacket outside the digester.

The last two variations suffer from the disadvantage of allowing heat to escape at a high rate, thus restricting their use in cold climates and making them inefficient. Heat losses with the fixed roof design are less, but here the scum accumulation problem is such that the only solution is a complete clean out. At a municipal sewage plant in South Africa, cleaning out a digester of about 200 ft. (60 meters) diameter took about a year to complete. Most of the time was spent on rinsing and airing the unit before the bulldozers could be brought in to load out hundreds of tons of scum and sand. Other disadvantages are mentioned in Chapter 6.

d) Multiple chamber digester. It would appear illogical to construct two chambers when one would do better with respect to both the physical and biological successions through a digester. One chamber also affords more positive control for the operator. An interconnecting siphon would be prone to blockages, thus leading to the worst of all evils: A complete clean out.

e) Grouping vertical digesters in series makes much better sense particularly in large operations. If two or more are grouped close together, the pumping, instrumentation, gas storage, heating, etc., can be shared between all digesters.

2) **Displacement-Type, Continuously-Operated Digesters.** These are terms I have coined to define the type of digester I pioneered on my farm in South Africa in the mid-1950's. This type of digester consists of a long cylinder lying horizontally on the ground, partly beneath the surface, or even completely below ground. The roof portion can consist of a half cylinder and the base can be constructed of concrete cinder or slag (for better thermal insulation). The latter materials permit far greater capacity in relation to cost but cannot be transported to a new site as can the full cylinder.

When in full operation, raw slurry is loaded through the inlet or one of the inlet pipes. As it enters, the slurry displaces the previous load and so on down the length of the digester.

Benefits of This Design

1) From a practical standpoint, displacement digesters are easy to handle.

2) It is easy to provide these units with sampling pipes to withdraw material for analysis at any point throughout the length of the digester.

3) If the digester contents begin to sour for one reason or another at one point in the digester, strongly buffered material from further down the unit can be pumped to that point to restore the methane producing bacterial action. This transfer of material may be from the supernatant level at the effluent end, or it may be from a point nearer, as experience dictates.

4) Gas may be compressed and injected back into the digester at sampling points or through other inlets set in the floor of the digester. It has been found that recycling gas is not only beneficial in increasing movement but also in promoting bacterial action.

I would like to emphasize here as strongly as I can that if an effective digester is to be built it must be designed to incorporate such features as sampling points, scum removers and grit cleaners right at the start so that major structural changes causing costly shutdowns later are eliminated entirely.

5) Should a displacement digester require periodical washing out, hopefully only every 10 years or so, the job is considerably easier than with vertical digesters. The scum doors can be opened to allow a draft of clean air through, assisted if necessary by fans.

6) Better control of detention time can be maintained by the operator on a horizontal digester. (Detention time is the period each load remains in the digester before withdrawal.)

Double Chambers and Baffle Plates are frequently suggested as means to control the fermentation better or to screen off scum, sand or some other layer. The complications of construction involved with these suggestions, as well as their doubtful value in bringing about any real change in the succession of the digestive process, and above all the added work involved when cleaning out, would seem to rule out those suggestions. This is especially the case with baffle plates which silt up on either side, trapping grit and sand. The design for a long, continuous-displacement digester given later, is simple but has proved effective in practice.

Multiple digesters, as distinct from double chamber

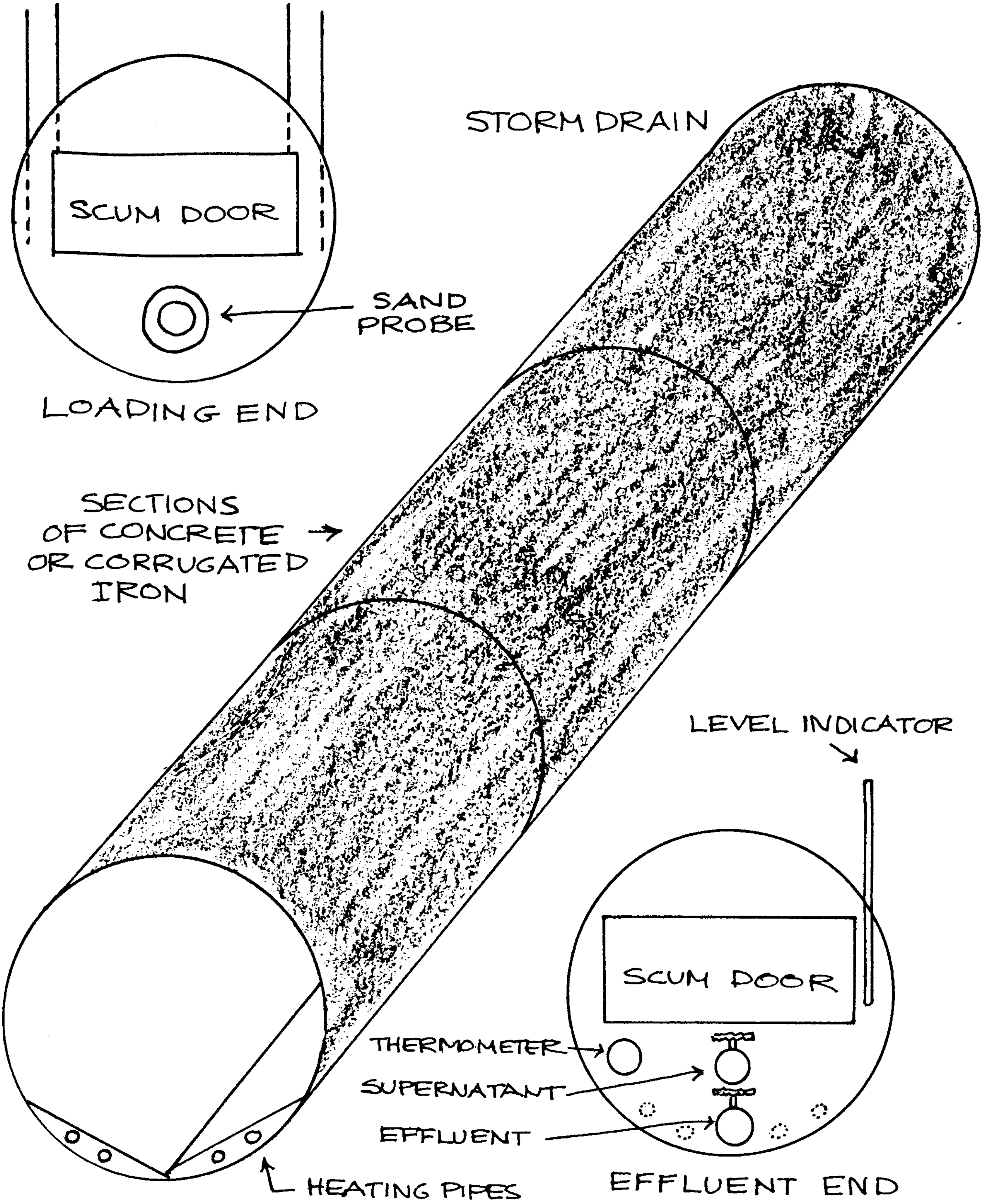


Figure 29: One digester design using modular sections.

units, are strongly recommended where large scale methane plants are desired. The ideal is a 3-unit or more power plant for a farm with at least 2,000 hogs, 20,000 layers, or 200 cows.

Each digester would receive ⅓ of the daily load except for the occasional time when one might be out of action for a few months, in which case the other units would share the extra load. For heating purposes (mentioned later) one digester's full gas output would fuel an engine from which the cooling water and exhaust could supply all the heating needed to keep all three digesters at the best operating temperature (95°F or 35°C).

If the engine is kept running continuously (to supply electricity for refrigerators in the home, etc.) there would be times when some of the power could be diverted to filter and compress the gas from the other two digesters into cylinders for use on farm machinery later, or for outside sale. Thus the cost of compressing the gas would not be a liability, except for machinery maintenance and lubrication.

Conclusions

Sewage plant digesters bear a strong similarity to methane plants but are not directly comparable.

1) Costs of sewage plants are borne by the community in general; they are designed by experts in the field and for a specific purpose, namely to process wastes so as to eliminate pollution.

2) Methane pants for animal manures and other wastes admittedly achieve the same result but the raw materials are different and require different digester designs.

3) Capital costs are considerable to buy and build methane plants, but upkeep and maintenance should be low for many years. Legislation is now being considered for drafting to allow farmers special encouragement for building and operating methane plants. Low-interest loans, tax write-offs, subsidies, etc., are being considered.

Displacement Digester Size

The size of a displacement digester is dependent on the amount of raw material to be fed (the loading), the time each load of material is to remain inside the digester (the detention time), and on the temperature. Each of the four factors is dependent on the other three.

For example if the digester is not heated or insulated and the contents kept at 60°F (15°C), the capacity would have to be twice that of a digester kept at 95°F (35°C) if the other two factors are maintained. Similarly, if detention time is 70 days the digester would have to have twice the capacity of the one designed for a 35-day detention time. Understanding those factors is essential to methane plant design and operation.

Detention Time

Detention time is the number of days that a given mass of raw slurry remains in the digester. Since raw manure cannot be loaded straight into a displacement digester, urine and water are necessary to dilute the material into a slurry. If too much liquid is added digester space will be wasted, thus reducing detention time. If too little moisture is present the over-dry slurry will not flow easily into the digester, the pipes might become clogged with solids, and sand and grit will not separate from the solids as they should before loading. Also, such an over-dry state would prevent the digester contents from moving freely and being seeded with methane bacteria. In practice, it is very simple to apply the rule of thumb making the slurry to the consistency of cream.

As we are considering a displacement digester, for the sake of visualizing detention time we could assume that each regular loading occupies a volume represented by a vertical line as shown in fig. 30.

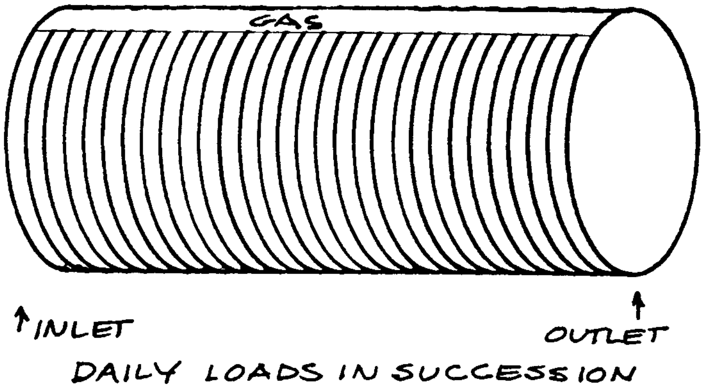


Figure 30: Representation of loadings in a displacement digester.

The theory of anaerobic digestion tells us that raw material is acted upon by different bacteria: First by acid fermenters and then by methane bacteria. Many textbooks say that these stages may take place at the same time in a well-buffered brew. The process can be likened to a factory production line where raw materials are processed and passed on to others with different skills, then finally to workers who produce the finished article. A typical gas production curve would look something like this:

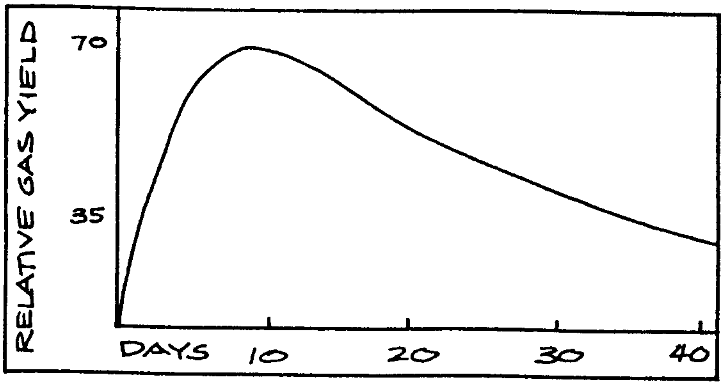


Figure 31: Relative gas yield in relation to time at 95°F (35°C).

Some claim that since this production curve clearly shows that most gas is produced in the first 10 to 20 days, digesters should be designed to take only the best days of production and discard the rest or transfer the material to a secondary digester.

In practice I found that if I overloaded one of my digesters the effect was to shorten the detention time in just this way. Gas production would rise for about three months and then begin to decline. At this point I noticed that when effluent was withdrawn to make space for fresh raw material the effluent kept in my tank truck produced a large amount of gas. What was happening was that the digester contents were beginning to turn sour, the buffered condition was being overcome, and the true methane bacteria were being pushed out in the effluent withdrawn to the tank truck. In effect the tank truck became a mobile, secondary digester.

The temperature at that time had been maintained at 95°F (35°C), but the loading rate had been increased to such an extent that the detention time was reduced to less than 15 days. The excessive loading would permit the true methane fermentation for a short time only. When the second digester was brought back into use soon after and both digesters were loaded in proportion to the load they could carry, production returned to normal. This was an adequate indication to me that on a farm a practical methane plant would have to be designed for a detention time far in excess of 15 days.

Glancing back to fig. 30 and assuming that each line represents a daily loading of raw slurry, we see a detention time of 30 days. This detention time would be adequate to maintain a well-buffered fermentation and to yield about 80% of the total gas available from most raw materials. The remaining 20% would not be worth the capital costs for detention for a further 30 days. However, we have not considered here the accumulation of grit at the bottom of the digester and the scum on top over a period of, say, one year. Both those factors waste space and reduce the detention time. Thus, for a practical working digester, trouble free in design as far as possible, and not requiring constant attention or causing concern at every drop in gas production, or being equipped with sophisticated mechanisms to agitate or beat up the digester contents regularly, we can assume an optimal detention time to be between 35 to 40 days, at the best temperature.

Loading Rate

The loading rate is the amount of dry weight volatile solids of raw material fed into a digester at regular intervals. In practice, the dry volatile solids weight is determined by taking a representative sample of your own raw dung or vegetable wastes and testing them. Only one test is needed to allow calculations of the capacity you require to process the amount you intend to load. Apart from the samples no raw materials are dried out, of course.

The liquid is only a carrier added to the solids to make a slurry of suitable consistency. In sewage plants the loading of a digester is usually measured in pounds of volatile solids per cubic foot (or kg. per cubic meter) of digester capacity. A commonly used figure is .1 to .15 lbs. VS/day/cu. ft. (1.6 to 2.4 kg. per cu. meter).

Human sewage is carried to the sewage plant by an average of 40 U.S. gallons (152 liters) per person per day. Consequently most of the alkalinity of the urine is diluted before the solids are collected and pumped to the digester for fermentation. In contrast, animal manures and urine, particularly from fowls, have a high akalinity (measured pH fresh raw droppings of 8 or even 8.5). As a result loading rates using animal and particularly fowl droppings can be considerably higher than the figures given for sewage plants.

As an example from my own practical experience on my farm in South Africa, each digester had a capacity of 3,000 cu. ft. (85 cu. meters). The daily loading was 1,340 lbs. (609 kg.) of total solids. Note that these values were TS, not VS. The weight of grit, etc., was included in TS and might have been 10% or slightly more than VS weights. The VS determination was never made since it was the first digester of this design and there were no guidelines to follow. My guess at digester capacity proved to be accurate for the output of my 800 to 1,000 hogs.

This daily loading was normally divided equally between the two digesters. The total digester capacity was therefore 6,000 cu. ft. (170 cu. meters). Loading was 1,340 dry lbs. TS to 6,000 cu. ft. or .233 lbs. per day per cu. ft. (3.57 kg. per cu. meter per day). If all the manure was loaded into one digester these figures were doubled but the strain became too great after about three months, as mentioned under Detention Time.

It would be logical to conclude that hog manure can be loaded at the rate of 0.22 lbs. per day per cu. ft. (3.2 kg. per day per cu. meter) safely for long periods of time and up to double that rate for a few weeks only.

For practical demonstration let us assume that an old cylinder lying about the farm is being considered for use as a digester. Let us say that the diameter is 4 ft. (1.22 meters) and the length 12 ft. (3.66 m.). The surface area of a cross section of the tank would thus be 4 x 4 x .7854 sq. ft. (square of diameter x constant x .7584) or 12.5 sq. ft. The capacity would be 12.5 x 12 or 149 cu. ft. (4.2 cu. m.) though the effective working capacity would be slightly less than that to leave a small place above the working level of the digester contents so that scum does not block the gas outlet. Thus 140 cu. ft. at a loading rate of .22 lbs. per cu. ft. per day (3.5 kg. per cu. m. per day) would amount to 31 lbs. per day dry weight. If a 14% solids-to-liquid slurry is used the total weight of the slurry would be 221 lbs. (100 kg), of which 190 lbs. (86 kg.) would be liquid.

However the 31 lbs. dry weight, in practice, would be naturally damp droppings plus perhaps urine and in this state would weigh at least 3 x 31 or 93 lbs., so that 100 lbs. (or 12 U.S. gals. - 45 liters) of water would have to be added.

These calculations may appear to be complicated but once established need not be repeated. In practice your 4 ft. diameter, 12 ft. long tank would have a loading of one high-sided wheelbarrow of 2 cu. ft. (0.06 cu. m.), perhaps a little more, which would be tipped into a mixing basin and about 10 to 15 U.S. gals. (37 to 76 liters) of water added until the slurry reached the consistency of cream. This would most likely finish at between 12% to 14% dry solids slurry. The outlet from the basin to the digester inlet could be an inch or two above the bottom so that sand and grit would settle out and not be loaded into the digester.

The gas yield that can be expected can be estimated quickly by a simple rule of thumb: Whatever the digester capacity in cubic feet or cubic meters you can expect that same amount in cubic feet or meters of methane gas. In this case the capacity is 149 cu. ft. Thus you could expect 149 cu. ft. of gas per day. This is assuming that regular loadings are made and the temperature inside maintained at 95°F (35°C).

On my farm the twin digesters with a total capacity of 6,000 cu. ft. produced 8,000 cu. ft. of gas per day with peaks of up to 12,000 cu. ft. In general the larger the digester the greater the overall efficiency.

Temperature

For the digesting methane bacteria to work at the greatest efficiency a temperature of 95°F (35°C) is best. Gas production can proceed in three ranges of temperature as different sets of acid-producing and methane bacteria thrive in each of these different ranges:

1) Thermophilic or heat-loving bacteria in the range of 120° to 140°F (55° to 60°C).

Digesters are only very rarely operated at this high temperature because a) most materials will digest well in the middle or mesophilic range, b) thermophilic bacteria are easily killed by changes in temperature, c) the sludge effluent is of poor fertilizer quality and is smelly, and d) it is uneconomical to maintain such a high temperature, especially in cold climates.

2) Mesophilic or middle range of 55°F (13°C) to 105°F (40°C).

These bacteria are easier to maintain in a well-buffered state and can remain active through slight temperature changes, especially if those changes occur slowly. At the low end very little activity is discernible. For instance, at 60°F (15.5°C) the rate is about half that at 95°F (35°C). However, at this low temperature, activity continues and might be of interest to those who do not intend to heat their digesters.

At temperatures around 50°F (10°C) to 45°F (7°C) and below activity almost ceases and this range of bacterial fermentation becomes dormant until the temperature rises past these figures again. As an example a digester can be constructed for summer seasonal use and manure slurry loaded during the warm season until activity ceases in winter and again resumed in spring. Seeding with bacteria would not be required.

Operation at 105°F (40°C) is not recommended. Gas production becomes sporadic as great outbursts occur for a few hours while little is produced for the rest of the day. If the temperature should rise to 105°F steps should be taken to lower it very slowly, by 1° per day for instance, but certainly not by 10°F overnight. This could very easily kill the bacteria.

3) Psychrophilic or low range of 32°F (0°C) to 45°F (7°C). Very few bacteria thrive in this range.

Since the object of a methane plant is to decompose raw wastes and produce gas, it follows that the likes and dislikes of bacteria have to be understood. Every part of the design and operation of a methane plant should be directed toward generating the most activity from the bacteria and to keep them in as near ideal conditions as can be done.

Having determined that the best temperature range is 60°F (15.5°C) to 105°F (40°C), and that 95°F (35°C) is the best temperature of all, the problem resolves itself to two facets:

1) **Insulation.** This problem is complicated by the relatively large size of the digester itself, by rainfall, weather and the fact that certain porous materials might not be suitable.

One solution would be to imbed the digester in dry earth and then cover the entire structure to prevent rain from seeping through to the digester since wet earth quickly transmits temperature changes.

Styrofoam (sometimes called expanded polystyrene) is an extremely good insulator and also has the useful property of being a closed cell material. This makes it far safer than open cell materials which might soak up a leak of gas from the digester walls or top and form an explosive mixture of gas and air.

Another possibility might be to surround the digester with another structure, such as a greenhouse, and maintain the temperature at 95°F (35°C). This solution might be found still more advantageous at large installations where four or more digesters would lay side by side.

Packing a half-buried digester in a massive compost heap might be another solution in certain climates. In the tropics, little or no insulation may be required. If the digester temperature drops to 80°F (27°C) the drop in activity might not warrant the expense of heating. In considering insulation and/or heating one fact should be borne in mind: Bacteria will not stand up to violent (15°F) changes in a short time, such as overnight.

2) **Heating.** If you have a geothermal spring gushing water at 130°F (55°C) on your property you have no problem. However, the chances are you don't and here are some ways to heat your digester:

a) One of the most effective methods is to have an engine, fueled by some of the methane gas, circulate the cooling water and exhaust gasses back to the digester. An engine has about the same efficiency as a hot water boiler (50%) in converting raw energy to heat. The useful energy from the engine (about 25% of the original) can be profitably used to generate electricity or power to an endless variety of farm machinery (see Gas Uses). A limiting factor here is that the water circulated through pipes in the digester should not exceed 130°F (55°C) since sludge will cake on the pipes and prevent the dissimilation of heat. This problem can be overcome by burying the pipes in the digester floor so that the heat could pass through the floor material into the digester contents. The rule is that one sq. ft. (929 sq. cm.) of the outside surface of pipe be allowed for every 100 cu. ft. (3 cu. meters) digester capacity. These are minimum requirements. Of course, more pipe can and should be used to ensure heat transfer. In practice I would strongly advise two sets of pipes being installed and firmly set in the floor. Should one set fail for any reason there would be no necessity to clean out the digester to make repairs.

The digesters on my farm were heated in this way but the pipes were not laid in the concrete floor. They were laid against the inside walls of the digester on the floor. As a result the pipes became displaced, bent, kinked, or ripped by the scum remover. Black plastic pipe was used at first, but I switched to steel pipe which clogged up after a few years, and then I tried copper pipe which I do not recommend because of its high price. Finally I used galvanized pipe, passing the circulating water through a water softener to prevent clogging the pipes and engine cooling system with deposits.

b) A quick way to raise temperature is to pipe steam into the digester. Only small pockets of bacteria are killed by the steam and overall gas production is not reduced. To illustrate I once left my farm in winter to go to England and when I returned I found the digesters were not operating. The temperature inside the units was down to 68°F (20°C). I rigged up an old 50-gal. drum on a stand a little off the ground and laid horizontally. I used one outlet aperture on top as a steam outlet. A lagged hose pipe connected the drum to a yard-long length of straight pipe which was inserted through a supernatant sampling pipe into the digester.

The pipe was sealed off by rags and clamped into place. I bought four tons of cheap coal, lit a fire beneath the drum and arranged to keep it going continuously. I controlled the water supply so as to provide equal amounts as driven off by steam. Within four days the temperature rose to 90°F (32°C). The remarkably fast rise was all the more surprising since each digester contained about 90 tons of material. In addition to this must be added the concrete structure itself, making a total of some 300 tons altogether. There are many forms of steam generators which can be useful for speedy heating.

When the temperature of the digesters reached 90°F gas began to be generated in large volume. As soon as one of the gas storage tanks was full I started the 13 HP engine. The plan was to continue the heating by using the engine cooling water and exhaust. To my surprise the engine consumed all the stored gas as well as the strong flow from the digesters within a few hours. Fuel consumption was almost double the normal rate. Then I remembered that the first batch of gas generated in a methane plant when starting up or restarting is nearly always of poor fuel quality. The carbon dioxide content is often twice that of the normal 30%. The engine had gulped through the gas in order to obtain enough methane to keep going. The next day the storage tanks were full again. This was released to atmosphere and the engine started on the fresh flow from the digesters. Overnight the bacterial process had returned to normal and the engine continued at its normal rate of about 6,000 cu. ft. (170 cu. meters) per day. Surplus gas slowly filled the gas storage tanks. All was well.

c) Digester contents can be heated by circulating raw slurry or mixed sludge from the digester through a heat exchanger outside the digester. This method is used in sewage plants but requires frequent inspection as blockages are a big problem. A heat exchanger is a costly item and there are better ways of solving the problem.

d) Burning the gas in a submerged or underwater heater, or beneath the digester itself, may also be a solution to the heating problem. I have not tried c) or d) so cannot speak from experience, but it would be logical to assume the latter would be an efficient method in that heat would be applied directly to the working contents of the digester. If the flame is on the digester at the bottom it should be a quarter of the distance along the digester from the inlet end. This would provide heat at the most needed point in the process. The extreme local heat might cake the sludge but this is unlikely due to the almost inevitable layer of sand which would dissipate the heat.

A word of warning: The burnt gas is sometimes highly corrosive if forced to burn with an excess of air and can damage steel or iron digesters, as well as the flues leading the gas off.

e) Another way to heat digester contents would be to introduce hot water or steam into the raw slurry before it enters the digester. As recounted earlier I have tried that method with success. It stands to reason that the daily influx of a relatively large volume of raw slurry at near-freezing temperatures would drop the general temperature of the digester in only a few days. This happened on my farm once causing a problem that was compounded when far too much cold water was added to the slurry, reducing the solids content to below 5%.

When the engine was running, so much surplus heat was generated that it did not matter if the raw slurry was near freezing when it was loaded, provided it was not diluted beyond the normal 12% solids content. Thus, even in winter raw slurry was not heated as long as the massive heating of the engine continued. Many think of South African winters as warm, but from May to late August frosts of 15°F (—9½°C) were frequent at night. In fact, on my farm 8 miles south of Johannesburg, situated on land at an altitude of 5,500 ft. above sea level, there was frost nearly every night during the winter.

It has been estimated that one third of the energy heat value of the gas generated in a digester would be sufficient, with thorough insulation, to maintain the temperature at 95°F (35°C) in cold climates. I was using ¾ of the gas generated to fuel my engine. Thus the heating was more than enough despite the fact that the digester roof itself was hardly insulated and the raw slurry was near freezing. I imagine the same conditions would exist where most plants would be put into operation in winter.

In extremely cold climates good insulation is the first essential, and the second is that the raw slurry temperature should be raised to 95°F (35°C) or higher so that the general temperature of the digester is maintained at the optimum despite heat losses through the sides and roof of the digester.

f) One method of preserving heat, employed in sewage works, is to use warm supernatant as the liquid mixed with the raw material to form a slurry.

A tank outside the digester is built to receive the raw material which is then reduced to a slurry by recirculating liquid taken from the outlet end of a digester at a point about halfway between top and bottom where it is thinnest. The second advantage of this method is that the raw material is thoroughly seeded with bacteria when pumped into the inlet end. The disadvantage is that the digester contents tend to thicken and become too dry over a period of time. Also, the outside mixing tank means that oxygen has access to the methane bacteria when the mixing is vigorous, as it has to be. Smells are obnoxious.

Alternative systems are discussed under Digester Operation. In nearly all cases some form of raw slurry heating is essential to efficient methane plant operation.

Digester Size. Those planning to build their own methane plants should be aware of the full scope of such an undertaking. A significantly productive plant is no backyard, weekend project. The size of a methane plant in relation to the quantity of manure loaded is 35 or 40 to 1. For instance, Santa Barbara with a population of 78,000 has a sewage plant with two digesters each of 700,000 U.S. gallons or about 100,000 cu. ft. capacity (2,750 cu. meters). Yet this plant is too small for the city and a new plant is being built. The important point is that methane plants, even highly efficient ones, have to be large to handle the vast volumes of raw materials for the amount of gas required.

From what is known about methane digestion at the present time the requirements pertaining to digester size are as follows:

1) A digester must have a capacity 35 times (preferably 40) that of the slurry mixed to the right consistency for daily loading.

2) The digester must be insulated and the colder the climate the better the insulation required.

3) A digester of displacement design allows the operator far better control of the continuous operation aspect.

Should a more efficient method of fermenting be devised in the future, the original digester would not be rendered obsolete, but could be loaded at a higher rate to give better results. Oxidation (rusting) is not possible since there is only a trace of oxygen inside the digester. The outside must be covered with some form of insulation and therefore keeps dry. A steel roofed design should have a long life even without coating or painting.

A displacement digester can consist of a complete cylinder, or of simply the roof half of the cylinder bolted down to a concrete base thus affording a much greater capacity than with the lower half of the complete cylinder (see drawings of both versions).

The proportion of length to diameter (or surface area of a cross section) are important to keep within certain bounds:

1) If the digester is too long and thin the fresh slurry loaded will not be seeded properly with active methane bacteria so as to start the fermentation process speedily. One essential feature in the design of an efficient digester is that the raw slurry loading should come into contact with the previous loadings which, in turn, should be in the active stages of decomposition leading to the final stage of methane fermentation.

2) If too short or wide the physical and biological succession would be foreshortened. If taken to extreme the action would be no better than that of a vertical digester without the benefits of slow digestion over a distance.

The proportions of width and depth (or diameter) to length is not critical. A ratio of 1 diameter to 5 in length is optimal. The ratio of 1 to 8 in length or 1 to 3 in length each would be the outside extremes of proportions. Any cylinder longer and thinner or shorter and fatter would not be suitable for a digester.

In selecting an existing cylinder for use as a digester one further requirement is that the cylinder should have flat ends. Scum removal doors at each end of the digester are more easily installed on flat surfaces than on curved ones. A note of caution: It is dangerous to use oxy-acetylene torches on tanks that have contained petroleum products such as gasoline, solvents, etc. A qualified authority should be consulted before thinking of acquiring any such cylinder.

In summary the four most important points in this chapter are:

1) A loading rate of .22 lbs. per cu. ft. per day total solids dry weight manure can be maintained continuously with a reasonable certainty of not overloading a digester.

2) Detention time should be 35 to 40 days. Thus, the digester must be 35 to 40 times the amount of a daily loading of slurry that is 14% solids, i.e., the consistency of cream.

3) The temperature should be maintained at 95°F (35°C).

4) A displacement-type, continuously-operated digester must be cylindrical in design (or partly cylindrical with a concrete base, for instance) and be within limits of length to surface area (height times width). The size is dependent only on the dry weight measurements of the solids to be loaded continuously.

To illustrate the interrelationship of the factors at work in a displacement digester I will cite four examples:

Example No. 1: Three 50 U.S. gallon oil drum digester.

The true capacity of each drum is approximately 58 U.S. gals. (220 liters) but since a small space must be left on top of the digester contents for the gas, 55 gals. (201 liters) is the working capacity. Thus the total working capacity is 165 U.S. gals. (603 liters) which equals 22 cu. ft. (.623 cu. meters).

If the loading is to be .22 lbs per cu. ft. per day (3.4 kg. per cu. meter per day) the dry weight manure will be .22 x 22 lbs. or 4.8 lbs. (2.2 kg.). Natural damp droppings would weigh three times this or 15 lbs. (6.7 kg.). The loading would have a capacity of 165/35 U.S. gals. = 4.5 gals. (17 liters).

Thus, quite simply, one would weigh off 15 lbs. (6.7 kg.) into a container of at least 6 U.S. gals. capacity and add urine and/or water until the container held a total of 4.5 U.S. gals. (17 liters).

If the temperature is maintained at 95°F (35°C) the gas yield would be at least 5 cu. ft. per pound of raw dry weight (0.31 cu. meters per kg.) or a total of 25 cu. ft. (.7 cu. m.) gas per day.

Example No. 2: Large scale, 100 ft. long, 25 ft. in diameter.

Capacity: 25 x 25 x .7584 x 100 cu. ft. = 49,000 cu. ft. or 366,000 U.S. gals. working space. (7.62 x 7.62 x .7584 x 30.48 cu. m. = 1,389 cu. meters.)

At a loading rate of .22 lbs. per cu. ft. per day (3.4 kg. per cu. m. per day) dry weight droppings would be 5½ tons (5 tonnes). The gas yield could be expected to be 5 cu. ft. per pound raw matter (0.31 cu. m. per kg.) or over 50,000 cu. ft. (1,524 cu. m.) daily. In a digester of this capacity the efficiency of the whole process could be expected to produce a gas yield of twice this amount in peak production and to average at least 20% to 70% more than the basic volume quoted. This is due in part to the greater depth of the vertical surging action, and in part to the generally greater efficiency of larger units.

The total daily slurry loading would be 1/35 x 366,000 U.S. gals. or about 10,500 U.S. gals. (38,000 liters) composed of just under 14% solids with the remaining 86% consisting of water and/or urine to bring it to cream consistency.

There is no technical reason why digesters of this large capacity should not be built and no doubt the time will come when such digesters are in common use.

Example No. 3: A power plant that might be operated on a livestock farm of, say, 3,000 hogs, or 300 cattle, or 30,000 layers. Three digesters constructed side by side, with the loading being spread equally, or between two should one of the units be out of operation.

Capacity of each unit is 124 sq. ft. cross section to 50 ft. long. The cross-section could be roofed by a half cylinder bolted down to a concrete or cinder concrete base, or a complete cylinder of 14 ft. diameter. (Using the formula of a diameter squared x .7854 x 50 ft. = 7,700 cu. ft. = 57,500 U.S. gals. [218 cu. m.].)

The loading of each digester would be at least .22 lbs. per cu. ft. per day (3.4 kg. per cu. m. per day) dry weight, or 7,700 x .22 lbs. = 1,694 lbs. (770 kg.). This figure would be a reasonable estimation from all the droppings on such a farm, assuming the livestock are fed an average amount. Total figure 3 x 1,694 lbs. = 5,082 lbs. dry weight (2,310 kg.). Total gas yield 25,000 cu. ft. per day (720 cu. m.) could be expected with peaks to twice this amount and an average 20% to 70% higher.

Assuming a gas yield of 30,000 cu. ft. (850 cu. m.) per day one third that amount (10,000 cu. ft. or 283 cu. m.) could be used to fuel a 20 BHP engine continuously. In practice it would be advisable to use a higher BHP engine such as a 24 or 30 BHP heavy duty engine and operate it at 20 BHP to increase endurance and lower maintenance costs. The heating generated would be enough to replace heat losses from the digester even in cold winter climates, provided the digesters were well insulated thermally, and the daily quota warmed before loading.

The advantage of a methane plant designed along specifications mentioned in this example include:

1) Gas from the other two digesters would be available for compression into cylinders for use on tractors, cars, or for resale. The compression costs would not be a factor since the engine is made to operate continuously. Time could easily be found to compress gas when the engine is not required for other purposes, such as at night, under automatic controls (see Gas and Gas Usage).

2) Dependability would be increased by having three digesters.

3) The heating problem of the digesters would be solved by the engine, backed up by the availability of more gas from the other two digesters for use in an emergency or extreme cold.

4) The methane power plant would supply most of the power needs of the farm independently of outside sources of fuel which are subject to price changes and taxation.

5) About 5,000 U.S. gals. (19,000 liters) of fertilizing material would be available per day (a figure based on a calculation of 1/35 of the total capacity of all three digesters).

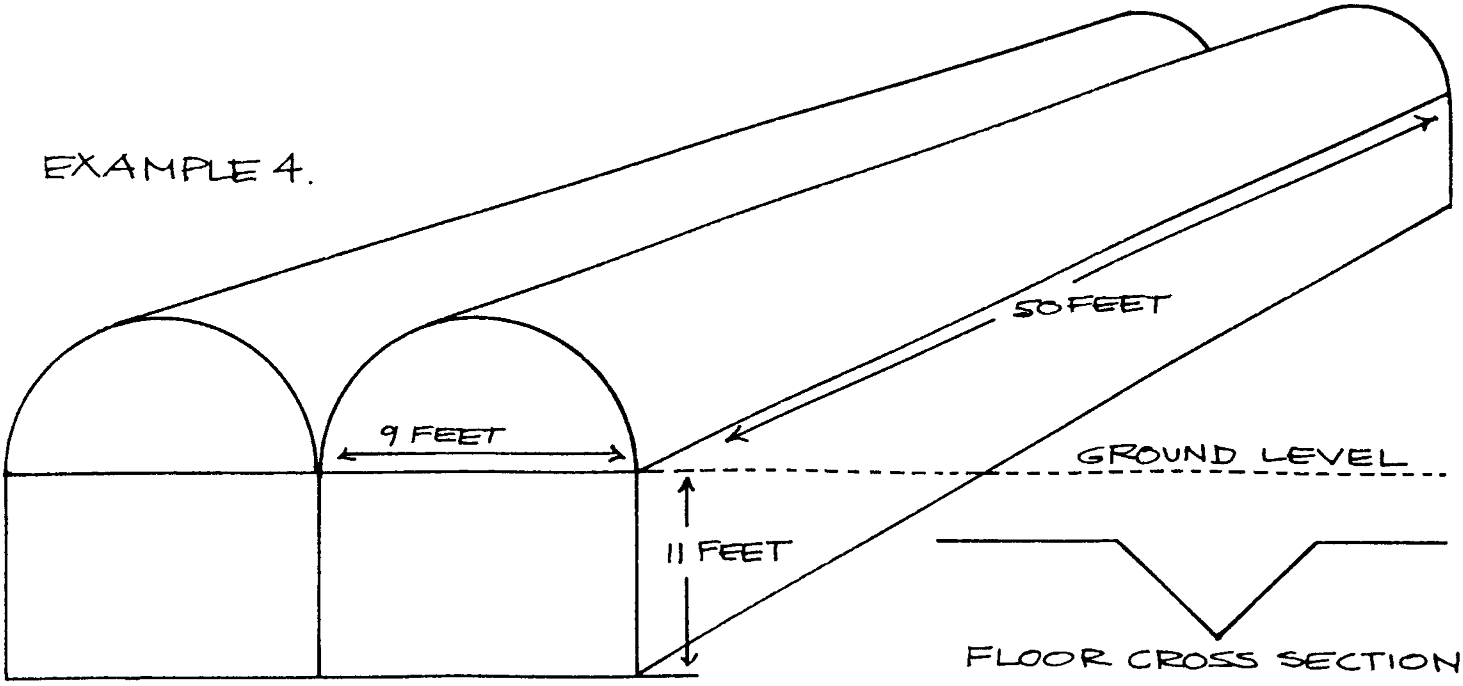
6) Although farms with less livestock could operate an engine continuously it may be found that the overall economics of this example would compensate the farmer generously whereas any smaller methane plant might not pay so generously.

Example No. 4: A farmer buys a complete cylinder 9 ft. in diameter and 50 ft. in length. He wishes to build two digesters by cutting the cylinder into two half shells and by using these as the digester roofs. How deep should the base walls under the roofs be to accommodate manure from 2,000 hogs?

1) The surface area of a cross section of roof is 9 x 9 x .7584 x ½ = 31.6 sq. ft. The length is 50 ft. and therefore the capacity is = 31.6 x 50 = 1,580 cu. ft. with a working capacity of 1,500 cu. ft.

2) All the available manure is weighed over a period of days and is found to average 10,000 lbs. per day natural damp weight, for instance. Two identical volumes of sample are then weighed. One sample is dried out in a makeshift oven (50-gal. drum) at about 200°F until absolutely dry, and then weighed. The other is placed in a larger container in which a hose pipe is positioned until all the manure floats away, leaving clear water and sand. The sand and other inert material is weighed. Dry solids minus sand gives the approximate volatile solids. The damp weight sample is a fraction of the total daily manure production. Thus it is then determined with moderate accuracy that the 10,000 lbs. is made up, for instance, of 7,000 lbs. moisture and 3,000 lbs. of solids, of which 300 lbs. is sand. There is therefore 2,700 lbs. per day of volatile solid to be decomposed by methane bacteria to produce a basic 22,000 cu. ft. of gas. Each digester is to process 1,350 lbs. per day.

3) Since digestion will process about .2 lbs./cu. ft./day volatile solids, the capacity of each digester must be 1,350 ÷ .2 = 6,750 cu. ft. The roof capacity is 1,500 cu. ft., leaving 5,250 cu. ft. of walled digester. Allowance for the V in the floor can be assumed as 250 cu. ft., leaving 5,000 cu. ft. between walls. The length (50 ft.) x width (9 ft.) = 450 sq. ft. Thus, 5,000 ÷ 450 = 11 feet depth. The proportions of width x depth would be within acceptable limits. Means would have to be devised to bolt the roof section down securely to the walls.



CHAPTER 11

Digester Operation

Basically the operation of all displacement digesters is the same, whatever the size. The same piping arrangement is required, but to scale. The general requirements:

1) An inlet pipe with the outside opening higher than any pipe open to atmosphere to prevent back flows from the most smelly part of a digester. The pipe should deposit raw slurry near the bottom of the digester but should have a clearance from the floor to prevent blockages caused by the back-up of sand deposits. The pipe should not slope inwards towards the far end since this might tend to force raw slurry too far down the digester.

2) An effluent pipe equipped with a valve, of at least 3 in. diameter (about 8 cm.) with the interior portion leading to the lowest portion in the digester.

3) Provision for passing circulation pipes through the outlet end for heating the contents of the digester.

4) Supernatant withdrawal pipes with valves on the outlet face.

5) A 3-in. (8 cm.) diameter pipe (at least) on the outlet face, positioned from one third of the distance up from the floor of the digester (at the supernatant level), with the top open to atmosphere one foot or more (30 cm.) above the highest point of the digester contents. This constitutes an automatic overflow device in case the digester gas outlet should get blocked for any reason. The pipe disgorges supernatant until the blockage to gas flow is removed and prevents damage to the digester caused by rising pressure.

6) Scum doors at both ends and a reliably engineered drag to remove scum.

7) Gas outlet piping (as well as all other piping to the gas holders) of sufficient diameter to avoid restricting the necessary flow of gas at any time such as during effluent removal (negative) and loading (positive).

8) Provision for a thermometer to read temperature of digester contents.

9) A small transparent plastic pipe with each end arranged as in 5) so as to note the level of the digester contents from outside and to be used as a level indicator.

10) Pipes of 2-in. (7 to 10 cm.) diameter with valves to be used as supernatant sampling points located along the side of the digester about one third up from the bottom of the digester measured vertically.

11) Gas recirculation piping to the center of the digester floor at intervals down the length of the unit.

If all these outlets, etc., are not shown on the drawings to follow that is because of the difficulty in depicting them clearly and because particular features of each type of construction are emphasized.

Sand and Grit Removal

Essential to all digesters is a device to separate and remove grit, sand and most of the coarse inert materials in manure, thus permitting efficient operation over long periods of time. Should the device used not function digester space will be wasted. And as previously discussed, maintenance of temperature is strongly affected by the temperature of the raw slurry loaded. Various different methods are suggested here whereby the two requirements can be dealt with simultaneously:

a) For small digesters (inner tube model, three-drum unit, etc.) suggested is a plastic bucket with an outlet two inches (5 cm.) up from the bottom. First, warm or hot water is mixed to make the slurry. When the slurry is ready for loading, stir the mixture lightly (to avoid raising the grit) as it is loaded, holding the bucket level. A little water can then be added, mixed with whatever organic matter is left and flushed in. Grit is then removed.

b) For larger digesters a loading basin can be positioned either at ground level for pump loading, or raised one foot (30 cm.) above the highest point of the digester and supported by suitable bracing. The inlet is sealed with a stopper fixed with a wire for easy removal when the slurry is ready to be loaded. While the slurry is being prepared a gas flame, protected from high winds by screening, can be lit under the basin. When the required temperature is reached the stopper is removed, allowing the warmed slurry to pour into the digester. The same procedure as in a) is followed.

c) For digesters intended to handle over one ton dry weight per day, or designed for continuous loading of large quantities of slurry, the corrugated sand trap would be more efficient. As slurry flows over the corrugations, sand settles in the hollows. If steel sheeting with deep corrugations is used a gas flame could be lit under one or more of the corrugations so that the slurry is heated as it flows toward the digester inlet. After loading or at intervals, in the case of continuous flow, one side of the sand trap is removed, the grit swept into the gully for final disposal and the side replaced.

d) Another type of sand remover using small piping (in this case 4-in. salt glazed pipe) enlarging to 13 in. in a T piece operates on the principle that the flow-through of slurry is slowed by the larger diameter in the T and deposits sand in the vertical portion of the 3-in. pipe. This was tried in practice and did deposit grit as intended. However, since the vertical part of the T narrowed back to 4 in. at the bottom, the sand became wedged against the sides and proved difficult to dislodge into wheelbarrows beneath meant to take it away. Since heating would be difficult to accomplish in such a grit remover it is not recommended for a cold climate, although the design could be adapted. An advantage to this suggested method is that the material is kept enclosed in piping right until it is introduced into the digester.

Figure 32: *Sand trap made from salt glazed sewer pile.*

Other systems of grit removal can be researched in any patent library.

It should be noted that if raw slurry with the grit still in it is to be piped to a grit remover the pipe should slope down toward the device. At no point should the gritty slurry flow upwards in a vertically placed pipe since grit will block the pipe at the low point.

Starting-Up Procedure

The following procedure is common to all digesters:

1) Obtain starter brew which, very simply, is any other digester's effluent rich with methane bacteria. Starter can also be made in bottles, or it can be drawn from any other digester. Generally, the more starter brew you have, the faster fermentation can be started. Never more than 50% of the solids content should be added at any one time in case the methane bacteria are overloaded and not able to maintain a buffered condition.

As an example one gallon of starter brew should never have more than half a gallon of fresh manure slurry added to it. On the second and third day an equal amount should be added, but on the fourth day, for instance, it may be advisable to add nothing, just to be sure of not overloading. On the fifth day, over half a gallon is added. By the end of three weeks and keeping to the 50% rule, the daily quota will have risen to over 5 gals. per day and will increase in quantity sharply from then on. If a digester is filled near full with working material all at once it will continue operating without interruption, provided the brew is not cooled in the transfer or exposed to atmosphere excessively.

The digester level in the meantime will rise at an increasing rate covering the lowest portion of the inlet pipe. All other outlets to the open air, except the gas outlet, should be blocked off temporarily. When the level inside reaches its normal working level of about 95% of the digester capacity the automatic overflow must be left open.

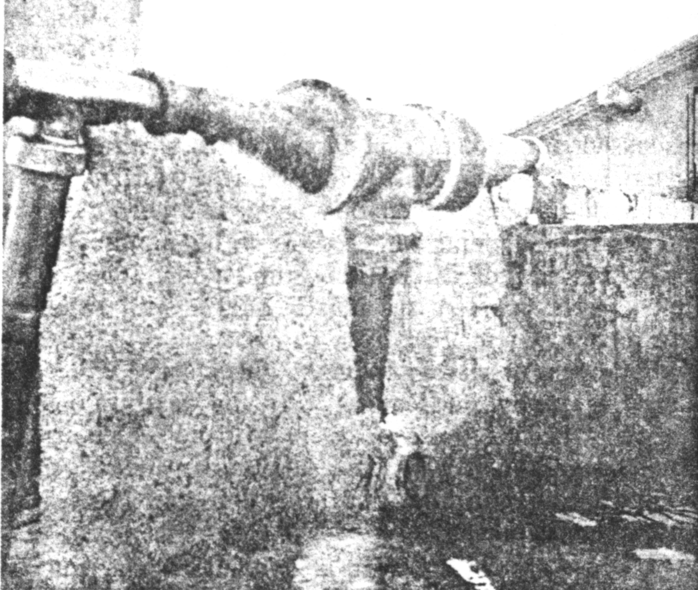
An alternative method of starting up is to fill the digester about 80% full with water at 95°F (35°C), thus closing off the bottom end of the inlet pipe and the automatic overflow, and then placing the starter into the water. Dilution will not obstruct fermentation provided the raw slurry to follow is mixed thoroughly through the digester. By filling the digester 80% full with water most of the air is forced out and the bacterial starter will deplete the oxygen in the water in a short time. Further entry of air is thus prevented. Continual loading of fresh slurry will eventually thicken the brew.

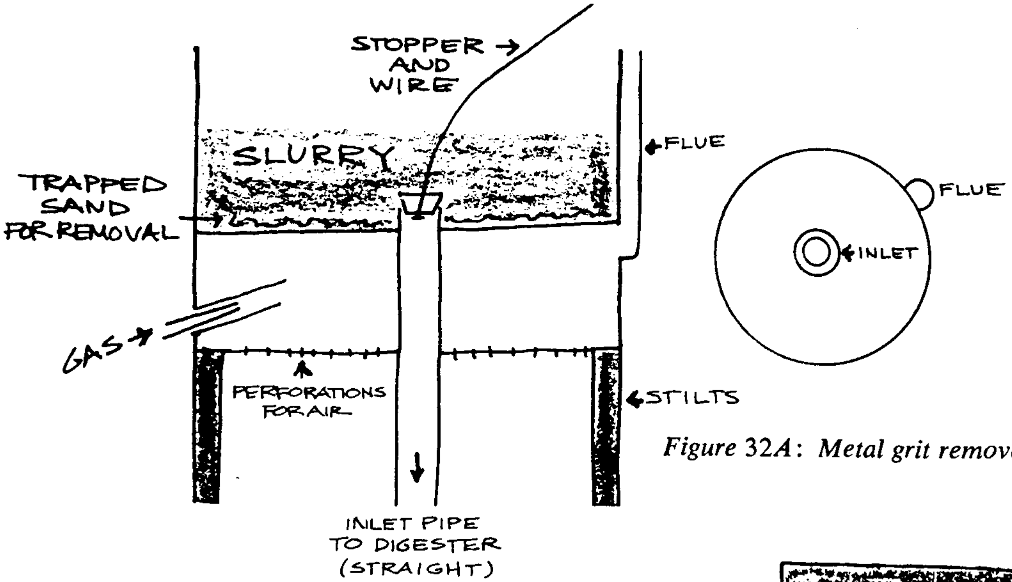
I have tried both methods with success, and as a third alternative I suggest adding starter and about three times that volume of water before putting in the raw slurry.

The extra water provides more mobility between starter and fresh slurry. After starting do not allow air into the digester. In practice oxygen in the air inside the digester is soon depleted and finally exhausted by bacteria. The vapor smells acrid and rank, and later as gas begins to be generated, the characteristic musty odor of sludge gas is detected.

It is most important that the first filling of gas to the gas holder should be vented to the atmosphere. To be extra sure vent the second batch as well and flush the air out of all the gas pipes. A sample may then be taken in an inner tube (flushed twice with gas to remove the last trace of air) to a safe distance away and tested for burning quality by squeezing gently on the tube and igniting through a suitable burner attachment.

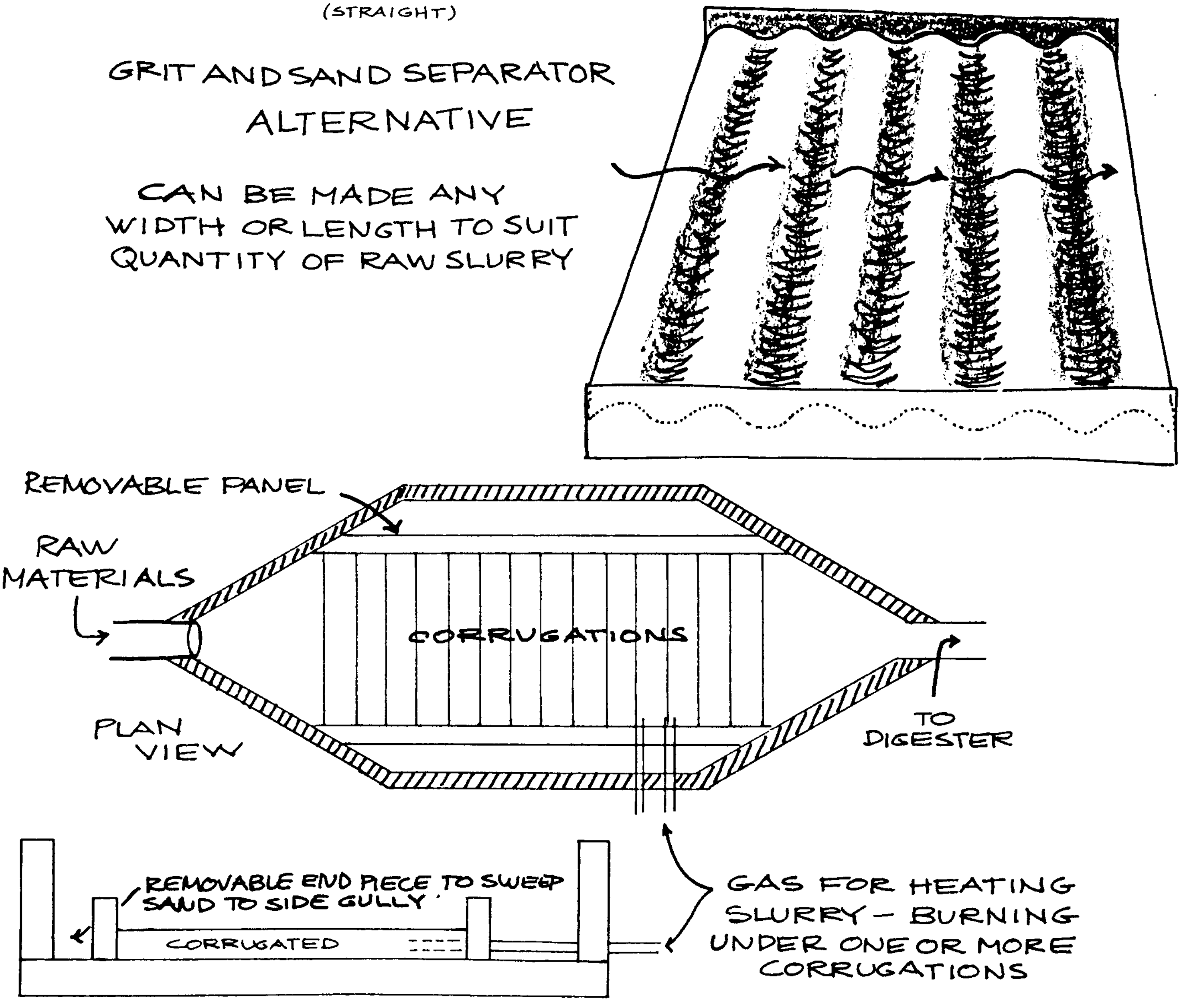
Routine loading and withdrawal can be done simultaneously by adjusting the level of the outlet end of the effluent pipe a few inches above the level of the contents. The gas is then closed off only as long as it takes to load the digester. As the fresh raw slurry is





FOR UP TO 1 TON SLURRY MIX

Figure 32A: Metal grit remover and heater combined.



END VIEW SECTION

Figure 33: Grit remover for larger quantities of raw slurry.

loaded the effluent pipe will disgorge digested material into whatever container is beneath it. If the effluent is in the form of thick sludge it may not easily flow at first. Care must be taken not to load too quickly, thus causing overflows at the level indicator and at the automatic overflow pipe outlet.

The moment loading is finished the gas outlet valve must be opened. If kept closed effluent will continue to disgorge in proportion to gas output, thus reducing the level in the digester. A notice placed in a conspicuous position should help remind one to open the gas valve. If forgotten the digester level will continue to fall until the balance is reached between gas production and the increasing pressure required to force out effluent due to the drop in level of the contents.

An alternative method of loading without withdrawing effluent simultaneously is to withdraw effluent ahead of loading. If a withdrawal is made the volume in the digester will drop and gas must be drawn back to replace this volume.

Thus the first step is to check that the gas holder(s) contains enough gas to replace the volume of effluent to be withdrawn. For instance if your gas holder has a 200 cu. ft. capacity you can withdraw 200 cu. ft. (or 200 x 7.48 U.S. gals. - about 1,400 gals.) of effluent. When effluent is withdrawn the digester level (shown by the indicator) will drop. It is not advisable to withdraw more than three days' worth of effluent because any more might draw on the most active and best buffered gas producing material in the digester. It is known that souring can occur by excessive withdrawal, as can a severe drop in gas yield. Whatever volume of effluent is withdrawn can then be loaded in equal volume at regular intervals until the digester level is back to the normal mark of 95% full. Each loading will displace an equal volume of gas back to the holders.

Always make a point of double checking all valves for correctness before leaving the area for other work. Also check that water in the lower part of the gas holders is topped up as a routine measure. In fact, a log book should be kept of date, loading temperature, pH of input and effluent, and other pertinent details.

SITE SELECTION

The following factors must be considered when selecting a site for a methane power plant:

1) On a farm where an engine is to be installed the site should be a short enough distance away to hear whether the engine is running, but not so close as to be a constant din.

2) Access roads should be useable in all weather conditions.

3) Vegetation should be cleared out from the vicinity.

4) The field beyond and below the digester should be available for discharge of effluent in an emergency or in case of automatic overflow. In that connection, the unit should be downwind (prevailing wind) of the homestead.

5) Use can be made of sloping ground as raw slurry can be made to gravitate, thus avoiding costs of pumping equipment, and likewise effluent can be removed through gravity.

6) Raw gas will flow hundreds of yards for use in the homestead if piped uphill or downhill but will not flow over level ground (or in freezing weather) unless dried at the plant. A filter of calcium chloride and/or sawdust will dry the gas sufficiently if the filter is maintained.

7) It is an advantage to have a view of the plant from the homestead so that gas holders can be checked easily.

8) Special, unchokeable open-impeller pumps are available to pump prepared slurry over considerable distances, so that mixing basins need not be immediately adjacent to digesters, although for many reasons it is advisable to have them close. Aluminum, salt-glazed or plastic irrigation piping is preferable to steel.

9) Concerning labor, the major problem involves the regular withdrawal of effluent. The ideal site is one near a major (internal) water furrow. Effluent could then be poured into the flow and straight out to certain forms of growing plants as a liquid fertilizer in dilute form. Alternatively, manure guns are available to spread the effluent in a radius of up to 200 yards, though here some of the more volatile nitrogen will be lost when propelled through the air. A tank truck spreading the effluent at low level straight to the earth has been proved speedy and most efficient.

10) Areas prone to flooding must be avoided due to the potential drops in temperature that would cause failures and the fact that the condensation trap, being open to atmosphere, would reverse fill and shut off the gas flow.

11) The site should have access to electric power lines for water circulating pumps where engines are not used for digester heating.

12) Availability of water both for regular loading and eventual cleaning out is another site requirement. If the chlorine in the water is excessive it can be neutralized by bubbling sulphur dioxide ($SO2$) through it before use. This gas is produced by burning raw sludge gas with a forced excess of air.

13) If an engine is to be part of the plant the site should also be selected in terms of the most convenient use of the power generated.

14) The potentials of growing algae as a supplementary feed for animals is not yet known, but a site where effluent could be mixed into a body of water to stimulate growth should be considered for possible future use. Research is underway to devise practical methods of harvesting algae as a high protein food for livestock, relying on digested effluent as a stimulant and on photosynthesis.

CHAPTER 12

Economics of Digestion

When determining the costs of a methane power plant a number of far-ranging factors must be considered:

1) As a result of the ever-increasing intensification of livestock enterprises, rivers and underground waters are being contaminated at a proportionately faster pace. Cries are heard to clean up the waterways and there are those who say we are polluting ourselves off the face of the earth. But storm waters continue to wash down vast quantities of animal wastes into our waterways. River deltas often have the same musty odor of a digester being cleaned out — an odor pervading mile upon mile of countryside. Mother Nature does what she can, but her systems don't include harnessed fermentation in a closed container! As a result farmers are harassed to clean up or shut down their enterprises. Some have had to go out of business.

2) Recent letters to me indicate that interested groups are suggesting legislation to their Congressmen to encourage farmers in the construction of methane power plants, not only to help clean up the environment, but to provide themselves with an independent source of energy free of price fluctuations and political blackmail from overseas.

3) The price of fertilizer both in terms of cash and in the energy required to produce and transport it to the point of application have risen to the extent where starvation faces many areas of the world.

In India, Mr. Ram Bux Singh has struggled valiantly to introduce the technology of methane gas production and has succeeded to the extent that thousands of small plants are being built to supply local fuel and fertilizer needs. I emphasize the world local since Indian transportation is costly and farm areas are often inaccessible by road or rail. The same conditions apply to most of the "third" world.

In effect, the demand is worldwide and the need is immediate. Only the technology for large and small scale local production has been lacking for universal application. This book is intended to fill in at least some of that lack of knowledge and to show how the technology can be applied in a practical manner.

Over the years since 1957 when I started on this lonely long-distance run I have looked over my shoulder hoping that someone would be there to share the vision, to take the baton, and help carry the burden. I could fill a book simply by listing the frustrations I have met in trying to advance the benefits of digestion. However, nothing is gained by sour grapes, and criticism is negative. Rather, a positive polarization is needed to face whatever remaining problems exist in the production of methane gas from organic matter. I am convinced that a small group of engineers, thinking positively, could overcome any associated problem in a matter or weeks or months, rather than the decades required to develop such systems as hydrogasification that produce pipeline gas all right, but at the expense of the organic matter itself which could have been used as critically-needed fertilizing material.

The cost of a methane power plant can be high. After all, human sewage plants are expensive items for a community to finance. By contrast a methane power plant is intended to make a profit from digestion through a variety of end products, and much depends on how sophisticated the power plant is to be. I cannot and would not quote highly suspect calculations as to X amount of dollars in capital costs and operation per cow, hog, chicken, etc., since the cost of a methane plant depends on the machinery, gas holders, and digester tanks the farmer needs to meet his requirements. Also, construction costs are reduced as the per unit volume of a digester increases. The larger the power plant the lower the cost per ton to process and the greater the efficiency. In addition, less heat is required per unit volume since heat losses are proportional to the surface area of the walls of a digester.

The overall cost of a methane power plant can be kept low through the use of famous American ingenuity, or it can skyrocket with the use of electronic switching gear, automatic loading and effluent withdrawal mechanisms, and electronic sensing devices and controls. Even the necessary checking of pH can vary in cost from a few pennies a week spent on narrow gauge litmus paper to hundreds of dollars for elaborate pH meters. The fact remains that corners can be cut. For instance I have heard that recently several prospective builders of methane plants have purchased by bid a quantity of reject railway tank cars in the Southwest, thus pushing the price per car up from a low of $800.

Judging from hours spent answering long distance telephone calls there are a large number of farmers in this country anxious to break free of the horse and buggy era of manure and waste disposal.

In suggesting that not only are methane power plants feasible, but a practical reality, I have trodden, quite unintentionally, on the toes of a large number of agricultural engineers and scientists whose profession it is to find answers to problems of manure and waste disposal. Some of these engineers stress the importance of cost accounting, and I agree that installing a methane power plant must be preceded by an evaluation of the cost in time and money. However, an accurate evaluation must also take into account the mounting costs of fuel that could be replaced by methane gas, the costs of shutdowns due to power shortages and failures, and the costs, for instance, of manufacturing ammonia for fertilizing, a process which requires some 33,000 cu. ft. (almost 1,000 cu. meters) of natural gas to produce just one ton of the material.

One of the root causes of inflation lies in the price squeeze involved with the production of food produced by energy and fertilizer — two products of a methane power plant, along with labor saving, that are vital necessities in farming. Further justification for the development of methane plants is the overwhelming desire for independence and self-sufficiency, whether urban or rural, local or national, or indeed worldwide. Decentralization of fuel and fertilizer sources, while instituting local supply centers would alleviate many shortages of fuel and reduce fertilizer costs sharply.

Ten years ago I was frustrated by the pessimism of agricultural engineers concerning methane power plants, and I was turned away without being able to expound my ideas and designs. Now, however, with the much-publicized energy, fertilizer and impending food shortages as propellants, the proper, positive atmosphere should exist for the direction of massive engineering skills to be directed to the development of methane power plants, not only in this country but throughout the world.

In large parts of the world people are starving. The feasibility of local power and fertilizer producing methane plants is real. My inner-tube methane plant is ideal for some areas of the world on a small scale, but none of my efforts have been successful in moving the idea off the shelf and into mass production for tropical countries.

The demand from farmers for details on the practical application of the theory of methane production has been overwhelming and worldwide. My hope is that this book will serve as a stepping stone toward universal application of this process which actually dates back to the beginning of time. I am not a cost accountant, nor an agricultural engineer, nor a biochemist, nor a civil engineer, nor a construction engineer. I am simply a farmer who overcame a problem in a different way. I cannot give precise costs of locally available construction materials around the world, but I can give the costs and returns I made on my own farm.

The capital cost of my South African methane power plant (in terms of U.S. dollars) was $10,000 and I produced over 8,000 cu. ft. of methane gas per day. This values at $7.57 worth of natural gas per day, or $16,578 (at 1974 prices in Santa Barbara) over the six years the plant was in operation. The gas' value as electricity was $7.43 per day, or $16,271 over six years. Most of the gas I produced was used as electricity, and some as gas. On top of that I enjoyed labor savings down from 8 man/days per week to 1 man/day, and I benefitted by 5 tons of nitrogen, 4½ tons of phosphates, and 1 ton of potash per year of highly effective, nutrient-rich, naturally produced fertilizing material in liquid form.

The amortization will be seen to have been about 3½ years on the fuel value alone, and this on a pilot project where costs are normally expected to be so great that the amortization is reached in 100 years, if ever.

Most of the $10,000 went to buy engines, motors, generators, and pumps. My records show a cost of 600 pounds sterling ($1,440) for the plant itself, not counting labor. At present prices (trebled between 1958 and 1974) the materials for the digesters and holders might cost 2,000 pounds ($4,800) and return $2,950 (or 57%) in fuel value alone per year. I did not attempt to maximize my returns on fuel, fertilizing material, or labor saving. It was enough to sit back and enjoy the excess of farm power, the lessened labor requirements, the almost total absence of flies and smells, and the independence from outside sources of energy. Also I found my effluent in great demand for playing fields, golf courses, etc., since it promoted growth in the spring, weeks ahead of other fertilizers.

In conclusion initial capital costs need only be the price of two coffee cans or a few old oil drums to test out the process and then graduate to whatever size unit is needed to meet your particular needs. Since it is easier to evaluate costs by using known easily available construction materials several usable designs are proposed.

In a world full of pessimism a new and exciting industry is proposed to those who have the vision and ability to work for the benefit of mankind.

CHAPTER 13

Gas and Gas Usage

The Gas

The raw gas produced by anaerobic digestion is variously called sewage gas, sludge gas, bio-gas, dungas, and in India Gobar gas (literally cow dung gas). It is also the "will-of-the-wisp" of folklore, rising naturally from marshes and bogs.

The will-of-the-wisp flames seen on marshes may be due not only to marsh gas which must be ignited to flare, but also to another gas called phosphine (H3P) produced during the decay of organic matter containing phosphorous. Phosphine has the odor of decaying fish. If sludge gas and phosphine combine in the air, the result is spontaneous combustion — a flame. This fact is not only of interest as a trick for magicians, but as a factor in safety precautions around a methane plant which must be kept clear of decaying animals. Incidentally, those will-of-the-wisp flames may explain some of the mysteries surrounding the leprechauns of Ireland.

As methane gas is generated in the fermentation process it rises to the surface, forcing up lumps of solids in a strong, welling-up volcanic action described previously. And as the gas accumulates it expands, creating pressure to escape. This can be seen clearly where anaerobic decomposition takes place in water: Bubbles rise to the surface. Some ingenious truck farmers of Portuguese ancestry in Africa were known to throw a cover over an active pond, sink the outside edges of the cover into the water as a seal, and to pipe off the gas, just as it came, to supplement the power source for their diesel engines used for irrigation. Considerable economies were claimed.

It is advisable not to let the gas build up more pressure than it takes to float a gas holder (6-in. [15 cm.] water gauge) since this might inhibit the fermentation through back pressure.

The raw gas is about 70% methane (CH4) and 29% carbon dioxide CO2) with insignificant traces of other gasses, noticeably hydrogen sulphide (H2S) which gives off a distinct musty odor similar to rotten eggs, a fact useful for detecting leaks. For every pound of volatile solids decomposed, 1.25 lbs. of weight of gas is generated. In practice this can be seen if a digester is not fed raw material for about a month. The level in the digester will fall and this is caused by a contraction of the solids content.

Comparing raw gas from a methane power plant we find that 1,000 cu. ft. of it is the equivalent of 600 cu. ft. of natural gas, 6.4 gals. of butane, 5.2 gals. of gasoline, or 4.6 gals. of diesel (all U.S. gals.) (ref. 30). Since the methane content can vary by 10% below and 4% above the 70% mark, the exact value of raw gas cannot be determined exactly in practice except by repeated sampling.

The weight of the raw gas is 6.81 lbs. per 100 cu. ft. (1.09 kg. per cu. meter) and the methane component has a specific gravity of .553 in relation to air. The carbon dioxide content has a specific gravity of 1.5. The mixture in the proportions of 70% to 30% therefore rises slowly when released to atmosphere.

An analysis of my South African plant's gas transported in an inner tube to the City of Johannesburg Gas Department showed the methane content to be 69.9%, the carbon dioxide content 27.4%, with traces of other gases, on the basis of temperature at 60°F (15°C) at sea level, with a BTU value of 711 per cu. ft. (6,320 K. cal. per cu. meter) but since my farm was at an altitude of 5,500 ft. (1,676 meters) the BTU was less — 585 BTU (5,190 K. cal. per cu. meter). The more methane there is, the higher the fuel value. The fuel value of the methane content above is about 963 BTU/cu. ft. (9,345 K. cal./cu. meter). Carbon dioxide is the other main component and is non-combustible. Other gases are in such small proportions as to be insignificant as a fuel.

A natural gas analysis typical of gas available across the U.S. (as given me by the Southern California Gas Company) shows the content to be 90.32% methane, 5.65% ethane, 0.92% CO2, 1.19% propane and traces of other gases. It will be seen that methane and ethane, both combustible, constitute almost 96% of the gas. It is piped dry (less than 1% moisture) and a typical heating value is 1,057 BTU per cubic foot (9,403 K. cal. per cu. meter).

Since the specific gravity of natural gas is so low at .617 to air at 1 it will rise swiftly if released to atmosphere. It is piped into the kitchen stove and other appliances at a moderately low pressure of about 8 in. water gauge (20 cm.) and burns with a blue flame when adjusted to mix with the correct proportion of air. A trace of aromatic gas is added by the gas supplier to serve as a warning of leaks and prevent unnoticed leaks which could form explosive mixtures with air. It should be remembered that natural gas originated from the same source of decaying organic matter trapped in earth formations perhaps billions of years ago and is exhaustible. Sludge gas generation, however, is inexhaustible.

Gas Uses

A clear distinction should be made between a) the sludge gas as it issues from the digester in a raw state, and b) the gas as scrubbed of impurities and after removal of water, intended for specialized uses, and generally referred to here as methane gas.

Sludge gas can be used in a variety of ways. It is not toxic like the turn-of-the century coal gas, but it is asphyxiating, meaning that when breathing only that gas a person would soon lose consciousness and die. When gas is mixed in the proportions of 1 in 4 to 1 in 14 with air, the mixture explodes if ignited and therefore can be used as a fuel in internal combustion engines.

Raw sludge gas does not burn in the same way as natural gas in a stove or other appliance, but it is possible to cook just as quickly and with as much control with this gas as with natural gas.

The flame of raw gas burning is a deep mauve with flecks of red, barely visible in sunlight but clearly seen in dimmer light and even in a TV studio. The one big difference of this gas is that it has a low flame speed. If a fast stream of gas with an audible hiss is ignited, the flame will lift off and away from the pipe or orifice and go out. The flow rate must be reduced so that the gas burns gently on contact with air. This can be achieved very simply in a number of ways described later.

Practical experiments were made at the Watson House laboratory in England with raw sludge gas and it was found that a gas burner should have flame port holes (where the gas actually burns) 300 times the area of a cross section of the jet. For instance they used a burner with 36 ports 0.114 in. (2.9 mm.) in diameter. They tried different diameters of jet and different pressures and found they obtained stable flames for ports of 0.038 in. (0.9652 mm.) to 0.041 in. (1.0414 mm.) and for gas pressures of one to eight inches water gauge (2.54 cm. to 20.32 cm.). However the heat output within these ranges varies from 3,360 to 11,000 BTU per sq. in. per hour (sq. in. of port area) or 132 K. cal. to 430 K. cal. per hour per sq. cm. of port area.

Most gas appliances can be made to burn raw gas by:

1) Enlarging the jet or even removing it altogether provided the gas flow is reduced to make a stable flame.

2) Adjusting the air intake, usually opening it slightly.

For lighting, raw gas can be fed into any gas lamp of the mantle type, but will not be as bright as propane for instance. Mr. Ram Bux Singh of India suggests an ingenious and simple method for improving the brightness by piping gas through a container holding gasoline at the bottom. The gas is not bubbled through the gasoline but is allowed to pass through, and blend with, the vapor which evaporates above the gasoline. The method has its dangers in that there must be no leaks in the container and of course no sparks or flames allowed anywhere near it. Designs for this method are commercially available in India.

Personally I would prefer to use a lamp with a large mantle specially designed for this gas and not use dangerous gasoline.

Whatever appliance is used it is important that an adequate volume of air is made available to burn with the gas. This need not necessarily be pre-mixed. The gas will burn on contact with air, but what is important is that air should not be restricted in any way. If it burns freely in air, the burnt gas will contain only CO2 and slight moisture. If gas is made to burn with an excess of air the burnt gas may contain SO2, making the eyes smart and causing a sharp acrid smell.

I used the raw gas for years in our kitchen in South Africa and the pots and pans remained spotless. I did experience two relative failures, however. One involved a gas iron in which a flame burnt to bring about heat. The flow of air into the appliance was excessive for the amount of gas, resulting in a foul odor. The other had to do with a refrigerator of the absorption type which was fuelled on raw gas for about three years with a special burner. The problem here was the pilot light. The flame was small and delicate. A draft would blow it out and worse yet, if the kitchen door slammed the concussion blew out the flame.

Another small point to mention when using this gas in a kitchen is that the match should be alight before turning the gas on. A waft of raw gas can drift and become objectionable to some. I tried the gas once in an anthracite type stove. It was piped through a half-inch pipe (about 1¼ cm.) to the point where the anthracite normally burned. This caused a ball of flame about one foot in diameter (30 cm.). Consumption was not measured but it was considerable. The stove and internal boiler functioned as well as on anthracite, however.

A very simple burner for raw sludge can be made out of a short length of pipe. Doubling the diameter of a pipe increases its capacity four times and also decreases the speed of flow to a quarter. For instance if gas flows from a one-inch (2½ cm.) pipe into a two-inch pipe (5 cm.) the gas can be made to burn at a low flame speed at the other end.

Engines

Any internal combustion engine (except a two-stroke) can be fuelled by raw gas. Also, certain gas turbine engines can be powered when sufficient gas is available. Many people have asked me, since Harold Bate can run his car on raw gas from chicken manure why can't I? The answer is that anyone can run a car on the raw gas or scrubbed gas compressed in a tank and then reduced by a regulator to provide a flow to the engine through a jet set in the carburettor. It is perfectly possible to switch from gasoline to gas. But it is not efficient.

Car engines are designed for gasoline and thus have a compression ratio limited by the octane rating of the intended fuel and are designed around this ratio of between 6 to 1 and 9 to 1. If low octane fuel is used in a car designed for high octane fuel the engine will ping audibly. This indicates that the fuel is igniting too soon on the compression stroke and before the spark plug ignites the mixture. Octane ratings are typically from a low of 92 to a high of 100 and sometimes higher. It is a law of combustion that the more a fuel and air mixture is compressed before ignition the greater the detonation on ignition.

The principle of a diesel engine is that air is compressed to about 15 to 1 and ignited with a fine spray of diesel fuel under high pressure which detonates on contact with the compressed air since diesel fuel has a low enough flash point to detonate at this pressure. That is why a diesel engine gives more miles per gallon than a gasoline engine.

Since raw sludge gas has an octane rating of about 120 it can be compressed together with about 90% air to a ratio of at least 15 to 1 without detonating spontaneously. This relatively high ratio allows greater value in the use of this gas (thermal efficiency) than in an engine designed for gasoline at a ratio of 8 to 1.

As stated in the New York Manual for Sewage Treatment Plant Operators (ref. 28), "Gas engines of the heavy duty type with dual fuel require approximately 6,500 BTU (1,632 K. cal.) including that of the oil per brake horse power per hour as compared with 9,500 BTU (2,375 K. cal.) for the spark ignition type, equivalent to 10 and 15 ft. (.283 and .424 cu. m.) of sludge gas per BHP hour respectively."

In terms of engine performance or miles per gallon or kilometers per liter, the gas will give you 50% more mileage in a diesel type engine than in one run on gasoline. I have read of an experimental engine with a 23 to 1 compression being fueled by raw gas and air without predetonation, thus raising the thermal efficiency higher still. Construction of such an engine poses problems of heavier components.

From the practical aspect, this gas offers some interesting prospects:

1) Replacing gasoline as a fuel, though at a relatively low efficiency. To equip an average sedan with the equivalent of an 18-gallon (U.S.) gasoline tank, it is estimated that 20 high-pressure steel cylinders weighing 90 lbs. each (total of 1,800 lbs.) would be required, as compared to 150 lbs. for a gasoline tank. Apart from weight, the space for 20 cylinders would require enlargement of the car, and further lower mileage. It would seem that the gas guzzler is not an economical proposition for methane gas as fuel. However, the magazine Mother Earth News has developed a small car intended for short range driving to be powered by electricity or methane gas.

2) Replacing up to 98% of the fuel in a 500 HP or up, diesel-type engine when operating near full load at a higher efficiency than in 1.

3) Replacing up to 80% of the fuel in diesel engines of small size up to about 50 BHP. Greater economies can be achieved but there is a risk of blockage in the diesel injector nozzles caused by "dribble" since only a small quantity of diesel fuel is required to ignite the gas and air mixture to cause detonation.

4) Operating on gas only in a high compression engine (a true gas engine) with spark ignition.

5) Operating gas turbine engines (at large methane power plants) with even greater efficiency. They are more compact and have a lifespan of 15 to 25 years which is as long or longer than most reciprocating engines.

Many have asked me if my 13 BHP Crossley, slow-speed engine showed any corrosion due to the hydrogen sulphide content of the raw gas. Engine wear was only very slight after six years of continuous operation. The fact that combustion took place at high pressure and at a relatively high temperature could account for the hydrogen sulphide being combusted along with the methane and remaining in the cylinder for so short a period of time as not to corrode. However, the exhaust gas was comparatively hot at 1,000°F (535°C) and caused "pitting" of the exhaust valve requiring maintenance a little more frequently than one would expect with a diesel engine. When I bought the engine (at a scrap yard) the diesel fuel pump and injector were missing. When the engine was loaded onto my truck the seller informed me that the cost of these items to provide the fuel to it would be prohibitive. I told him that I wanted to install a spark plug and a magneto and fuel it with gas from animal manure. The look on his face showed deep sympathy. I saw him shake his head as I drove off. A few years later he wrote me a congratulatory note.

This is how the engine was converted:

1) A magneto from a six-cylinder bus was bought at a scrapyard. Five of the six cams were ground off so that only one spark was given off per revolution. The magneto was linked to the engine crankshaft by a simple bicycle chain around a sprocket welded to the magneto and another to a pulley on the drive shaft.

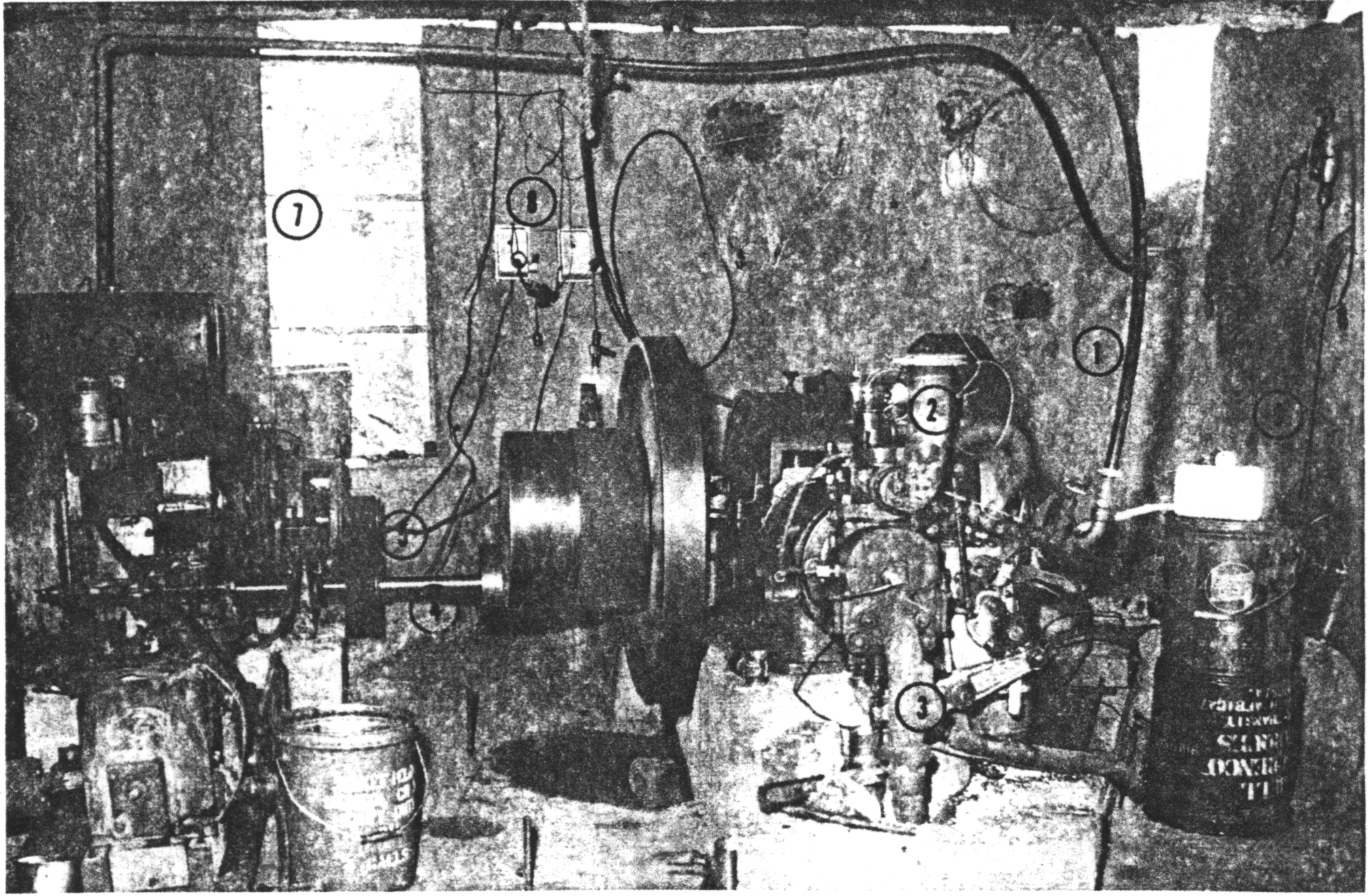


Figure 34: The engine room. 1) *Gas pipe.* 2) *Air intake.* 3) *Exhaust leading to digester at rear.* 4) *Two-inch shaft.* 5) *Alternator/generator.* 6) *Starting engine.* 7) *Gas holder (once struck by lightning).* 8) *Main switch boxes.* 9) *Water cooling pipes.*

(In the six years about eight bicycle chains were worn out.)

2) The spark plug could be screwed in either at the top of the combustion chamber directly opposite the piston, or at one side. It was found that the side position ran best. The plug gap had to be set at 8 thousandths of an inch (.2 mm.) for the spark to leap under the high compression of 15 to 1. When it burned to 16 thousandths (.4 mm.) after about 15 days continuous operation the spark would not occur and the engine stopped. A routine was developed to reset the gap at two-week intervals, regularly.

3) Gas was piped in a one-inch (2.54 cm.) black plastic pipe through a gate valve to a "butterfly" taken from the base of a Ford carburettor. The gas then mixed with air at the air intake. Intimate mixing of gas and air took place in bends in the manifold before the gas/air mixture entered the combustion chamber itself. The butterfly-operating lever was connected to the engine's speed-regulating governor.

Engine speed was 475 revolutions per minute. The engine was run with the conversion as above but was found to increase and decrease speed — or to "hunt", as it is called. To prevent this a shock absorber of lever movement (Armstrong type) from a small English car was installed. It was bolted to a plate on the engine and the lever to the governor control point. The engine ran perfectly smoothly and if a sudden extra load was imposed on it, the speed pick-up took a fraction of a second. Electric lights would dip momentarily. The engine drove a 2-in. (5 cm.) shaft which ran the entire width of the engine room and right outside (through a hole in the wall) where a flywheel was mounted to keep the revolutions steady. From this shaft a combined alternator (6 AC kw.) and generator (6 DC kw.) was driven. The DC was used to drive a water pump for irrigation 200 yards away. When in use the AC load had to be reduced to prevent overloading the engine.

Belts could be shifted so that the shaft could drive a water pump directly. A deep well pump was also kept permanently in action pumping water. The small pump for circulating water through the engine and digester was driven directly from a pulley on the engine.

The importance of the detailed description of the machinery run from the engine is that a schedule had to be adhered to so as to spread the power available over a series of different forms of work in succession. Although there are numerous advantages to this almost free power, it is also impossible to draw on that power as from electric power lines to drive a number of motors all at once.

I was once asked to estimate the electric power that could be available from a chicken farm's droppings and concluded that 30 kw. would be available continuously.The farmer scorned so low a figure and said his workers were used to a routine in which a number of motors totalling 85 kw. were run at once for three hours of the day, and that 10 kw. units were used continuously for fans, etc. He was not prepared to change the routine. His mind then turned to the fuel crisis and he had the temerity to ask what he would do if his electricity supply were cut off, something that would be a disaster for his business.

Uses for the gas in the "third" world are legion. It has been said that, "The lack of energy sources lies at the root of poverty." A man in the Peace Corps told me recently that a special study he made in Africa showed that 35% of the available work day of the local people was spent collecting twigs and brushwood for cooking purposes. Manure pats are burned as fuel and the fertilizing nutrients go up in smoke (the leading cause of an eye disease) in parts of the world that are already so denuded that they can barely support any plant growth.

As the old saying has it "Give a man a fish and you feed him one meal. Teach him to fish and you feed him for a lifetime." Sludge gas could supply fuel and fertilizer locally to hundreds of millions of people around the world in real need of those lifesaving commodities.

The enormous versatility of this gas even in the raw state in which it issues from a digester could make it the fuel of the future — from a burner made of a piece of pipe for cooking purposes to huge gas turbines producing thousands of horsepower.

Gas Scrubbers

Since the gas' average composition is 70% methane, 29% carbon dioxide, plus small traces of other gases, most notably hydrogen sulphide, it may prove economical or even profitable to remove the carbon dioxide for diffusion, for example, in a greenhouse. As an alternative to the expense and technology required to scrub the gas of CO2, H2S and moisture, the gas could be burnt to create steam to drive a steam engine, for instance. Efficiency would be high and waste heat could be returned to the digester. Alternatively some live steam could be used directly to the raw materials to help form the slurry and provide the necessary heat at the same time.

The traces of hydrogen sulphide can also be filtered out by a sponge of saw dust mixed with ferrous oxide or iron filings from a machine shop, for instance, but when the filter is saturated with hydrogen sulphide care must be taken when opening the lid since this gas in explosive and iron sulphides are known to heat even to the point of burning when concentrated and then exposed to oxygen in the air. Hydrogen sulphide is corrosive to iron or steel only when damp. If the carbon dioxide is first removed and the remaining methane and traces of hydrogen sulphide then dried either by heating and cooling (to condense the moisture) and/or passing it through calcium chloride, the gas with a BTU value close to 1,000 (8,900 K. cal./cu. m.) would be in a better condition for bottling with the use of a compressor than raw gas and still retain the smell to assist in detecting leaks.

Another method of scrubbing the gas is with the use of molecular sieves such as zeolites. First, the gas is dried by heating and condensation while cooling. Then as the raw gas passes through small grains of zeolites, the carbon dioxide and hydrogen sulphide are sponged out. The zeolites are then subjected to a slight vacuum and the two gases are released to atmosphere. The cost and maintenance of such large-scale equipment would not be economically feasible on an operation producing anything less than one million cubic feet per day.

The calorific value per pound (or K. cal. per kg.) is higher than gasoline to the extent of 23,000 BTU/lb. compared to 18,000 to 19,000 BTU/lb. for gasoline. Note that this superior value is in terms of weight only, but since methane requires heavy bottles for high pressure storage this value is of little practical value. Sludge gas whether scrubbed or not, is weak in relation to the large amount of space it occupies at normal atmospheric pressure.

Three or more stage compressors are available (at a price) to operate at levels of 100 to 150 p.s.i. (7 to 10 kg. sq. cm.), 400 to 700 p.s.i. (28 to 49 kg. sq. cm.) and in four-stage compressors up to 5,000 p.s.i. (350 kg. sq. cm.) at which point methane liquefies. Another method of liquifying it is to reduce the temperature to —161.7°C. If this low temperature is not maintained the gas will "boil", i.e., return to a vapor state.

Methane is transported in insulated ships in liquid form by cooling. Whatever portion of the gas vaporises is used to fuel the ship's engines. For large scale compression it has been found that the most economical method is to cool and compress simultaneously.

At methane power plants, where a considerable quantity of gas is found surplus to the requirements of stationary farm equipment, the gas can be compressed into cylinders for use in mobile vehicles.

A cylinder or battery of cylinders can be located near the plant and gas can be compressed in a variety of ways. To suggest only two:

1) With a three- or four-stage compressor.

2) With a compressor to raise the pressure to about 900 p.s.i. (63 kg. per sq. cm.) and then by a ram pump to up to 5,000 p.s.i. (315 kg. per sq. cm.) for storage in high pressure cylinders.

The mobile vehicle can be equipped with storage cylinders and a socket for reception of gas through a high-pressure hose. The cylinders can then be filled to around 3,000 p.s.i. (211 kg. per sq. cm.) in a few minutes from the main storage. The vehicle can be equipped with a series of regulators to reduce the pressure often to a negative pressure of 1 or 2 in. (2.2 to 5 cm.) water gauge. The gas can then be led to the throat of a venturi in the carburettor. As air passes through the venturi it draws gas. The greater the air intake the more gas is drawn in proportion, thus self-regulating the ratio of air to gas in a diesel engine. In a gasoline engine a method of switching from one fuel to the other would be required since it would be technically difficult to mix the fuels in the right ratios for good performance on varying loads.

For farm vehicles with a relatively short range of operation and with frequent refuelling, the economics of the cost of compression equipment might be found profitable.

It is possible and even probable that subsidies will be made available for this since the benefits of generating fuel oneself could have far reaching effects on fuel imports. In theory methane gas converted from easily available organic wastes could supply 150% of the gasoline energy used by all U.S. farm equipment (1965), 7% of the 1970 natural gas energy, and 2% of the total 1970 U.S. energy demands (ref. 31).

Caution: Cylinders for compressing gas have to be inspected and tested regularly under strict legal requirements in nearly every country in the world. Metal fatigue and/or corrosion as well as age of the cylinders are taken into account. It is essential that cylinders be inspected by the proper regulatory agency before use.

The main practical reason for scrubbing out the carbon dioxide from sludge gas lies in the fact that if then dried, the gas would be almost identical to natural gas.

Within the total framework of anaerobic digestion, sludge gas is certainly a useful free dividend, but by no means is it the only benefit.

CHAPTER 14

Sludge and Sludge Uses

More than half the original raw solids loaded into a digester are converted to gas. The gas is saturated with water and therefore considerable moisture is removed with it. The solids, being a small proportion (12% to 14%) of the slurry, contract on digestion. Both losses together account for a bulk loss of about 20% from the raw slurry to the effluent stage. The remaining portions of the original raw solids, together with trace amounts of metallic salts indispensable to plant growth, including boron, calcium, copper, iron, magnesium, zinc sulphur, etc., fall to the floor of the digester as sludge, together with larger amounts of inorganic solids such as grit and sand. The coarse and fibrous solid particles unconverted to gas are not any more significant as plant nutrients than the liquid which saturates them. For instance, if you could separate the liquid from the solid particles in a press, the liquid would carry the soil nutrients and the remaining dry particles would only be useful as mulch.

Although varying with the raw materials used and the conditions of digestion, this liquid (together with the particles) contains many elements essential to plant life: nitrogen, phosphorous and potassium.

Nitrogen is considered especially important since it has a vital role in plant nutrition and growth. Digested sludge contains nitrogen mainly in the form of ammonium ($NH4$), whereas nitrogen in aerobic organic wastes (activated sludge, compost) is mostly in oxidized forms (nitrates, nitrites). Increasing evidence suggests that for many land and water plants ammonium may be more valuable as a nitrogen source than oxidized nitrogen. In the soil, ammonium is much less apt to leach away and more apt to become fixed to exchange particles (clay and humus). Likewise, important water algae appear to be able to utilize ammonium easier than nitrates (ref. 32).

Most of the information showing the poor fertilizer value of sludge has been based on municipal sewage sludge. This is a bad measure of the fertility value of the digested sludge in general as municipal treatment flushes away all the fertilizer-rich liquid effluent. In one case (ref. 33) digested sewage sludge was found to contain about half the amount of nitrogen in fresh sewage, whereas elsewhere (ref. 10) digested pig manure was found to be 1.4 times richer in nitrogen content than raw pig manure. Similar results have been found with digested chicken manure.

Sludge from a digester may be recycled in a wide variety of ways, both on land and in the water (pond cultures). The possibilities are plentiful and only brief descriptions of potentials can be given here.

Sludge Gardening and Farming

The application of digested sludge to crops serves a double purpose since it is both a soil conditioner and a fertilizer. The sludge humus, in the form of particles, besides furnishing plant foods, benefits the soil by increasing its water-holding capacity and improving its structure.

When spread to a depth of two inches (5 cm.) the liquid soaks down leaving a layer of solid particles on the surface. Sludge is usually black or dark in color due to the formation of hydrogen sulphide that has combined with the iron present to form ferrous sulphide (FeS). Considering that this takes place in any event from traces of iron in the raw material a little practical research might reveal that the addition of small amounts of iron at the time of loading raw slurry might eliminate traces of hydrogen sulphide, especially since the volcanic type action mixes the contents so thoroughly. Being dark, sludge absorbs heat. This may be of significance in parts of the world where crops can only be planted after snow has melted. Applications of sludge can hasten the melting.

The fresher the sludge is, the more it should be diluted with water before application. Alternatively, you could apply a 2-in. (5 cm.) layer, let it soak in and water heavily an hour later. The continued use of digested sludge in any one area tends to make soil acidic. If you intend to apply heavy repeated dressings it is advisable to add dolomite or limestone to the soil first and harrow it in thoroughly a few weeks before sludging.

If you add lime after sludging the ammonia will evaporate and cause a nitrogen loss, creating a powerful stench while doing so.

Unlike digested municipal sludge, sludge from farm wastes does not contain large amounts of heavy metals or salts so there is little danger of applying it too heavily over a period of time. However, you should pay attention to the structure of the soil. If it contains a lot of clay, the sludge will tend to accumulate and possibly present problems in the root areas of your plants. In general, keep close tabs on your sludge plots in the beginning until you become familiar with its behavior in your particular soil.

Sludge-Pond Cultures

As stated in Methane Digester for Fuel and Fertilizer (ref. 31) there are at least three general ways to integrate pond cultures with organic digesters: Hydroponic crops, sludge-algae-fish and sludge-algae-methane systems. All have their advantages depending on local needs and resources.

Sludge Hydroponics: Hydroponics is the process of growing plants directly in a nutrient solution rather than soil. The nutrients may consist of soluble salts, (i.e., chemical fertilizers) or liquid organic wastes like digested sludge and effluent. Plants grown hydroponically in sludge-enriched solutions can serve a variety of purposes for organic digester operations: 1) they can do away with the cost and energy of transporting liquid fertilizer to crop lands since they can be conveniently grown near digesters, 2) they tend to be more productive than conventional soil crops and thus can serve as convenient high-yield sources of fodder, compost, mulch or silage, and 3) they can serve as convenient high-yield sources of raw materials for the digester itself.

Information about the use of sludge to fertilize water plants comes from projects to treat waste water in run-off areas or "sewage lagoons" (ref. 38, 39). Some plants such as the water hyacinth (Ipomoea repens) and some cool season grasses such as rye, fescue and canary grass, have the ability to grow well in waste water and to take up great amounts of nutrients efficiently, thus helping to control polluted waters. These crops have the added advantage that they are easy to harvest for livestock feed, thus giving an efficient method of converting sludge nutrients into animal protein.

Usually the plants are grown in shallow ponds filled with a diluted sludge solution. The process consists of slowly adding sludge under a gravel bed lining the pond, and covered with a layer of fine sand. Over the sand, plants are sprouted in containers floating on the effluent that percolates up through the gravel and sand layers. After sprouting the grasses then root and anchor in the sand and gravel.

Sludge-Algae-Fish: The essence of the sludge-algae-fish or "aquaculture" system consists of placing sludge into ponds and stimulating the growth of algae. The algae are then used as feed for small invertebrates or fish growing in the pond. The idea is modelled after oriental aquaculture systems. During the last three years, under the direction of Bill McLarney, the New Alchemy Institute has established preliminary models for experimental fish cultures (ref. 40).

Sludge-Algae-Methane: In the sludge-algae-methane system green algae is grown in diluted sludge, then harvested, part dried and digested to produce methane for power and sludge for recycling. This procedure of transforming solar energy and sludge nutrients into the chemical energy of methane is potentially a very efficient and rapid biological process: 1) It is a closed nutritional system, and 2) the rate of turn-over is extremely high. Organic matter is decomposed relatively quickly by anaerobic bacteria in the pond while it is most rapidly made by green algae. The complete sludge-algae-methane system involves a series of processes. The principal features of the system are integration of the algae culture with the gas in such a way that nutrients and water are recycled from one process to the other. Most of the information concerning this system has been developed by researchers at Berkeley in a manner that has real potential for the homestead or small farm (ref. 41, 42-45). Space does not permit even a brief discussion of the considerations: 1) cultivated algae, 2) pond design and operation, 3) harvesting of algae, 4) digestion of algae, and 5) efficiency and yield. (See Drum Digesters for more information on algae.)

A sample of thick digested sludge (i.e., effluent drawn from an early part of a withdrawal) from my South African digester, tested in 1958, showed the following results:

	Moisture%	pH	Organic Matter %	Available Nitrogen %	Available Phosphates %	Available Potash. %
Liquid	90.6	7.8	8.7	.6	.5	.1
Dry	0.	7.8	92.6	6.4	5.3	1.1

The above figures give the analysis on a liquid basis, i.e. as taken from the bottle, and also on a dried basis when all moisture is extracted. On a dry basis this manure is well supplied with nitrogen, has a fair supply of available phosphates but is low in available potash.

It should be noted that I then thought thicker sludge (10% solids) would be richer in nutrients than the thinner supernatant that follows. Since, it has become apparent that when the solids content is lower the soil nutrients, volume for volume, are as great or greater in supernatant.

Dewatering has been suggested as a means of reducing weight for transportation. This would require the effluent (both sludge and supernatant) being exposed to air for a time and treated either by chemical coagulation (preceded by elutriation to reduce alkalinity), or thickening by flotation (stirring and centrifuging), or vacuum filtration, or by simply withdrawing effluent onto a walled-off enclosure over a sand filter which would allow the liquids to drain off. Such systems are used in sewage plants, a procedure followed in some cases by incineration of the dried out solids. Admittedly, transporting any unnecessary quantity of water, particularly over long distances, is a waste of time and money.

For a small-scale digester where withdrawals consist of only a few buckets, there is no problem. For medium-sized units (one ton of raw material per day) expensive dewatering systems would not be worth the expense. For large-scale units (5 to 50 tons per day) enough gas would be available to supplement diesel fuel in a tank truck for transportation to cut fuel costs by 80%.

Whatever the size of the unit, the best final disposal of sludge would seem to be to spread it locally through an irrigation furrow, if available, or in undiluted form with a tank truck. On my farm the tank truck was backed into a short excavation to prevent the entry of stormwater runoffs since the tanker had to be used in all weather conditions. The tanker was gravity filled through a 3-in. (7.5 cm.) pipe and driven to a predetermined point on the farm for sludging. Levers inside the truck opened a spreader which lay a swath two yards wide (2 meters) and about 50 yards (46 meters) long with a total of 625 U.S. gallons of effluent. Hence, 6¼ gals. of sludge per sq. yard (25 liters per sq. meter) were applied to the field. When water was available, this was applied soon after. More often, water was not available so that the sludge liquid simply soaked in, leaving a thin dark film on the earth surface. This contracted on drying, forming small flakes about two inches square, the edges of which curled upwards. The net effect was to prevent the sun from baking the earth.

Five days after an application of sludge on grass, the color changed to a darker, healthier green and growth into dense foliage was stimulated for months. Word of these results on grass spread and I was asked to supply enough (at about $25 per truckload) to cover a playing field in winter to promote growth in time for spring usage. That playing field was weeks ahead of the others, much to the pleasure of the owners.

The field lying immediately below the digester on my farm received heavy repeated applications of effluent over the years. Once, a rare and unusually heavy rain of two inches (about 5 cm.) had brought up the alfalfa, but I was surprised a few days later to see this field covered in white. On getting closer I found that edible mushrooms had sprung up in such profusion as to cover and hide the alfalfa! This was not the only occcasion when the combination of effluent and earth, together with water, had yielded mushrooms spontaneouly.

Another uncommon property of this effluent is to attract the flower fly (Eristalis Tenax) whose larvae thrive in highly polluted water. The larvae can be found in drains carrying raw slurry as well as effluent and are easily distinguished by "tails", almost as long as the bodies, through which they breathe, periscope style. Despite looking repulsive they are harmless either as larvae or in the fly stage when they resemble a bee in size but with swept-back wings. Entomologists consider them as beneficial insects since they prey on certain garden pests. One characteristic is endearing — they do not bite humans!

A person's first acquaintance with effluent is usually with a sense of repugnance. However, it should have a not-unpleasant tarry odor, or a certain musty tang similar to the gas which comes from it. But the black or dark appearance is certainly not reassuring. It looks as if it would kill any vegetation on which it was applied unless heavily diluted with water. This is not the case. It does not "scorch" plants as raw manure often does, and one relatively heavy application will often give the best results, followed by watering which also eliminates all smell.

Adequate research on digested animal manure effluent is sadly lacking. This is all the more significant since the potentials are so much greater than for human sewage. One possible application of special importance might be spreading on soil after strip mining operations. The effluent mixed with certain grass seeds might be sufficient to both protect and nourish the seeds through the early stages of growth, thus cutting down the time to restore the land.

The important general consideration is that once methane power plants are constructed the effluent will be available in quantity but not before. From then on ways and means will inevitably be found to make the best use of it, potentially at a good sales profit.

One avenue is as a nutrient for algae growing in shallow bodies of water. Collected and dewatered effluent could be made available as a high protein feed for animals and fowl. Alternatively the algae might be used as it is or mixed with certain waste vegetation as raw material to the digestive process, thus generating an endless chain of gas producing material.

Sales of inorganic fertilizers (particularly nitrogen) have accelerated in recent years resulting in a depletion of humus in the soil and therefore still heavier applications of inorganic materials (as opposed to the more soluble organic) and thus to an inevitable ecological imbalance. This lack of humus is causing serious concern.

The availability of a naturally processed fertilizing material (effluent) would offer the farming world a means to return to the classic use of the old style organic material in a new form, a choice made more attractive due to the recent price hikes of inorganic fertilizer.

Through the practices described in this book (the harnessing of methane bacteria) a golden opportunity presents itself to discover again the wonders of nature in order to provide food in a world faced with starvation, in a way that is ecologically feasible and acceptable.

I have found that farmers talk of the good results they have had from applicationn of raw manure both in dry and liquid form on their farmland. I had the opportunity to compare the results between the raw slurry and effluent. Fields of grass surrounding a dairy had received repeated applications of slurried raw cow manure spread with a manure gun. Scarcely any difference could be seen between treated and untreated portions of the land. The only discernible pattern was a series of complaints from neighbors downwind of where the flying spray of cow dung had splattered. On the other hand, digested effluent from hogs was sampled out to certain portions, left to promote the grass for a few weeks and then the cows let out to make a choice of which grass to eat. Within a short time they ate the grass down where the digested effluent had been applied, showing an obvious preference over the other grass.

	N (% dry wt.)	Reference
RAW SEWAGE	1.0-3.5	28
DIGESTED SLUDGE		
10 municipalities	1.8-3.1	34
12 Ohio municipalities	0.9-3.0	34
51 samples, 21 cities	1.8-2.3	35,36
General average	2.0	34
General average	1.0-4.0	28
ACTIVATED SLUDGE		
5 municipalities	4.3-6.4	34
General average	4.0-6.0	34
General average	4.0-7.0	28
DIGESTED MANURE SLUDGE		
Hog	6.1-9.1	10
Chicken	5.3-9.0	7
Cow	2.7-4.9	7
FINISHED COMPOST		
Municipal	.4-1.6	37
Garbage	.4-4.0	37
Garden	1.4-3.5	37

Table 4. Nitrogen Fertilizer Value of Various Sludges and Finished Compost

Since there are so many and varied advantages to digestion as opposed to any other form of treatment of animal and fowl droppings, research into the types of vegetation best suited to effluent application and production of algae is urgently needed, particularly in areas of frequency and rates of application in relation to growing conditions.

I have read a great deal about pathogens in sewage sludge. Conclusions were almost unanimous that pathogens are, in fact, destroyed. This may be explained, perhaps by the "blanket" action of the methane bacteria and/or by the lack of oxygen in a digester. I suspect that if pathogenic bacteria do indeed find their way through a digester, that is because of faulty design in the digester itself. In vertical digesters, the volcanic type action inside the digester at the point of maximum fermentation is not suitably controlled. It stands to reason that raw material loaded on a given day would be carried up and down by the volcanic movement and that some of the fresh slurry could be withdrawn the very next day when the effluent is removed to make way for a fresh loading. A displacement digester overcomes this problem.

CHAPTER 15

Safety Precautions

Following is a listing of safety measures that should be read with great care before any experimentation with methane power plants is begun:

1) Keep gas and air from mixing.

2) Check digester, gas holders and all gas lines for leakage at regular intervals.

3) Provide adequate ventilation around all gas lines.

4) Always maintain a positive pressure in all gas lines.

5) The engine room floor must be at or above ground level to avoid accumulation of heavier gases.

6) The engine room or gas-fired boiler room should also be vented at roof level to allow light gas to escape.

7) Flame traps should be provided near the point of combustion.

8) Means should be provided on metal digesters and gas holders to lead lightning away to the earth through conductors.

9) All vents from digesters and gas holders must be open to atmosphere.

10) All gas lines must be protected against slush ice and freezing up.

11) Take measures to protect methane power plants from vandalism and grass fires.

12) Compost heaps, piles of garbage or bodies of dead animals (rodents) should be kept at a safe distance should spontaneous combustion occur through phosphine gas generation.

13) Gas lines must drain to a condensation trap.

14) Do not smoke or light matches near a methane power plant.

15) A fire extinguisher should be available within easy reach.

Most of these safety precautions are self-explanatory, but some need elaboration:

1) Raw gas and air are explosive in ratios between 1 in 4 and 1 in 14 when ignited. Ignition may come from a broken light bulb in an ordinary extension cord or fixture, a sparking switch, sparks from shoe nails or tools, lighted matches, cigarettes or pipes, and even from flashlights. When a power plant is first started up, all air must be flushed from gas lines and holders. As an added precaution, a sample of pure gas can be drawn off (into an inner tube, for instance), removed at a safe distance and ignited as a test.

When a digester is scummed out or cleaned there will be a short period of time when the gas and air mix will be present in the dangerous proportions mentioned. It is obviously vital to safety to keep flames, naked lights, sparks of any sort, and even flashlights well away until the contents are well ventilated. This applies equally to containers into which effluent is poured.

4) A negative pressure (part vacuum) could draw air into the digester or gas holder, thus making an explosive mixture. A 6-in. (15 cm.) water gauge negative pressure on a gas holder will cause water to siphon down the gas pipe. If allowed to continue unchecked the holder will buckle and break.

7) The methane plant on my farm did not have flame traps since gas cannot burn or combust without air and there was no air in the lines of my plant at any time. It is advisable, nonetheless, to install and maintain flame traps.

8) Means of grounding (sometimes called earthing) the gas holders have been mentioned in the chapter on Gas Holders. It is prudent to ground metal digesters as well.

9) The automatic overflow pipe, inlet pipe and level indicator must all be open to atmosphere.

General Precautions

Extreme care must be taken with any appliance to flush out any air/gas mixture that might be present when the flame is extinguished, other than by turning off the gas, before igniting again. The ABC of it is Always Be Careful.

Despite the precautions listed above, situations will arise when the operator of a methane plant will have to trace down a problem of blockage or a leak to its source. Always bear in mind the danger of mixing gas and air. Smell is a poor guide. Soapy water is safe and easy to use in tracing leaks.

At any site, water, soap and clean towels should be readily available. It is advisable not to smoke in the vicinity of a methane plant, not only for the obvious reason of avoiding causing an explosiion, but also on grounds of hygiene because an operator's hands are nearly always contaminated to some extent. A shower room is also strongly advised around larger installations as anyone who has been "shot" (a word coined for the occasion) will quickly grasp.

As stated in the New York Manual of Instruction for Sewage Treatment Plant Operators (ref. 28):

"Sludge gas may contain a toxic concentration of hydrogen sulphide, can cause asphyxiation from lack of oxygen, is flammable and violently explosive when mixed with air.

"It may be odorless and not readily detected by smell. If it contains hydrogen sulphide it has the characteristic odor of rotten eggs sensed at concentrations of .001%. However, at higher concentrations the sense of smell will be dulled and brief exposure to concentrations as low as 0.1% may be fatal. Hydrogen sulphide in moisture laden gas is corrosive and damaging to metal. Where its concentration in the gas is more than 0.25 to 1% provisions are sometimes made to remove or scrub it out."

As emphasized above, hydrogen sulphide is a dangerous gas. It can indeed be scrubbed out by passing sludge gas through a scrubber. The reasons for repeating this fact in this chapter is because of the potential danger in cleaning out the gas from the scrubbing chamber or device when the time comes to regenerate the device for further scrubbing. This book does not even pretend to advise on this aspect of gas chemistry and the reader is strongly advised to seek competent advice and technology before scrubbing hydrogen sulphide.

I have summarized here the main dangers around methane plants, including the reference to phosphine gas mentioned by Abiet and Lesage in their book Gaz de Fumier (ref. 29), not commonly mentioned in sewage manuals. I sincerely hope that officialdom will not forbid construction of methane power plants, but rather cooperate by providing further knowledge to avoid possible dangers, according to their training and official capacity, remembering that as fossil fuels continue to be devoured, new fuels must fill the breach in pace with the times.

Methane is a lesser danger to life than many other fuels. However, in the creation and use of a new type invisible fuel, dangerous situations can arise unexpectedly and swiftly, such as when a gas pipe ruptures or is torn. Not all hazards can possibly be listed, and the object here is to offer as complete a summary as possible.

The procedures and precautions listed must be considered as an outline of steps to be observed. Any deviation could cause a risk of explosion and disaster.

On the other hand precaution can be exaggerated such as when automobiles first appeared on the roads, a man waving a red flag came first. Inevitably, and concomitant with the expected large numbers of methane power plants that will be constructed, there will be accidents. I cannot and will not accept responsibility for such accidents.

Remember the ABC's: Always Be Careful.

Since writing this chapter, in 1974, a means of storing gas in a plain steel tank has been suggested by a number of different people. The method came from some other source than anything I have written and is fundamentally unsound and dangerous.

This wrong notion assumes erroneously that dungas, biogas or marsh gas can fill a tank as water does, from the bottom up. A vent is left open at the top for air to escape. After an undetermined period of time the tank is assumed to be full of gas. No explanation is given as to how to withdraw the gas without mixing it with air. What, in fact, happens is that gas enters through an aperture near the bottom and rises slowly, mixing with air. Most gas escapes through the top vent. Since the vent is open there is no pressure. This notion is a classic case of how NOT to store gas. Both rules 1 and 4 given in this chapter are ignored:

1) Never mix air and gas.

4) Maintain enough positive gas pressure to prevent air entering the digester, piping and storage tanks.

Another potentially dangerous form of storage is in balloons. Large meterological balloons have been suggested. These could not be kept in the open air due to wind and sun. If kept in an enclosed room, should they leak or burst, gas and air would immediately make a highly explosive mixture. A pilot light nearby would be enough to EXPLODE it.

CHAPTER 16

Questions and Answers

Raw Materials

1) What quantities of organic raw material are necessary to produce definitive quantities of gas?

The methane digestive process can be accomplished on any scale from two coffee cans put together to more ambitious, sizable units. One pound will yield about 5 cu. ft. (1 kg. will yield about .3 cu. meters) and 100 tons will yield 1 million cu. ft. of 7,000 therms or 26,320 cu. meters.

2) Will the system produce higher quantities and qualities of gas if selected types of organic material are introduced, i.e., livestock wastes vs. household kitchen wastes?

Provided the carbon/nitrogen ratio is kept below 30 the gas will remain close to the 70% to 30% methane to carbon dioxide content. Certain raw materials that float cannot be used in a displacement digester.

3) Can a digester work with only human wastes and vegetable wastes?

Yes, if the C/N ratio is maintained. Local health authorities must be consulted before using human wastes.

4) Do all manures produce the same quantity and quality of gas?

Exact figures are not available. It would appear that well-fed hog and poultry droppings yield slightly more gas of a higher calorific value than the equivalent weight from an animal eeking out an existence on a poor diet.

5) What kind of figures do you have on the availability of organic material wastes in this country?

The Bureau of Mines Information Circular of 1972 (IC 8549) quotes the figure at two billion tons per year, qualified to 1.7 billion tons "manure", and later to 26 million tons of organic solids from manure. Agricultural crops and food wastes are given as 22.6 million tons organic solids available.

6) Can a methane system be adapted to a mobile home development?

See section on Human Wastes under Raw Materials. The same conditions apply.

7) Can seaweed be used in a digester?

Since it does not contain lignin, it could be used. The C/N ratio would have to be below 30 and seaweed has a low pH. Salt in the effluent might be a considerable problem.

8) Rabbit pellets are hard and slow to disintegrate. Would grinding and pulverizing in a shredder prior to mixing as slurry be advantageous?

Yes, as in the case also with many forms of vegetation.

9) Our hog manure is mixed with some fine ground corn cobs we use for bedding. Will this affect the production of gas?

The corn cob will have little effect on gas yields but would form a scum layer.

Gas Usage

1) Can the gas be introduced into an internal combustion engine without the prior processing of the gas, by scrubbing or purification?

Yes, without any apparent excessive corrosion since the high temperature or ignition combusts both the methane (CH_4) and the traces of hydrogen sulphide (H_2S). However, purification is preferable.

2) Can enough gas be stored through the summer to last most of the winter — like with a propane tank?

The cost of building large enough gas holders or of buying cylinders would probably not make the proposition worthwhile.

3) Can we use methane gas on our stove and hot water heaters with the same jets as we use for propane?

No. The jets would have to be enlarged or in some cases even removed.

4) Can a digester be fitted to a bus and the gas generated used as fuel?

The size of a digester in relation to the energy produced is far too great for the purpose. A small digester for cooking purposes might be feasible, however.

5) Can methane gas be used to run gasoline engines? Dual fuel engines?

Yes. This is discussed at length under Gas and Gas Usage.

6) I use 200 lbs. of propane per month to heat a house 625 sq. ft. How much methane do I need?

A digester of 80 cu. ft. would yield 80 cu. ft. of gas per day. The loading rate for such a digester would be 17 lbs. dry weight (50 to 75 lbs. damp weight without grit) per day.

7) What type diesel engine runs best on methane gas?

The higher the compression diesel engine the more efficient the gas conversion. Also, the larger the engine the less diesel fuel is required for ignition.

8) In converting a diesel to run on methane do I need to change the engine's compression ratio?

No.

9) Can methanol be produced from methane?

Yes. This is discussed in the Dec. 28, 1973, (Vol. 182, No. 4119) copy of Science magazine. Methanol is produced through partial oxidation with water.

10) Do you modify the injector system of a diesel engine to work on methane?

You do not need to. Most stationary diesel engines operate at a predetermined r.p.m. The load variable is governed by the fuel pump.

11) Can a digester be pressurized to say 10 lbs. per sq. in. and a ram pumping process used to pressurize a small amount to power farm vehicles?

Pressurizing the digester itself is not recommended for a number of reasons described elsewhere.

12) Wouldn't it be a simple thing to use the gas to direct feed "fuel cells" in generation of electric power?

It is feasible but only if the digester can be kept at working temperature by other means.

13) How do you safely store liquid methane at 1,100 p.s.i.?

Methane liquifies at 5,000 p.s.i. At 1,100 p.s.i. it can be stored in cylinders (duly tested by a competent authority).

14) Would hydrogen sulphide in flue gases of a house furnace eventually eat out the stack? Is hydrogen sulphide from cooking burner flames a health hazard? What is an effective way to remove hydrogen sulphide?

Burning raw gas produces little or no fumes. Removal of H2S can be accomplished but regenerating the container in which the scrubbing is done is a distinct hazard (see Safety Precautions).

Digester Design

1) Can a feeding system be built without plumbing, using gravity?

Yes, easily.

2) Can a digester be laid flat?

Yes, if it is a horizontal-type digester.

3) Can you provide plans for a 55-gal. drum digester?

See section on Drum Digester and use one drum instead of three.

4) Do you have any suggestions as to the best type of hog barn that can be used with methane gas plants?

Any hog farm equipped with channels slightly below the main floor area will usually encourage hogs to make droppings there. These can be simply swept down.

5) Can I use 250-gallon oil tanks for the digester?

Yes, if they can be modified with scum doors, other plumbing, and are suitable in the given ratio of width x depth to length.

6) I'm constructing a liquid manure setup for 100 head of dairy cows plus young stock. The soupy mixture is mixed with water in a sausage-type manure pump and is pumped through a 12-in. plastic pipe into an underground silo 12 ft. deep and 65 ft. in diameter, below frost line, for six-month storage, after which I would like to harvest methane. Any suggestions?

The condition of the liquid slurry when you pump it back after six months in a cold condition is unknown. If the pH is near 7 and you can warm daily loading to 95°F (35°C) you may be able to use it. Avoid loading the sand layer at the bottom.

Loading Rate

1) What kind of a process can lengthen the production of methane in a digester? Does the raw material used govern the quality and type of gas yielded?

Lowering the temperature will prolong anaerobic decomposition. If digestion proceeds at all the gas quality will be within narrow limits of 60% to 74% methane.

Scum Removal

1) What is the best way of cleaning out a digester?

For a complete clean-out, remove the scum as described then continue to pump until no more will flow out. Flush with water and repeat, using the sand probe to flush down the last of the sand for withdrawal with the water.

Bio-Succession

1) How can pH in a digester be raised?

Dilution and a great deal of patience should be the rule. The addition of lime does not result in generating the right conditions for digestion. Small amounts of ammonia are better, but too much is toxic to the bacteria.

2) I have been getting gas but it fails to ignite. What could be wrong?

A little patience is probably all that is needed.

Digester Operation

1) Can a methane plant be operated in very cold weather?

It depends on the efficiency of the insulation, heating system and temperature of the slurry loaded.

2) Is there an efficient way of returning heat to the digester itself?

There are a number of ways discussed under Digester Operation.

3) Would it be economically feasible to install a system that would only operate three months a year?

The capital costs would remain the same but it would take four times longer to amortize the venture.

Safety (See Chapter 15, Safety Precautions)

1) I am interested in the precautions required to keep the flame from "popping back" and causing an explosion in case of too lean a mix. Is there some sort of fine gauze (miner's lamp type accessory) needed in the line coming from the digester?

The principle of most flame traps is essentially a fine gauze filter. Also, the gas can be made to bubble through water so that if there is a backfire, the water stops it. The gas only burns on contact with air and not otherwise. It explodes when ignited within certain ratios with air.

2) What is the chance of accidentally igniting stored methane?

See 1) above. If a gas holder should get ruptured and the gas ignited it will burn on contact with air as it escapes, but raw or scrubbed gas cannot burn by itself without oxygen (from the air).

General

1) Do you have a rule of thumb for the amount of gas that can be produced per day?

A digester will produce its own volume per day: 200 cu. ft. capacity digester = 200 cu. ft. of gas per day, if kept near normal loading rate and temperature.

2) Can you provide a bibliography of gas technology?

See last section of this book.

3) Can one learn from a sewage plant? How?

Sewage plant operators are usually relatively lonely and only too ready to show interested persons over the different parts of the treatment procedure. Seek out the underlying principle of the digester.

4) Is odor a problem with a methane plant?

Only at the loading end depending on the time from collection to loading. Effluent spreading releases musty odors for a short time.

5) Can I funnel gas from a nearby lake and store it?

The Chinese use covered lagoons extensively but the gas production is seasonal.

6) How can I use methane gas from my septic tank?

By sealing and passing the gas to a holder if there is enough of it to warrant the expense.

7) Why aren't methane plants being used?

A number are now being built, but full-scale models are relatively rare. After the feasibility of large units is shown in practice, more will be built. Digesters on the batch principle have had a limited popularity in Europe since World War II. Ram Bux Singh's digesters are now being built in increasing numbers in India where the need is so great. Measures are being taken to accelerate both the knowledge and practical application of digestion. Briefly, the basics of methane plants are well known but the practical know-how for operating a plant for years on end has been lacking thus far.

CHAPTER 17

Digesters Today and Tomorrow

DRUM DIGESTER

Recorded here are suggestions and findings based on the actual experience in operation of three 2-drum units operated in Santa Barbara, California, between July 1973 and January 1974.

Suggested Construction

If the digester is intended for use on a small homestead, as opposed to experimental use, the minimum size recommended is three drums welded end to end. However, digesters can be made with one to four drums according to needs. More than four drums welded together would stretch the digester proportions of length to diameter too far to ensure proper seeding of incoming material. The bacteria would not be able to backtrack fast enough to the inlet end to effect the essential "seeding" with methane bacteria. Each drum would yield about 8 cu. ft. of gas daily at 95°F (35°C) with regular feeding of suitable manure. Thus a 3-drum digester would provide 24 cu. ft. of gas daily, enough to cook on with some left over for lighting and even heating. A 3- or 4-drum digester would provide optimal usage.

To maintain the required temperature of 95°F (35°C) the unit should be insulated to the maximum possible extent, preferably with sprayed-on styrofoam to a depth of at least two inches. Though insulation would keep heat losses to a minimum, some form of heating would have to be provided. This can be done in two ways: a) by heating the water (solar energy or gas) before mixing it with the daily loading of raw material, and/or by b) lighting a very small flame of gas beneath the digester itself in extremely cold weather. A small deposit of sand or grit lying on the floor of the digester would spread the heat evenly to the contents.

Either method would avoid the cumbersome, inefficient system of providing a boiler, circulating pump, and internal pipes which were used in the experimental digester to maintain an exact temperature for accurate comparisons of different manures and other raw materials.

In passing I should mention that during the latter stages of the experiment a method of testing manure and raw materials was tried whereby samples were soaked in water and pressed down with weights for up to 24 hours. If the material still floated, it was not used since it would also float in the digester, form a scum layer and eventually reduce the efficiency of the entire digester to zero. Grinding in a garbage disposer would turn it to a slurry but some materials still floated. Recommended is material that is colloidal in structure, finely ground, sticky and with a tendency to sink in water, i.e., have a higher specific gravity than water.

Only good drums without dents and bent rims should be selected. It is most important to choose drums which have not held paint thinners or any other petroleum products that could explode when welded. Finding good drums at the start might avoid considerable or even insurmountable problems later.

Construction Requirements

1) One of the drums should have a 2-in. outlet on the side positioned vertically. When in use this will serve as the gas outlet at the top of the drum.

2) The middle drum or drums should be oil drums with both ends cut out with a hack knife or chisel.

3) The last drum should have a removable lid (as with grease drums found around garages). This type of drum has a rounded lip and a removable lid. A clamp fits over the lip and lid rim to hold the lid firmly in position.

For the inlet pipe to the digester a 3-ft. length of 2-in. diameter lightweight pipe can be used. Being thin it is easier to weld to the thin metal of a drum than ordinary 2-in. pipe.

The first step in welding is to set the inlet pipe in position, weld securely, and seal the weld from inside with brazing, if possible, and/or asphalt roof coating material or asphalt emulsion making quite sure that no leaks are left. See fig. 35 for correct positioning of the inlet.

Before welding, cut out the tops and bottoms of the drums to make the digester into one long cylinder, with the inlet end closed and with the outlet end having

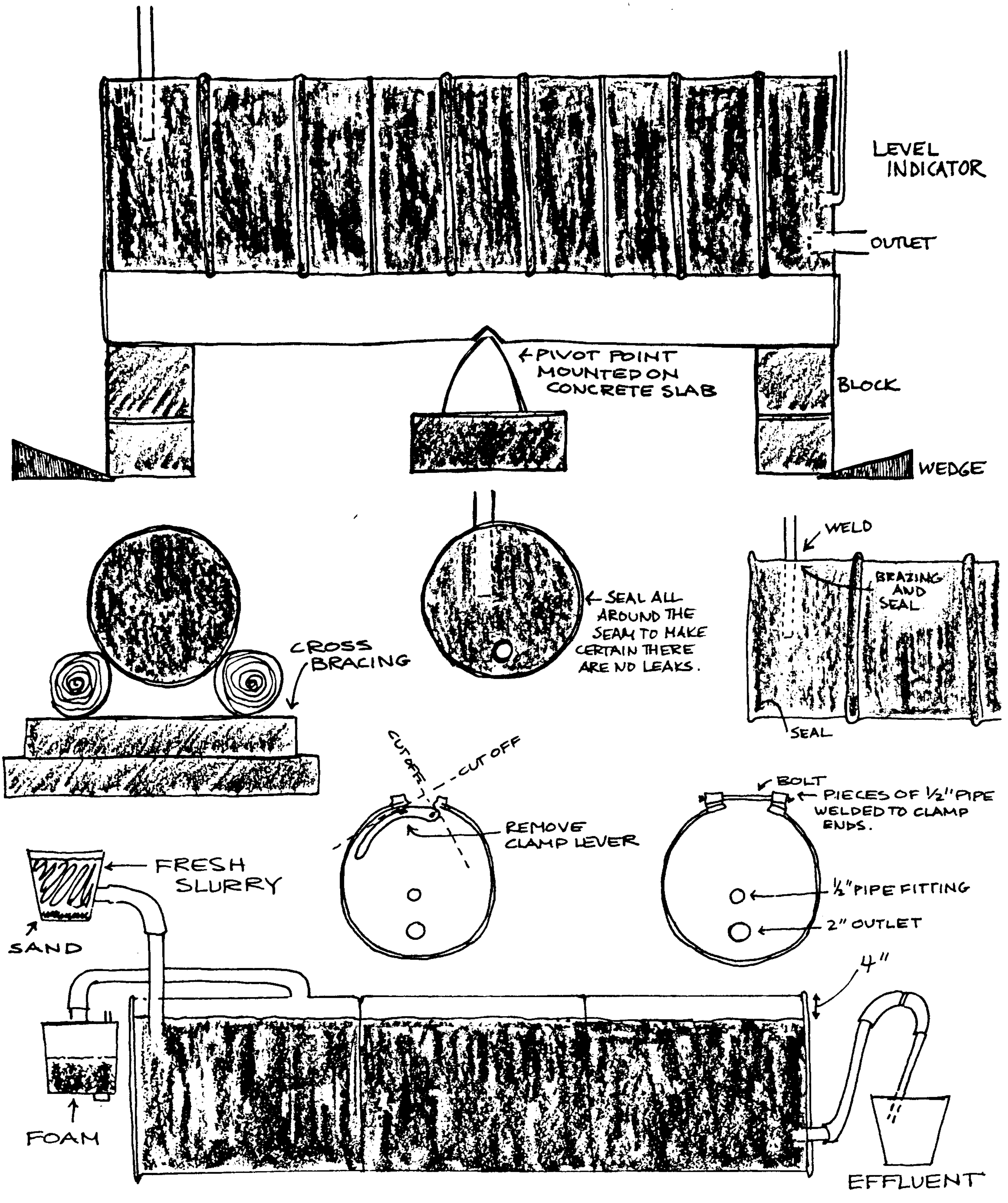


Figure 35: Drum digester loading and automatic effluent withdrawal.

the removable lid and clamp. The cuts should be made neatly since the welded portions will require painting to seal off any pin holes.

Fit one drum atop the next and adjust to as near perfect fit as possible. Use a hydraulic jack to stretch one or other drum if bent out of round. Spot weld at 0°, 180°, 90° and then start welding at 270° with a continuous overlapping weld around the entire circle, right on through the spot welds to prevent pin holes in the weld. When cold, paint the welds and all seams very thoroughly on the inside twice over to make certain there are no leaks. The seams on either side of the weld tend to move apart with the heat and must be painted particularly carefully. Cut a hole in the lid ⅓ of the distance up from the bottom and weld or braze a threaded half-inch water pipe fitting over the hole.

Cut off the device on the clamp by which the clamp can be operated manually. Replace the tightening device with 1-in. lengths of ½-in. pipe, one opposite the other on the outside of the clamp. When clamping in place, pass a long bolt (⅜ in. will do) through the ½-in. pipe and tighten. Before clamping, however, place self-adhesive foam plastic in the lid rim, place the lid in place and clamp over it. Tighten the bolt and hammer the lid lightly while tightening until the sound indicates a "solid" note and is firm.

The digester is now one long cylinder with the outlet end clamped off. The plastic foam seal is not enough to ensure that gas will not escape. The whole digester is then set up vertically and about a half gallon of asphalt emulsion plus about a cupfull of water (to make the emulsion flow easily) are mixed together and poured in from the top (inlet end). The drum is then turned around and around to allow the mixture to penetrate into all cracks and form a seal. After a few days to allow the asphalt to dry partially a gentle heat can be applied to the area to speed drying. When absolutely dry, the digester should be checked by filling it with water. Drain the water and apply the insulating material to the outside.

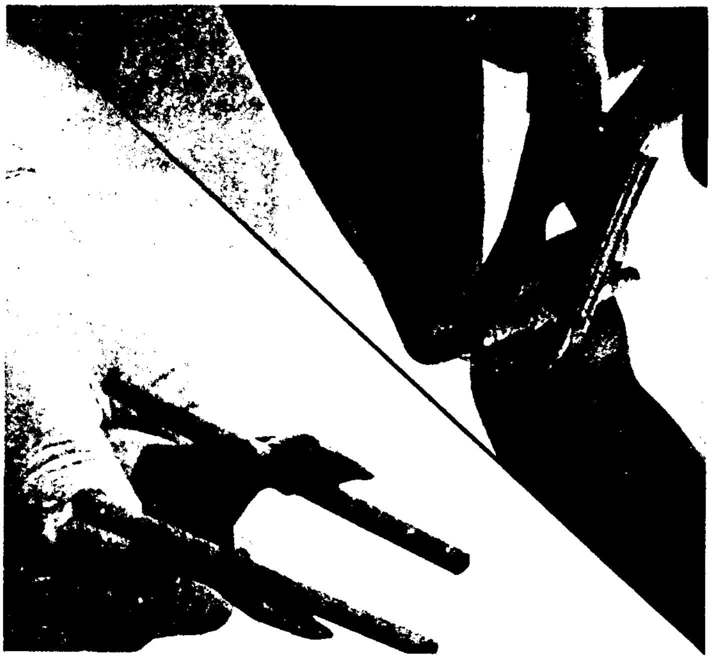


Figure 36: Clamp made with jumper lead clamp and short rods brazed on.

Operation

With the 3-drum digester installed as shown in fig. 35 a means of operating the digester is thus made possible without expensive gate valves. Jumper cable clamps with two short rods brazed to each jaw provide adequate pressure over folded motorcycle inner tubes for both loading and effluent removal. Effluent removal can be made automatic by using a U-shaped piece of pipe of about two inches as shown in fig. 35.

First the gas is shut off at the foam trap (with a jumper cable clamp on latex piping). As raw slurry enters, effluent discharges to a bucket through the U bend. Should the effluent not flow easily at first, fluid in the level indicator will rise until the flow begins, or is made to flow by squeezing the effluent pipe. As soon as loading is finished the gas pipe must be opened. A quick check of the level indicator completes the daily routine of loading.

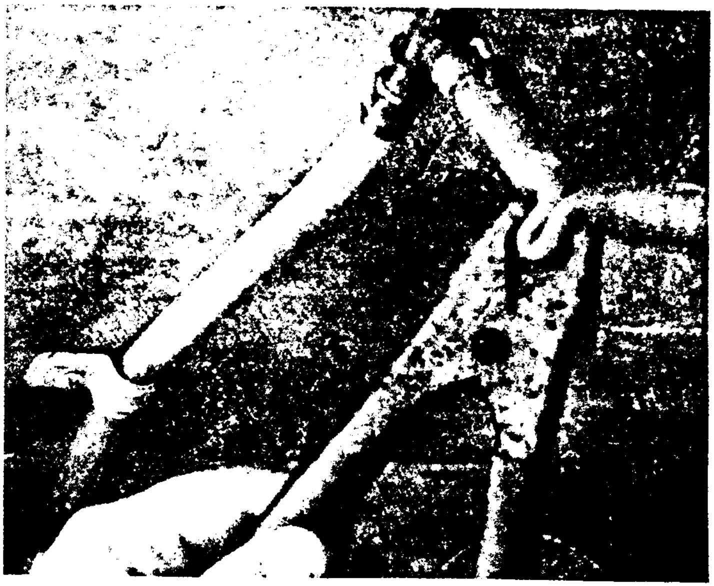


Figure 37: Clamp on latex gas pipe.

Starting up consists of seeding with as much effluent from another digester as can be obtained (see Digester Operation), plus the addition of some warm water and then the application of the 50% rule as regards quantity of raw slurry in starting up.

Loading for a 3-drum digester of 24 cu. ft. capacity would be .21 lbs./TS per day or 4.8 lbs. (2.2 kg.) dry weight per day. In practice this would amount to about 4 U.S. gallons (15 liters) of naturally damp manure to which urine and some water are added to make slurry. If the digester is 1, 2 or 4 drums in length the loading is proportional.

Scum Removal

A suggested method (not tried in practice) of breaking up the layer of scum through the agitation of the unit to mix in the scum layers would operate as follows:

1) Once the digester is assembled, welded, sealed and covered with insulating material, the entire unit could be mounted between two pieces of strong timber, sections of railway track, or other suitable material.

2) The digester would operate in the horizontal position until the scum layer becomes a problem. At this time the wedges and blocks would be removed and the entire unit rocked as in a see-saw, by pressing down one end and, simultaneously, lifting or levering the other end up. This could be repeated until the scum layer is given a thorough shaking by the sudden rush of liquid from one end to the other. It might be advisable to lower the level in the digester by one quarter to provide more movement.

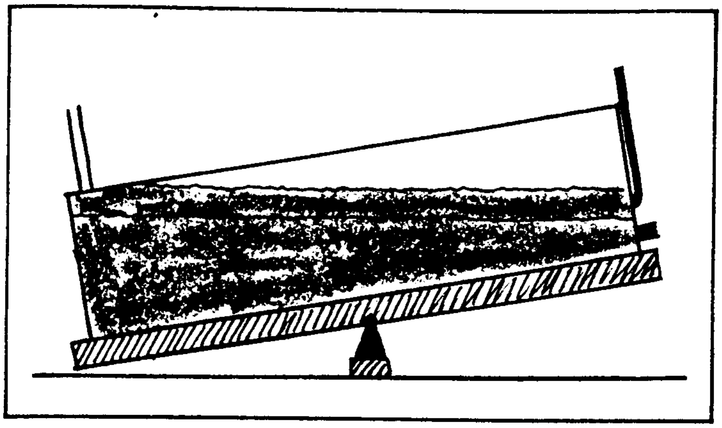


Figure 38: Suggested method of rocking to delay scum formation.

3) This procedure would not remove the scum layer but would extend the digester efficiency from a few months to perhaps over a year. Scum would be forced into the working layer of supernatant but would (and does in practice) reform in a different pattern. Alternatively to this suggested method of scum breaking, the liquid contents of the digester could be stored in drums outside the digester, preferably in mid-summer in order to preserve temperature; the outlet lid removed and the scum tipped out. After resealing, the digester would then be reseeded and put back into operation.

A scum drag could be fitted to such a small digester but the expense involved in doing this would not appear to be worthwhile.

Raw Materials

These observations were recorded on the raw materials fed to the two-drum digesters operated in Santa Barbara in 1973-1974:

1) Chicken manure was the sole raw material used in one digester. Since this has a high pH, I decided to dilute it with water and cactus of a variety called "red hot poker" (because of the shape and color of the flower which sprouts from the center) which has a low pH of 5.5 to 6. The cactus was ground in a kitchen type garbage disposer and mixed 30% with 70% chicken manure and loaded. Digestion continued unchanged except for a slight increase in gas yield.

2) Another two-drum digester loading hog manure produced 20 to 22 cu. ft. of gas per day steadily until the manure ran out. I needed another raw material to test. Then I remembered a factory processing abalones — a locally available shellfish. The guts were tossed away as waste. Why not ask if I could test some? Again, I went through the grinding and loading. This time the results were spectacular: The gas yield rose to 30 cu. ft. of gas per day, then to 40, and finally to 48 cu. ft. per day on the fourth day. Unfortunately on that day a surplus of guts were left over which had begun to turn putrid. The only means of quick disposal was to grind and load a double load. Gas production dropped back to less than 10 cu. ft. per day so this digester was left to recover without further loadings for a week. It did recover after the week's rest but held to a constant of about 15 cu. ft. of gas per day afterwards.

The situation could be logically explained as follows:

1) The hog manure had left a scum layer of material that floated (not true scum) since the manure had been collected dry and not slurried too conscientiously.

2) The entry of a high-nitrogen material (algae) had started a strong volcanic type surging, disrupting the false scum layer and bringing it into digestion.

3) The double load of abalone was fed in at a time when the digester was already working double time with abalone and hog dung, and the methane bacteria were overcome.

4) Later when abalone was loaded normal digestion continued. The significance of this account is twofold: a) to explain the rise and fall in gas production, and b) to point out that abalone guts consist mostly of algae that the shellfish gathers from the sea as food. The fact that algae decomposes anaerobically with a profuse gas yield confirms the reference to it in Sludge and Uses.

A sample of abalone effluent was tried on grass with the same excellent results as with other effluent.

DIGESTER IN MODULAR SECTIONS OF STEEL OR FIBERGLASS

Advantages

1) Ease of transportation (in sections). The half cylinder of the roof can be of thinner material than the bottom half which must withstand higher static pressure.

2) Flexibility in construction design. The roof half of the cylinder could be bolted down to a concrete lower half of walls and V floor.

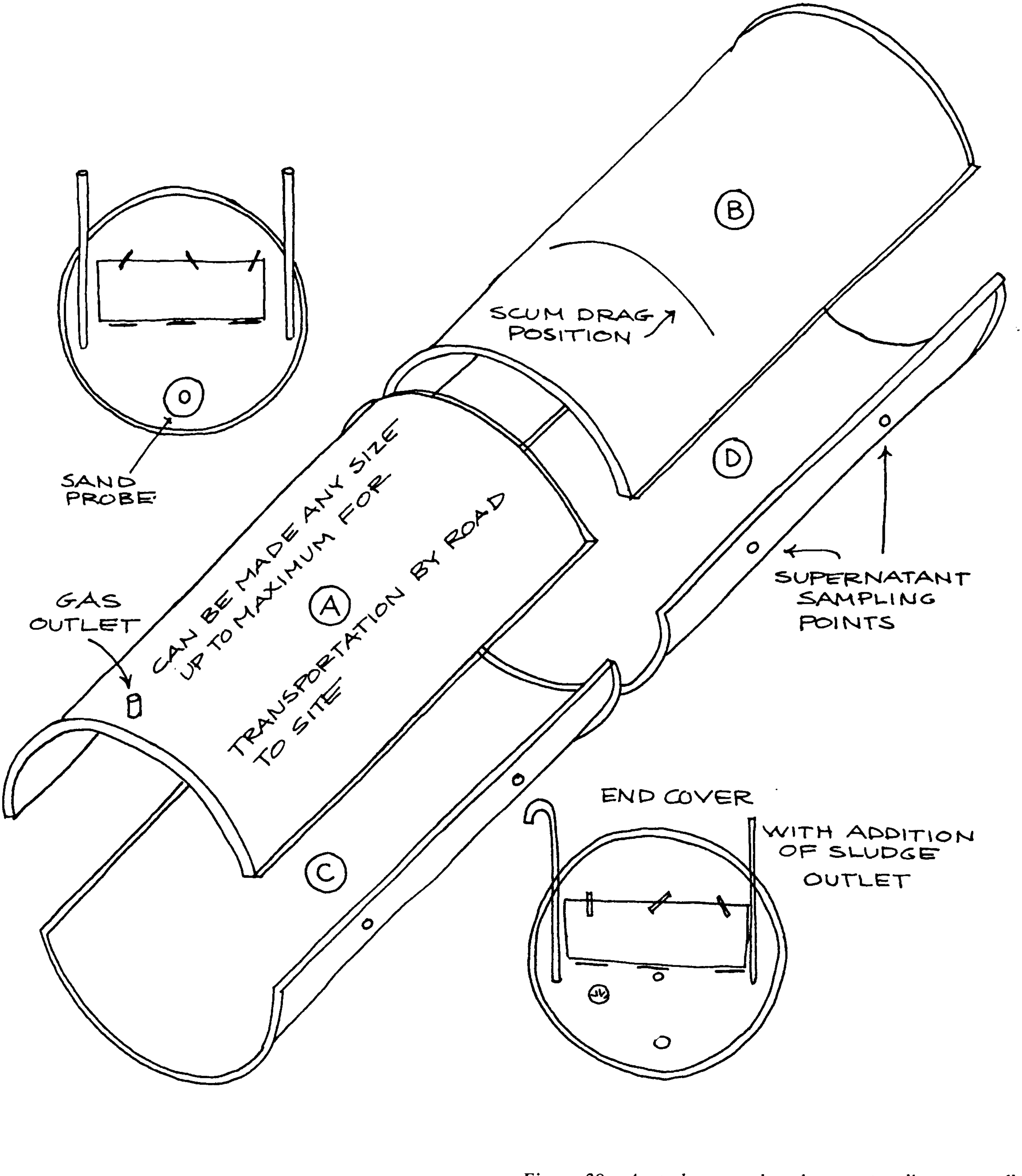
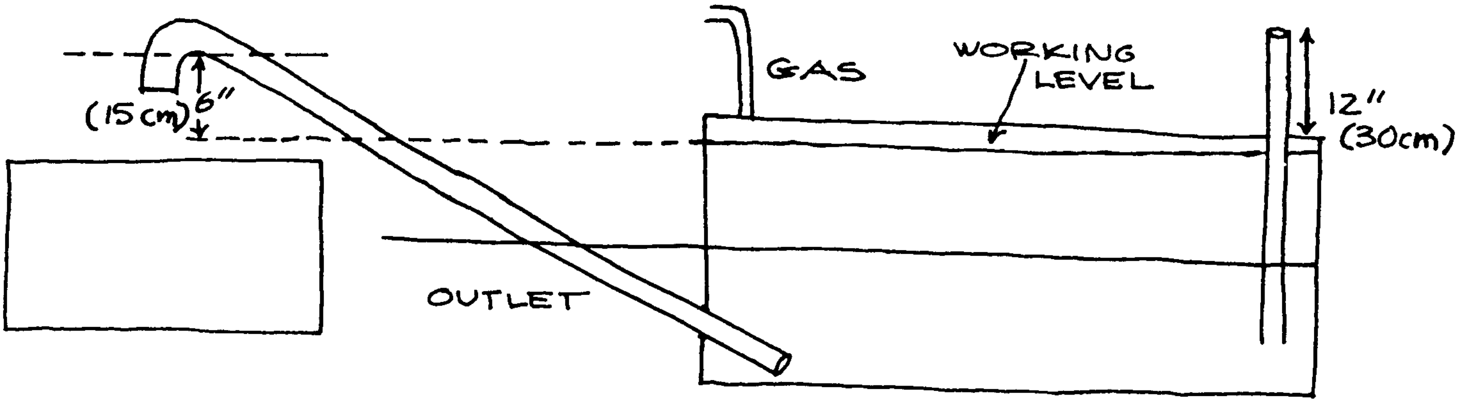
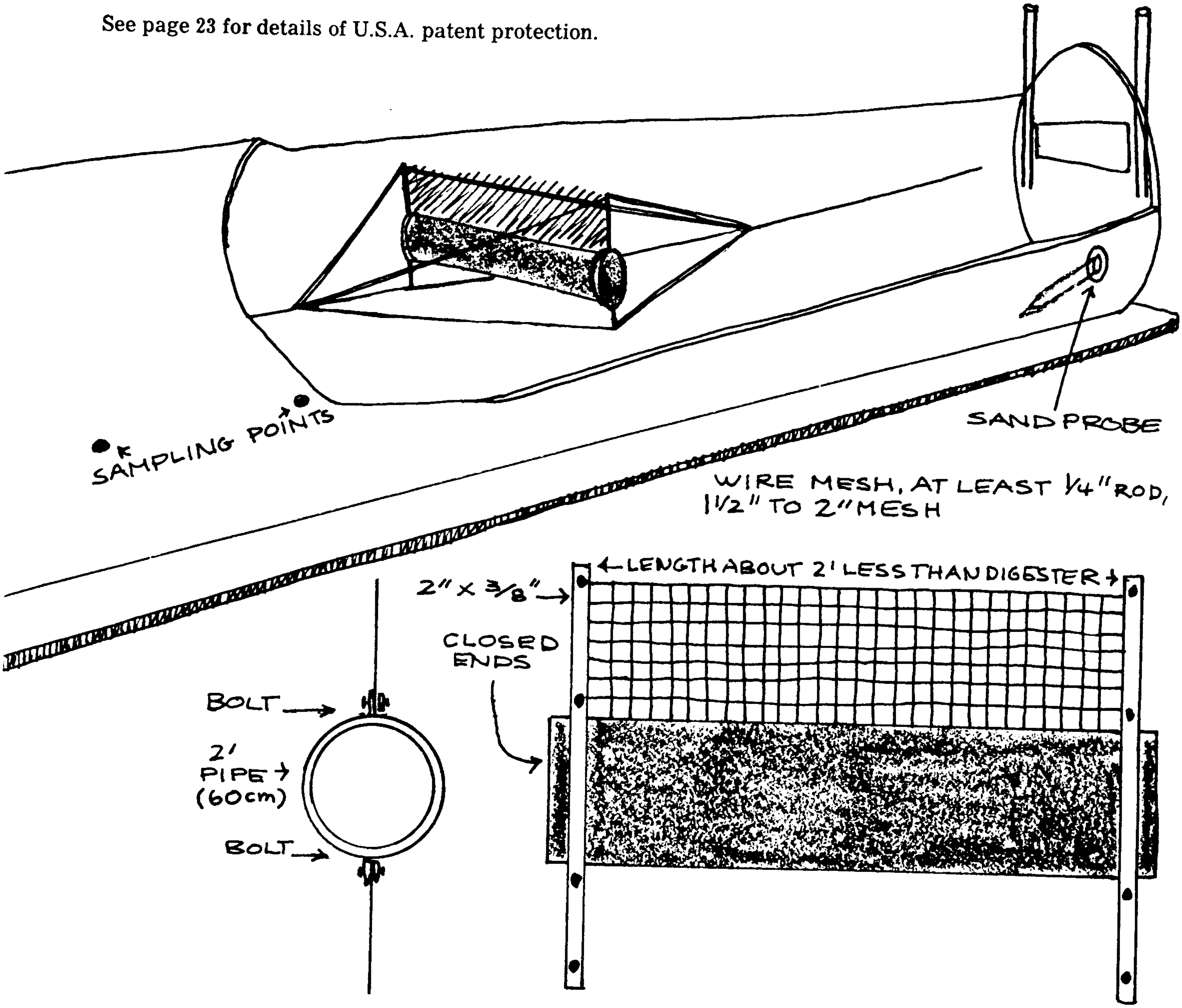


Figure 39: *A steel, or steel and concrete, digester small enough to be manufactured and transported to the site in modular sections.*



See page 23 for details of U.S.A. patent protection.



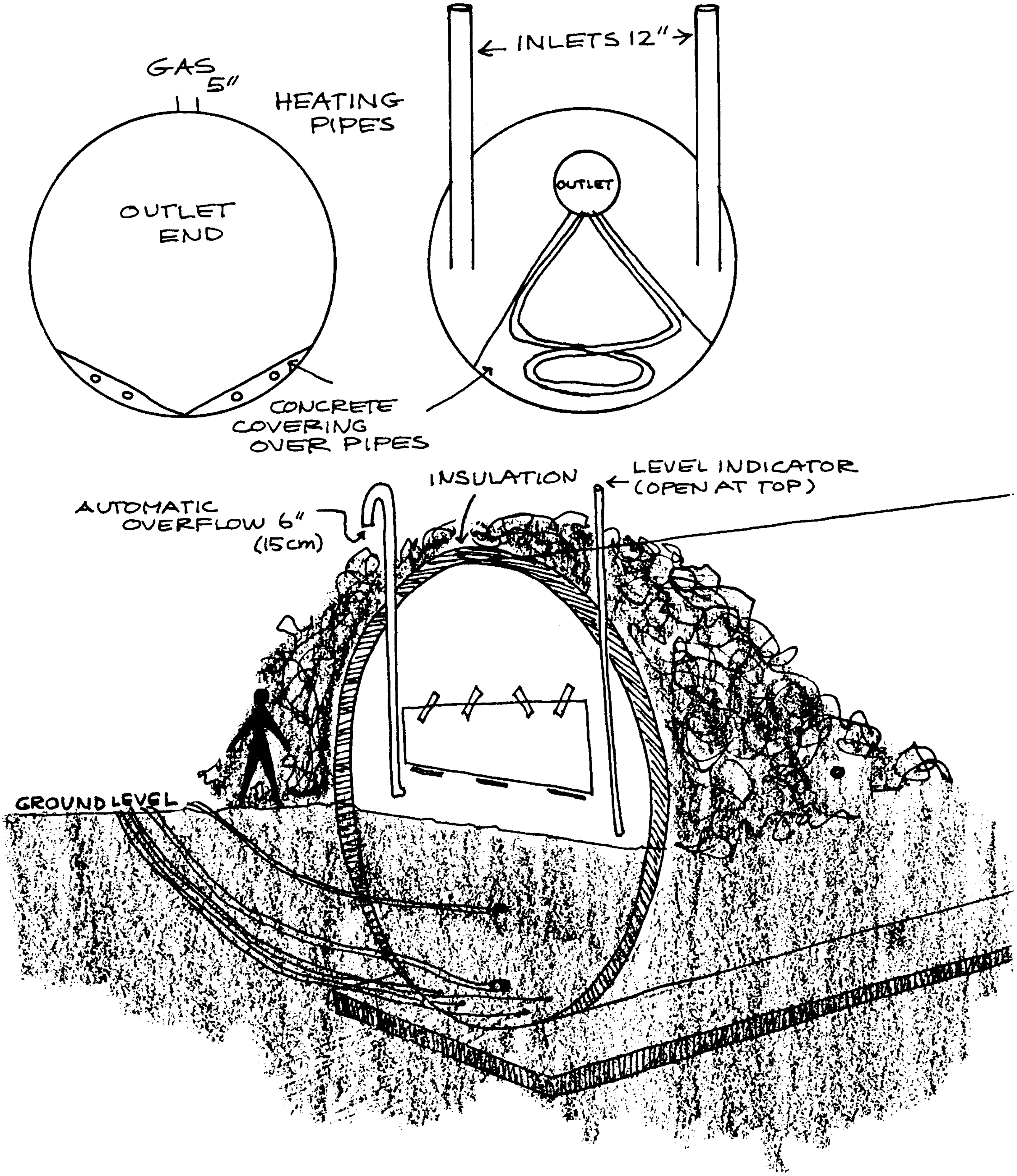


Figure 42: Steel digester 100 *ft. long,* 25 *ft. in diameter.*

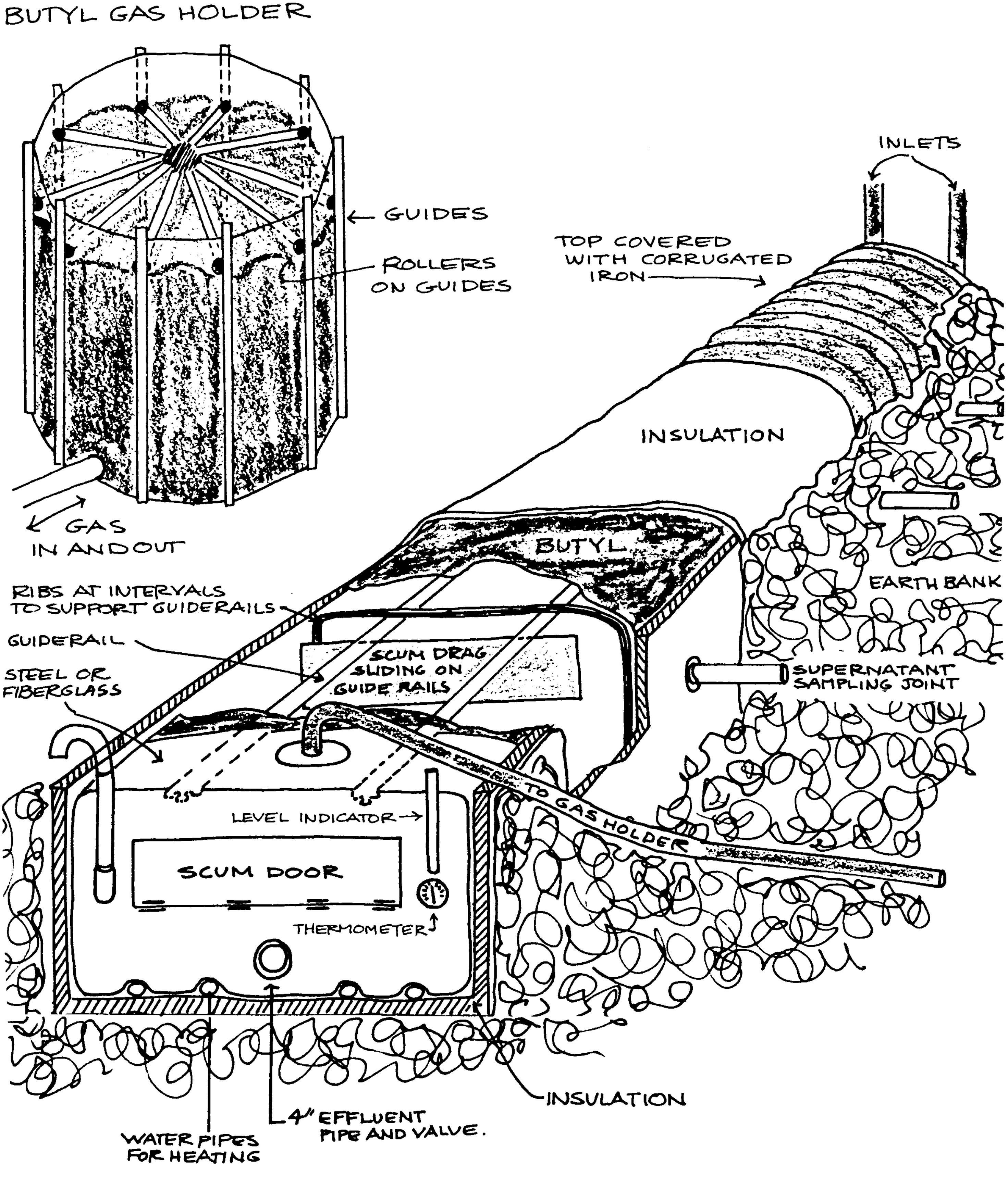


Figure 40: *Butyl or plastic digester and gas holder.*

3) Durable construction materials.

4) Can be buried or half buried with suitable insulation added.

Disadvantages

1) Relatively high cost of construction materials.

2) Necessity for a stable foundation for the digester to rest on, if in the form of a complete cylinder.

3) In a complete cylinder part of the space would be wasted by concrete used to cover the heating pipes with a thin layer so as to prevent movement, tearing and kinking.

BUTYL OR PLASTIC DIGESTER

A trench for the digester is dug out of the ground and lined with insulation of closed-cell material such as styrofoam since this would still insulate even when wet (as with a scuba diver's wet suit). Water heating pipes are then laid on or in the top face of the insulation. The floor can be flat or in a V.

The ends of the digester would carry most of the plumbing, except for the supernatant sampling points along the side of the digester. The ends would be of rigid material (steel or fiberglass) with provision for anchoring rails to run the full length of the digester, joining the ends at the top. The rails would be held in position by ribs set at right angles and at intervals down the length of the digester.

With the digester in position, covering insulation is drawn over and this, in turn, is covered by curved corrugated iron. The latter would then be part covered by the earth thrown out during the excavation, and vented so as to permit any accumulated gas to escape to atmosphere. Any remaining earth could be formed into a bank to surround the digester completely to prevent entry of stormwater runoff.

Advantages

1) The static pressure of the digester contents is balanced by the surrounding earth.

2) The digester can be made in a factory and easily transported to the site, complete with butyl gas holders.

3) The scum removal system is simple to incorporate. Alternatively, scum drags as described previously (but with rollers to prevent tearing the butyl) could be drawn through as with a rigid digester.

4) There would be no problems due to slight movements of the surrounding earth due to settling, etc.

5) Capital costs in relation to size would be low.

6) The relatively simple construction would not require highly skilled labor to assemble.

7) Rigid modular sections such as large storm drain cylinders could be used in place of butyl and sealed together (as in Fig. 29).

8) Digesters of truly large dimensions are feasible, i.e., 30 ft. (9 meters) in diameter and 120 ft. (36 meters) in length.

Disadvantages

1) Risk of ripping the butyl (rodents etc.).

2) Extreme danger to persons attempting to walk over the butyl.

3) Relatively short life of butyl and necessity to replace in years to come.

4) Problem of attaching butyl to the rigid ends.

(Note: Rights are reserved to apply for patents within 12 months of publishing this book on aspects of this digester design.)

STEEL DIGESTER 100 FT. LONG, 25 FT. WIDE

Advantages

1) Durability and long life.

2) Lack of possible leaks from joints.

3) Can be buried or part buried for insulation.

4) Multiple units could be laid side by side and insulated with a structure to cover the entire series of units, keeping the intervening space at a steady temperature.

5) Potential for extremely large-scale digestion.

Disadvantages

1) Digesters would have to be built on the site due to size, precluding transportation from factory to site.

2) Capital cost and amortization.

3) Lack of specially trained personnel to operate and maintain.

4) Present lack of knowledge in the use of animal effluent.

INNER TUBE DIGESTER

The following inner tube unit was made at a cost of about $20. If it could be produced in quantity, the cost might be as low as $2 using cheaper material. The unit has no working parts and should last the normal life of the materials used.

This inner tube digester has been tested out in Santa Barbara for over 18 months, during which all the "bugs" have been eliminated. It is a thoroughly reliable device.

Inner Tube Digester Parts List

1) Truck or tractor sized inner tube.
2) Plexiglass (⅛-in. thick) 7 in. x 28 in. (or circumference of inner tube). Plexiglass 10 in. x 10 in.
3) Methyl chloride liquid (hobby shop)
4) Plexiglass tubes (2 in. x 3 ft.)
5) 2 2-inch diameter bicycle inner tubes
6) Polyvinyl-chloride (PVC) tape
7) 3 5-gallon polyethylene buckets
8) 5-gallon container — metal or plastic — for foam collector
9) Epoxy resin
10) Rubber sealing compound
11) Rubber cement
12) Wire
13) Pipe adapter (kind that goes from steel to plastic)

Correction: Methyl chloride should read Methylene dichloride.

14) ¼-in. rubber or latex hose
15) 1 gallon jug with cork with 2 ¼-inch holes
16) Bottles
17) T pieces
18) Truck inner tubes (storage)
19) Screw type pinch clamp.

Main Chamber of the Digester

This consists of a discarded truck-sized (or better still, a tractor-sized) inner tube.

1) Test carefully for leaks. (Bear in mind that every part going into the digester should be carefully tested for leaks. Any gas escaping, out of even a pinhole, is a potential cause of explosion.)

2) Patch over, if necessary. If there is a large gash or hole, cut that portion completely out of the tube.

3) Make a clean cut at right angles to the long circumference of the tube. This is where the plastic cylinder will be inserted.

4) Thoroughly wash and dry the inside of the tube. The inner tube is now ready for the plastic insert.

The Plastic Insert

A. The Plastic Cylinder

1) Heat a ⅛-in. thick x 7 in. wide x about 28 in. long (length should be the circumference around the opening of the inner tube) piece of plexiglass in a 400° oven, until it will bend (about 5 minutes).

2) Bend it around a saucepan or other cylindrical object which has the same circumference as your inner tube. Make the ends of the plexiglass meet to form a cylinder.

3) Glue the ends together by generously applying methyl-chloride glue. The glue can be made by melting some acrylic scraps in methyl-chloride.

4) Cut a round flat piece of plexiglass to fit inside the cylinder, and glue this plate with methyl-chloride glue midway inside the cylinder. This will make a central dividing wall to keep the manure from circling around and around the inner tube.

5) The lip. Heat a ¼-in. x 29 in. strip in a 400° oven for 5 to 10 minutes. Wrap around the outside edge of the plastic cylinder to form a rim. (This will help keep the inner tube from sliding off the cylinder.) Hold the hot plastic strip in place with clothespins until cold. Eyedrop straight methyl-chloride between the two surfaces. Keep the clothespins on until surfaces are securely stuck together. Repeat for other cylinder edge.

B. The Inlet, Gas and Effluent Pipes

These are constructed of 2 in. diameter, heavy-duty

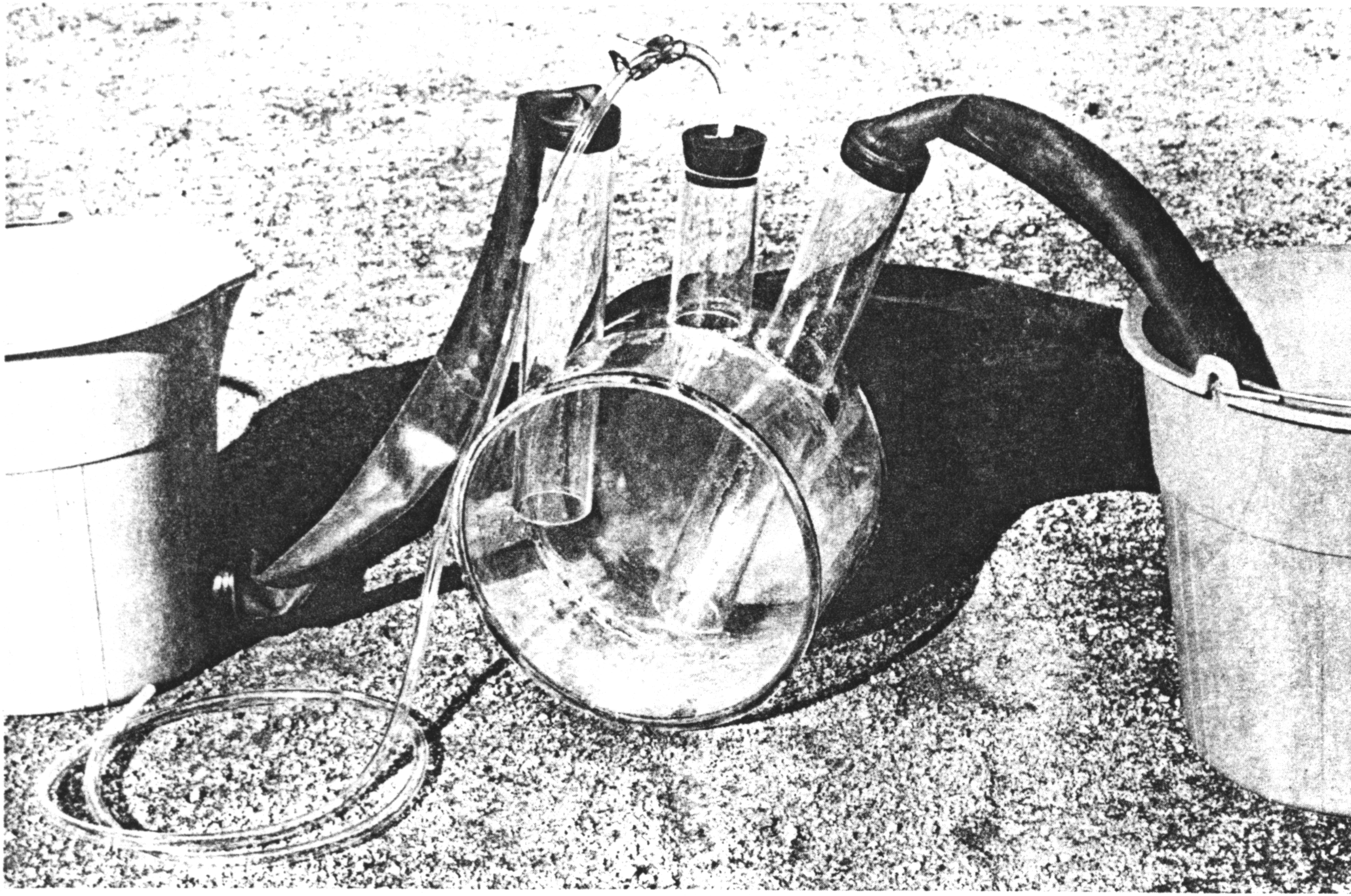


Figure 41: *The plastic insert.*

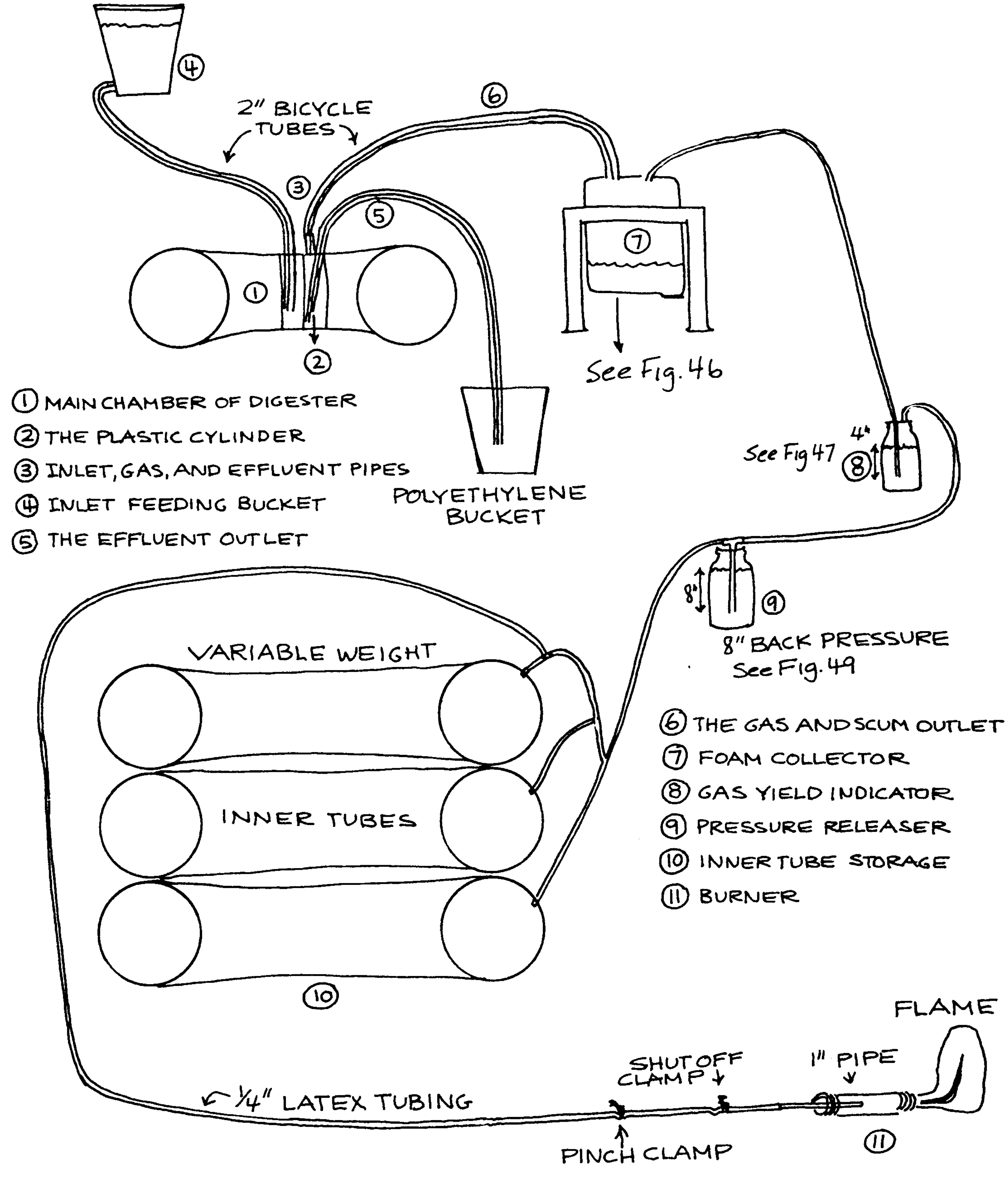


Figure 43: Diagram of inner tube digester.

plexiglass tubes. The inlet pipe will be inserted on one side of the central dividing wall of the cylinder and the gas and effluent tubes on the other side, as follows:

1) Make three 2 in. diameter holes, one on one side of the center divider, two on the other side. Exact placement is not important, but must be so close to the baffle as to touch it and in the general area shown in Figure 45. Apply a little glue at the touching point for added strength. Allow at least 1 in. between the tubes to the lip of the cylinder. We made the holes by burning around the outside edge of the hole with a simple soldering iron. A FRET saw would do a better job.

Inlet Pipe

2) Ream out the inlet pipe hole to allow the inlet pipe to go in at a slight angle. This angle helps the mixing in the inner tube, by tending to make the incoming raw slurry revolve in the tube.

3) Insert the pipe in at an angle, 4 in. down into the cylinder. The distance the pipe sticks out the top of the cylinder is not important.

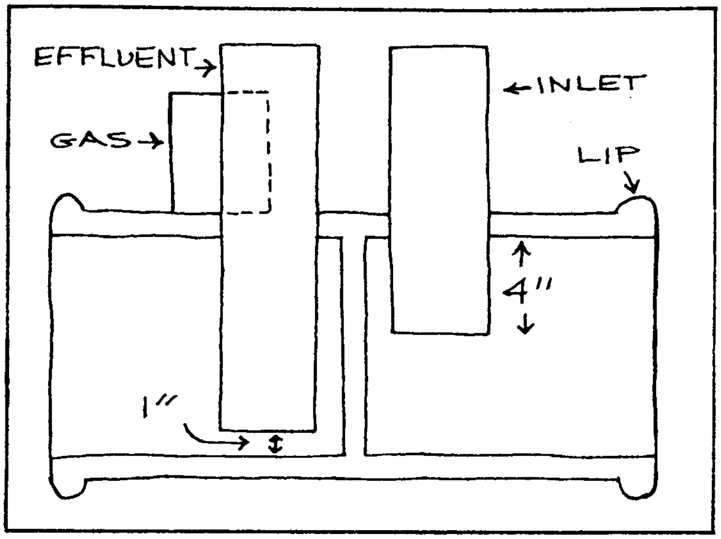


Figure 44: Cross section of the plastic insert.

4) To eliminate leaks, seal the seam around the pipe and hole with: (1) a layer of melted plexiglass and methyl-chloride and then (2) a layer of rubber sealing compound available in hardware stores (Silicon rubber sealant.)

Gas Outlet Pipe

5) This pipe is glued to the top of the cylinder. Again, the length of the pipe sticking out the top of the cylinder should be about 6 inches. Length in Fig. 45 is about right.

6) Seal as above.

Effluent Pipe

7) Insert the effluent pipe straight down into the cylinder to 1 in. from the bottom. Again 6 in. above top.

8) Seal seams as above. Where the inlet and outlet pipes touch the center baffle, apply a little glue to give added strength to them, as mentioned above.

Attaching the Cylinder to the Inner Tube

1) Paint the inside of each open end of the inner tube to a depth of about 2 in. with any kind of rubber cement.

2) Insert the cylinder into the inner tube, past the lip, to a distance far enough to ensure a good seal.

3) Tape in place with polyvinyl-chloride (PVC) tape to hold cylinder and inner tube securely in position.

4) Then wind wire twice around on the tape. Twist the ends of the wire to make a very tight hold. (The wire and the tape are never removed until cleaning out time.)

Inlet Fittings and Attachment of the Slurry (Feeding) Bucket

1) Cut a 2 in. diameter balloon bicycle inner tube to a length of about 3 ft., after checking for leaks.

2) Place it on the inlet pipe.

3) Tape with PVC tape which is adhesive on one side only, by stretching the tape very tightly around the pipe and inner tube. Make sure it is taped firmly.

Attachment of Bucket

4) Burn a hole in the polyethylene slurry bucket, 1 in. from the bottom of the bucket. When the hose is attached to this hole off the bottom, it will allow sand and other heavy indigestible material to settle to the bottom of the bucket and be left behind when feeding the slurry to the digester.

5) Attach an adapter in the hole of the type used to go between steel and plastic pipe.

6) Attach a length of 2 in. bicycle inner tube to the adapter in the slurry bucket with PVC tape. The tube should be long enough to allow the bucket to be held for gravity feeding the slurry into the digester.

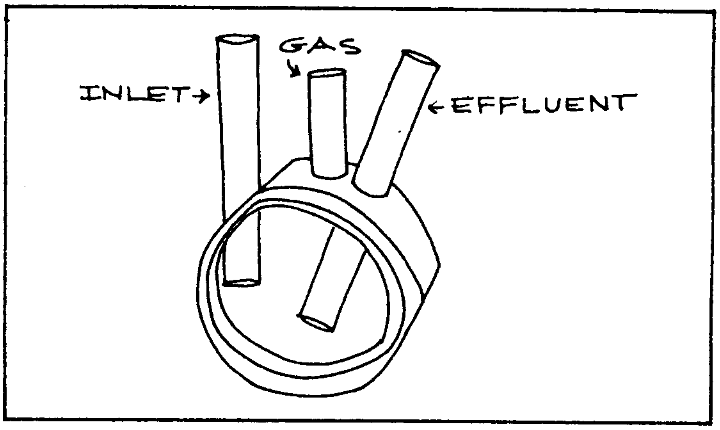


Figure 45: Diagram of plastic insert.

Fitting the Effluent Pipe

1) Simply tape another length of 2 in. bicycle inner tube to the effluent pipe.

2) Hang the tube in a bucket.

Fitting the Gas Outlet

1) Attach a 2 ft. or 3 ft. length of the 2 in. bicycle tire tubing to the gas outlet with PVC tape.

2) Lead it to the foam collector.

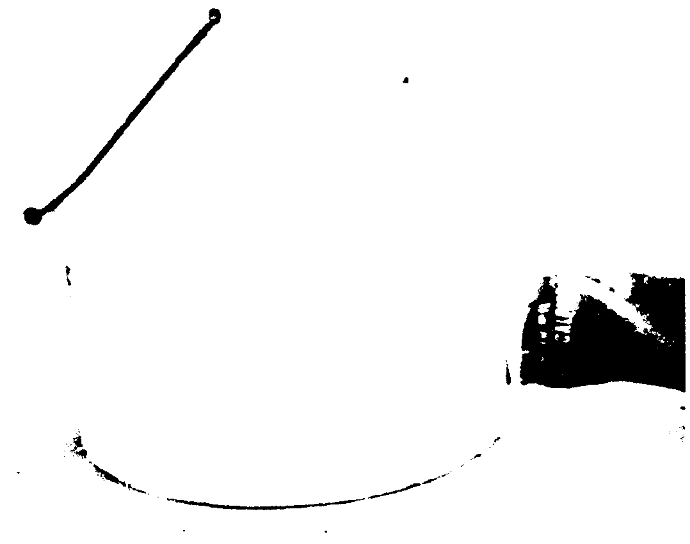


Figure 45A: Position of outlet to feeding — in bucket (off bottom).

The Foam Collector

If you remember, scum is a mixture of (a) floating material (bedding, straw, feathers, etc.) and (b) liquid interspersed with (c) gas bubbles. Foam rises up with gas out of the gas outlet.

1) Select a metal or firm polyethylene container with at least a 2 in. wide filler cap. We used a 5 gallon, plastic milk container. It is much easier to attach the pipes to a metal container, though.

2) Turn the container upside-down (filler cap underneath) and make a 2 in. hole in the top. Solder or weld a short length of 2 in. wide metal pipe to the top (this was the bottom of the container originally).

3) Firmly tape the inner tube coming from the gas outlet to the short length of pipe. Foam will be forced through the gas outlet, through the cycle tube and drop in the container. Gas will continue on its way to storage via:

Gas Outlet Continuation

4) Solder or weld a second pipe at another point on the top of the container. The hole should be ¼-in. in diameter.

5) Tape a length of ¼-in. rubber or latex hose to the ¼-in. pipe. This will go to the gas yield indicator bottle.

Gas Yield Indicator

This is a jug of water, through which the gas from the digester bubbles. It is a simple way to see that your digester is producing gas. (Also, if the water is changed frequently, it will filter out some of the carbon dioxide in the gas.)

1) Take a jug and place a cork with two ¼-in. holes in the bottle's mouth.

2) Place between the scum accumulator and pressure release bottle.

3) Fill the jug with about 6 in. of water.

4) Run the hose from the scum accumulator, through one cork hole and to 4 in. below the level of water in the bottle.

5) Run another piece of ¼-in. rubber or latex tubing out of the other cork hole, to the pressure release (overflow) bottle.

Pressure Release Bottle

This bottle is placed between the gas yield indicator and inner tube storage. It allows the release of extra pressure in the inner tube storage, or overflow of gas to escape through the water in the bottle, rise to the atmosphere, and disperse harmlessly.

1) A 12 in. or so deep bottle is fitted with a "T" piece.

2) The tubing from the gas yield indicator is attached to one arm of the "T" and a tubing to storage is attached to the other arm.

3) A plastic tubing is attached to the leg of the "T" piece and immersed in 8 in. of water.

4) In the event that the gas pressure is more than 8 in. water gauge, the gas will escape through the water, to the atmosphere.

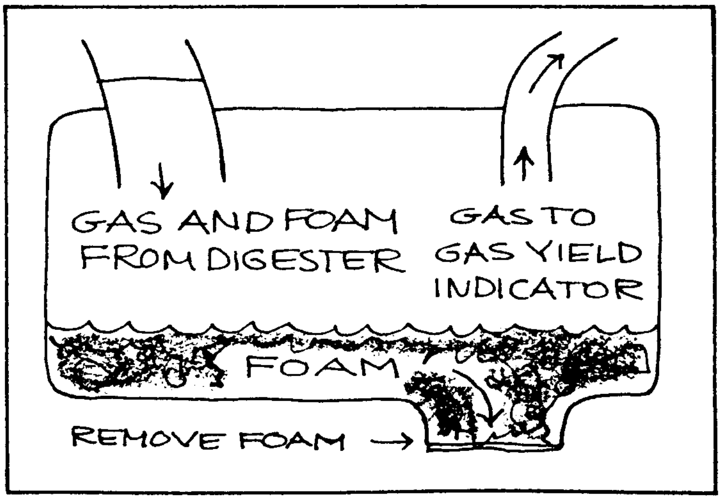


Figure 46: Diagram of foam trap.

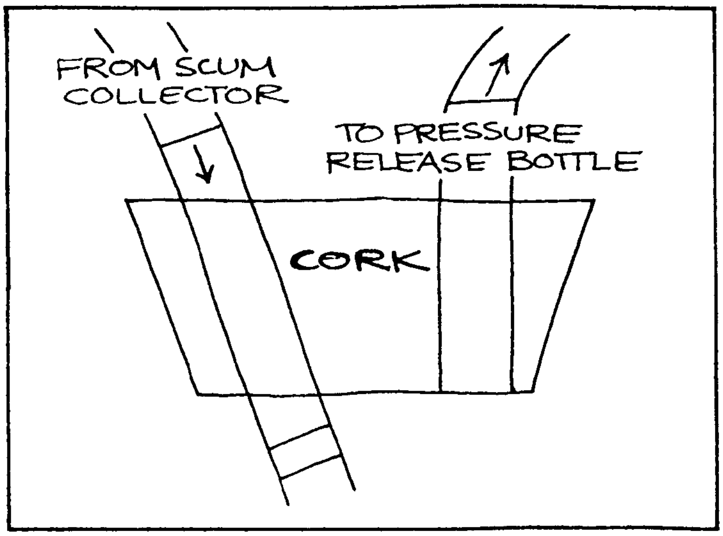


Figure 47: Gas yield (both visible and audible).

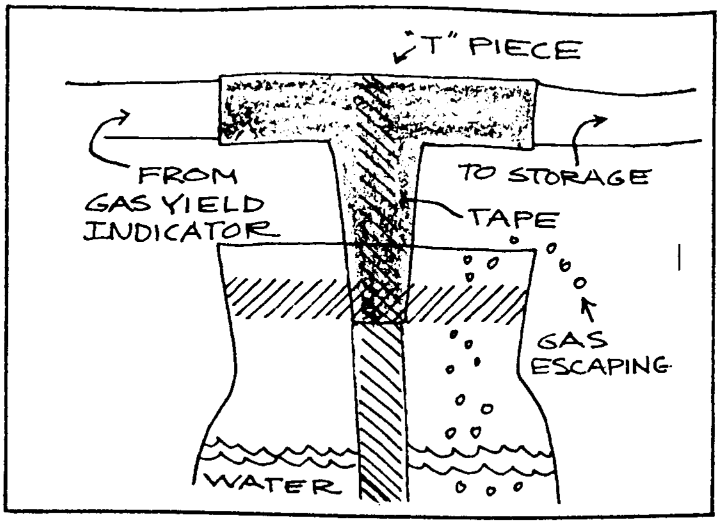


Figure 48: *Excess pressure release.*

Inner Tube Storage

1) Gas can be stored in one or a number of truck inner tubes, stacked on each other and interconnected with "T" pieces. Check for leaks and patch if necessary.

2) A weight, such as pieces of lumber, are placed on the topmost tube to create pressure.

Burner

The gas produced by this digester is about 700 BTU per cubic foot at sea level (585 BTU at 6,000 ft. altitude). The average daily production of this system is 5 cubic feet; enough to bring ½ gallon of water to the boil and keep it there 20 minutes. This is enough to cook a meal.

1) The simplest burner can be a piece of 1 in. metal pipe 6 in. long.

2) Insert a 1 ft. long piece of aluminum or metal ¼-in. pipe loosely in the 1 in. pipe.

3) Place some sort of on/off clamp on the tubing, plus a pinch screw to regulate the amount of gas.

4) The 1 in. pipe is laid between 2 bricks and a third brick is placed on the pipe to hold it in position.

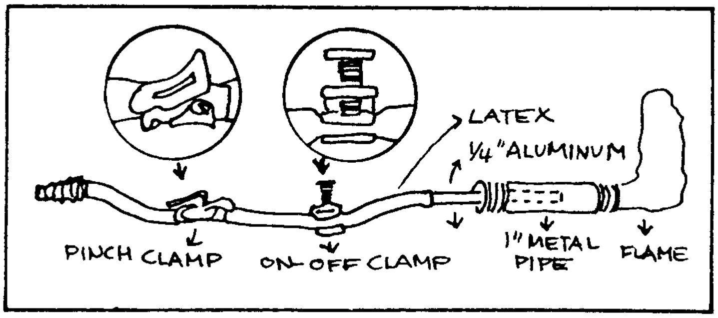


Figure 49: *Detail of simple burner — ¼-in. pipe laid inside length of* 1*-in. pipe.*

Temperature

Methane bacteria only work their best when kept warm. The best temperature is 95°F. Without artificial heating the only areas in which a digester will function is in or near the tropics. Thus, without supplemental heat, this unit is limited to the tropics. Alternatively, if placed in an insulated box and heated by two 100 watt light bulbs in series (this takes very little electricity and the bulbs last a long time), with a thermostat set to 95° in the circuit, it can be operated almost anywhere.

The Bacterial Brew

Start up as described with effluent from another digester.

Feeding

1) The daily routine consists of collecting three 1-pound coffee cans full of dry chicken manure. (Almost any kind of manure is suitable, but to avoid excessive scum formation, a finer texture manure is better.)

2) Stir in the slurry bucket with ¾-gallon of water or urine to form a slurry. If you can use urine instead of water, it will aid fermentation and make the effluent a better fertilizer after digestion.

3) Now raise the bucket high so that the slurry with gravity feed into the digester. It will mix with yesterday's load, which by now has been "seeded" with active, hungry bacteria. The inlet pipe (set at an angle) helps the mixing, by tending to make the incoming raw slurry revolve in the inner tube.

4) Dispose of the feathers, fiber, sand, etc., left in the bottom of the bucket.

The action inside the digester is the same on any scale. The raw material, heavily seeded, tends to skulk along the floor of the digester but as the bacteria work on it, gas is formed and lightens it in relation to surrounding material.

A reason of failure of the brew is an excess of water, particularly cold water.

Removing Foam and Effluent

A. Foam

1) When the foam collector container feels heavy, remove the filler cap from the bottom of the container and let the liquid out.

2) Care must be taken that air is not allowed to enter the container at this point.

B. Effluent

3) Effluent is drawn off daily or so to the extent of approximately 80% of volume of daily input at feeding. The other 20% of daily input is accounted for as (1) gas and (2) contraction during fermentation.

4) The superior fertilizing value of the effluent is discussed elsewhere. This inner tube digester will produce enough to improve growth of plants on an area of 2,152 sq. ft. per year — a good sized vegetable patch.

Safety Precautions

Check this chapter carefully before using and note the following:

An important safety factor is to check the unit daily for leaks; there will be a discoloration of the tubing in places where the gas has leaked out.

Finally, smell is important in safety handling. Never light a match in a room with a strong smell of gas — or even a slight smell. Air out the room first.

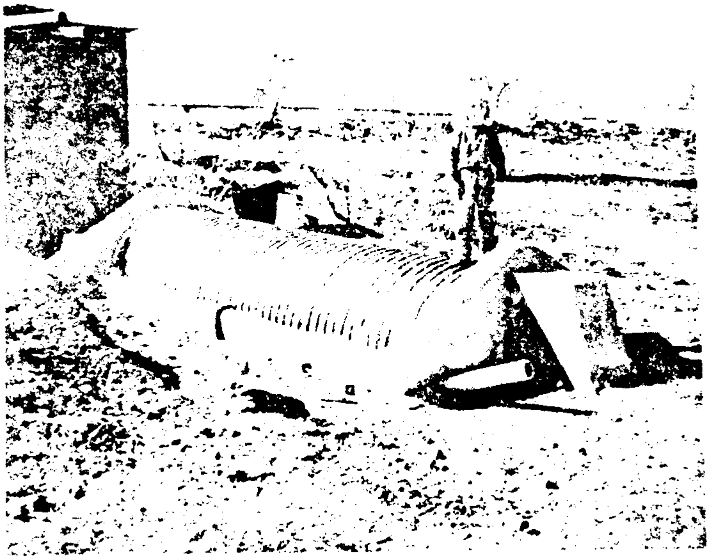


Figure 50: A trial digester with roof made of corrugated iron and concrete ends (with daughter Merle, age 3, providing size proportions).

Figure 52: Access door below working level of trial digester (note gas outlet pipe).

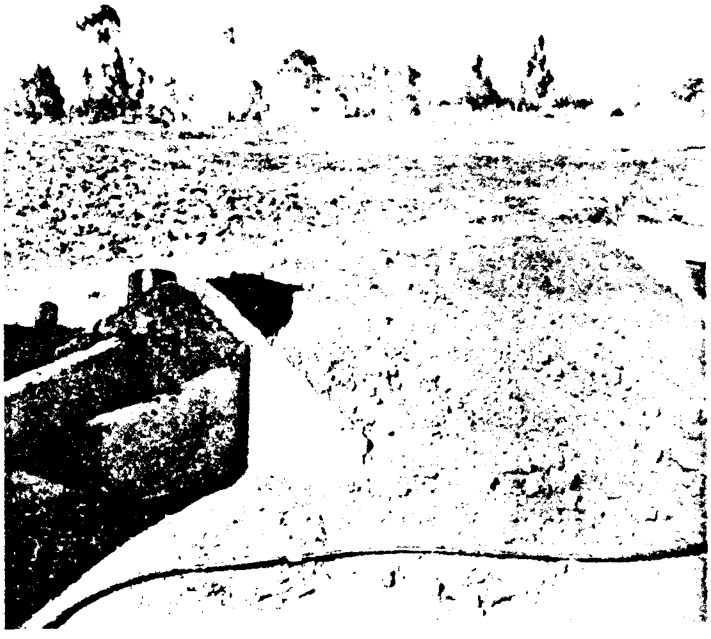


Figure 51: Trial digester insulated with earth.

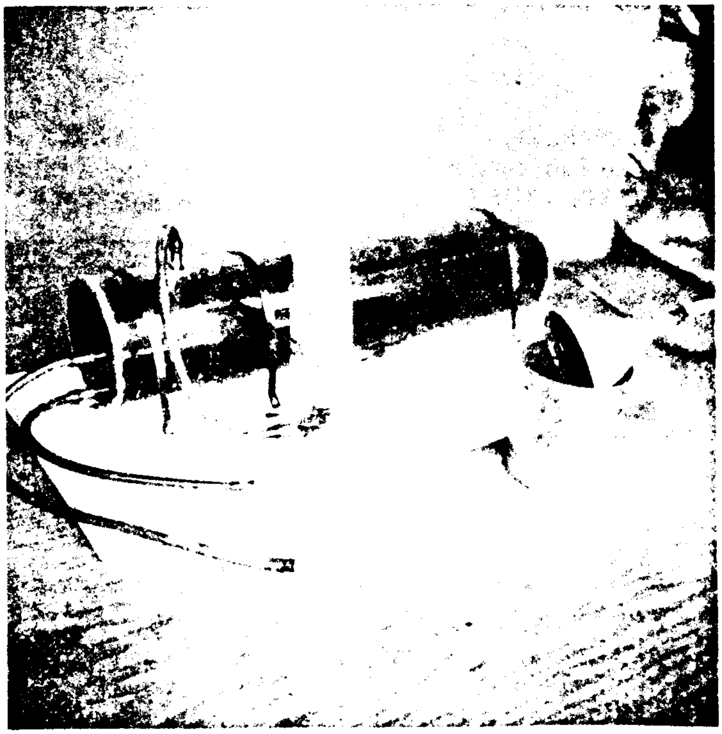
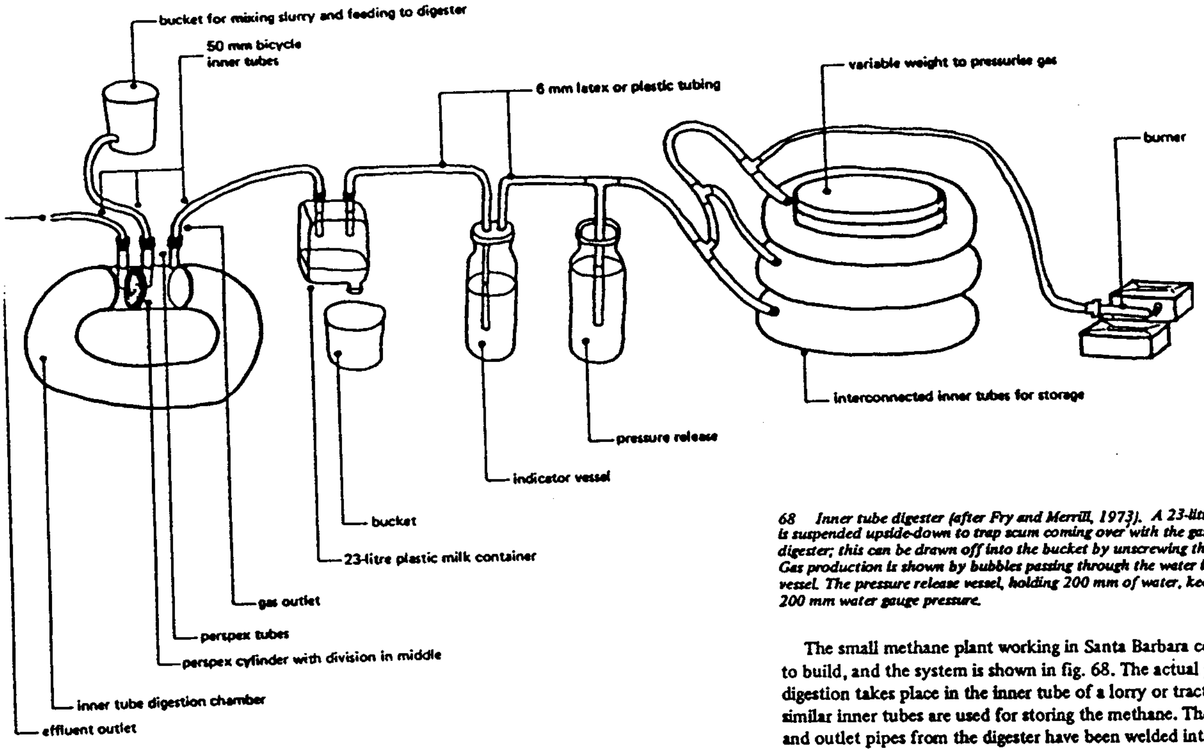


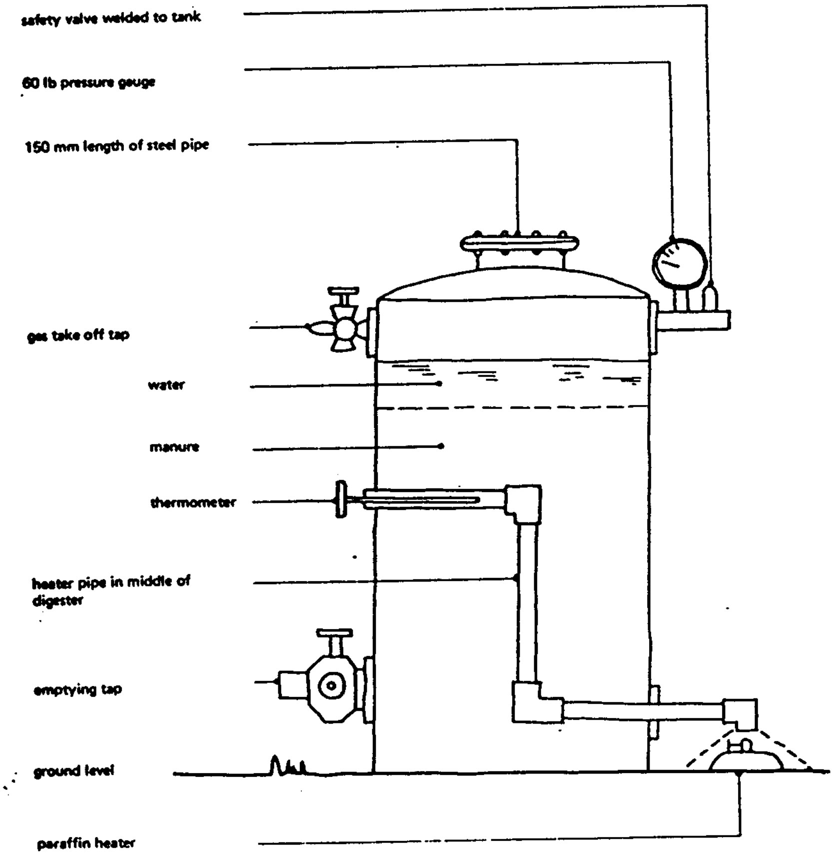
Figure 53: Transparent plastic table-top demonstration model in action raising gas holder.



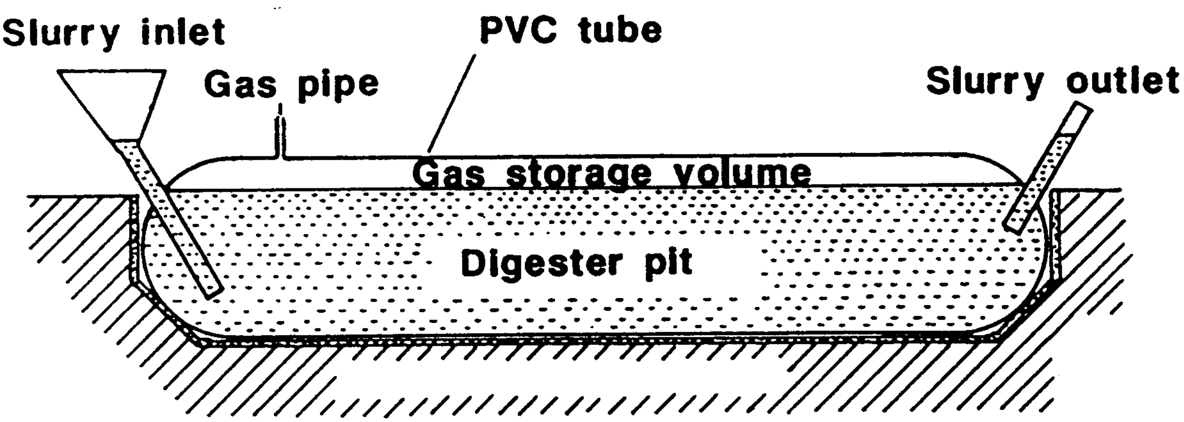
68 Inner tube digester (after Fry and Merrill, 1973). A 23-litre milk container is suspended upside-down to trap scum coming over with the gas from the digester; this can be drawn off into the bucket by unscrewing the container cap. Gas production is shown by bubbles passing through the water in the indicator vessel. The pressure release vessel, holding 200 mm of water, keeps the gas at 200 mm water gauge pressure.

The small methane plant working in Santa Barbara cost around $20 to build, and the system is shown in fig. 68. The actual process of digestion takes place in the inner tube of a lorry or tractor tyre, and similar inner tubes are used for storing the methane. The perspex inlet and outlet pipes from the digester have been welded into a cylinder of perspex made to the same dimensions as the circumference of the inner tube, and joined to the tube to form a complete doughnut. A circular perspex panel in the middle of the cylinder separates the start of the digestion process, where the slurry inlet and methane outlet are situated, from the end, where the fertilizer effluent outlet is placed. The completed tube digester has an approximate volume of 0.1 m^3 (depending on the size of the tyre tube used), and is fed daily with 1.4 kg of chicken manure. Chicken manure is preferred as it has a finer texture and the likelihood of scum forming on the surface of the digesting wastes is therefore reduced. The chicken manure is mixed with about three litres of water or urine to a slurry in the bucket, which is then raised so that the slurry is fed by gravity into the digester. The digested slurry can be drawn off from the outlet at the other end of the digester every one or two days, the total amount removed being about half the volume of the daily input to allow for gas production and contraction during the fermentation. About 0.14 m^3 of methane gas is produced daily with this system, the gas having an average calorific value of 7.3 kWh/m^3, which is enough to cook a very simple meal. If the tube digester is constructed in places where the ambient temperature is too low to maintain digestion, the New Alchemy Institute recommends that the inner tube should be placed in an insulated box in which are two 100-W light bulbs connected in series and linked to a thermostat set at 35° C. The other features of the inner-tube system are shown in fig. 68.

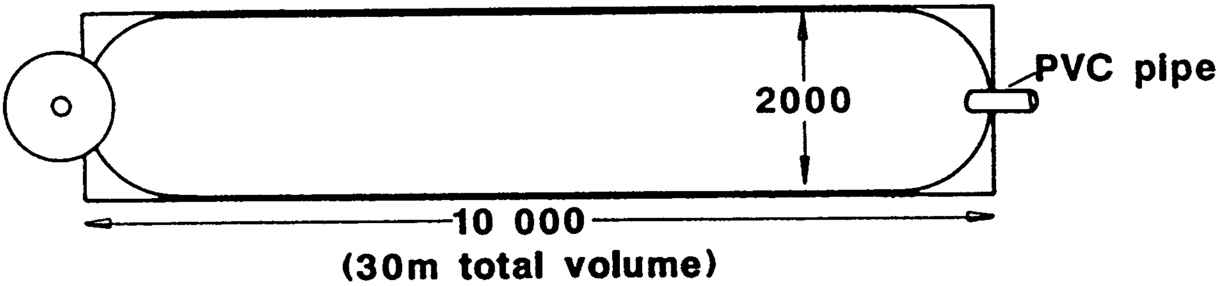
For some years before the present increased interest in methane plants, Mr H. Bate of Totnes in Devon has been running a methane plant in conjunction with his pig and poultry holding. Part of the gas produced is compressed and used to power his 1953 Hillman car. For Bate's system, digestion is always preceded by aerobic composting for approximately one week. The manure is mixed with straw and other vegetable waste, well watered and piled up into a traditional compost heap. At the end of the week, the materials are loaded into the digester and sealed from the air. Fig. 69 shows the modification of a domestic hot-water cylinder to form a methane digester. During digestion, gas production is estimated to be 0.3 m^3 for every kilogram of manure decomposed. Bate also suggests modifying a conventional septic tank into a methane digester by fitting a non-return valve to the inlet from the house, fixing a gas outlet in the vent pipe and sealing off the other vents. Gastight holes would have to be made in the lid of the tank, one to take a conventional domestic immersion heater and the other to hold a thermometer to check that the optimum temperature range of 29° – 32° C, given by Bate, is maintained. It is uncertain whether this suggestion has actually been tried, although a conventional, unaltered septic tank does process its wastes by anaerobic decomposition, the vent pipe affording a release for the gases produced, which include methane, to the air. However, if the digesting wastes are too dilute, methane formation is inhibited, and the use of a normal WC with a 9-litre flush linked to a modified septic tank would produce a water content in excess of that for optimum gas production.



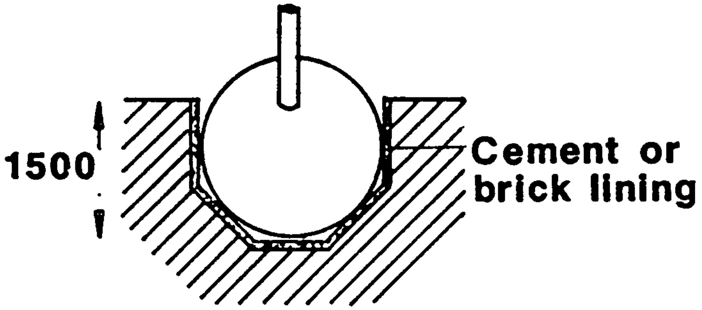
69 Conversion of 1219 mm x 610 mm domestic water heater to a methane digester (after Harold Bate). The digester is filled through the length of steel pipe welded to the top; the cover of this pipe is fixed with 9 mm bolts. The safety valve and pressure gauge, gas take-off tap, and emptying tap are also welded to the tank. The paraffin heater is replaced by a gas jet from the digester itself once digestion is under way.



Section



Plan view



End view

Figure I.5 *Bag digester details*

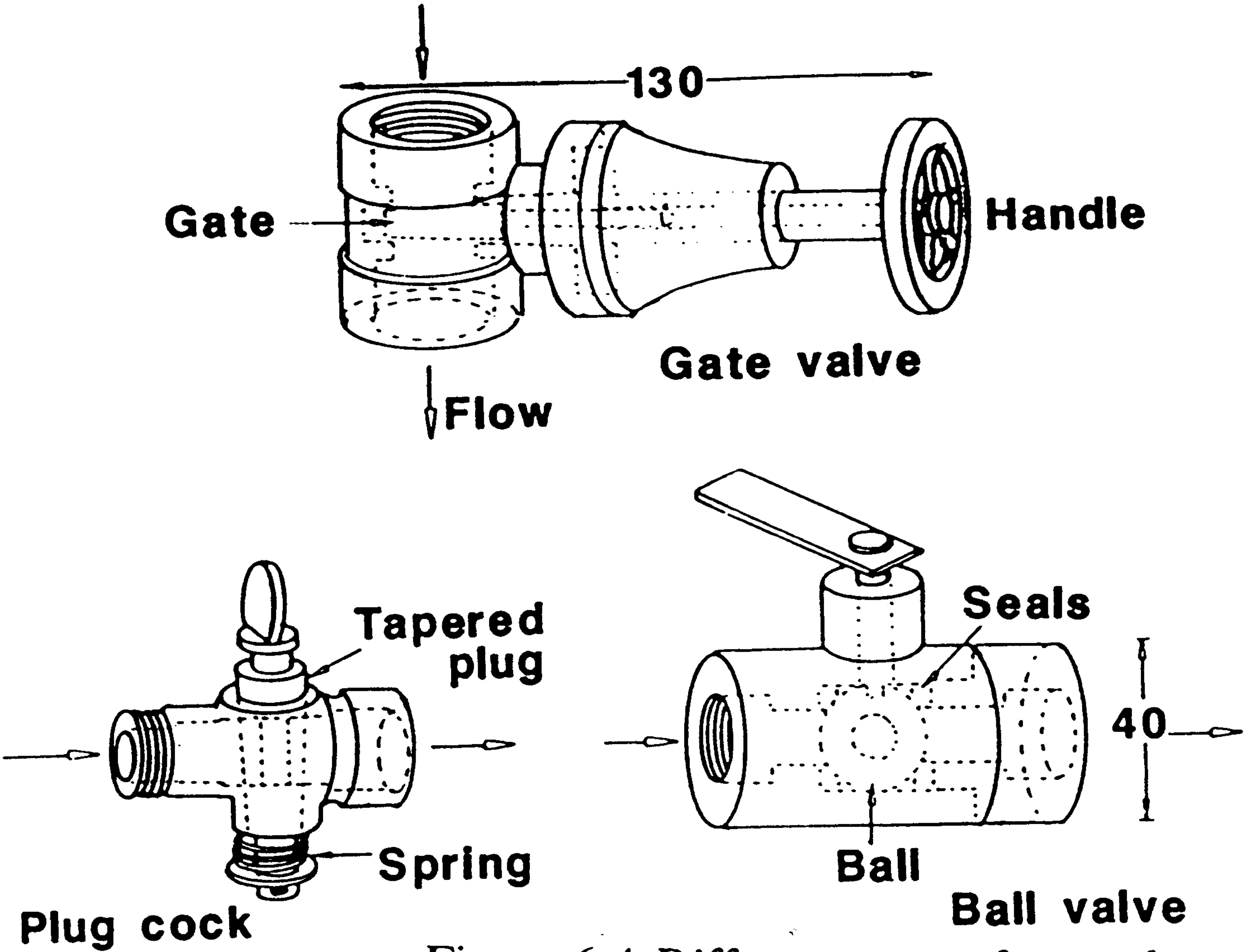


Figure 6.4 *Different types of gas valve.*

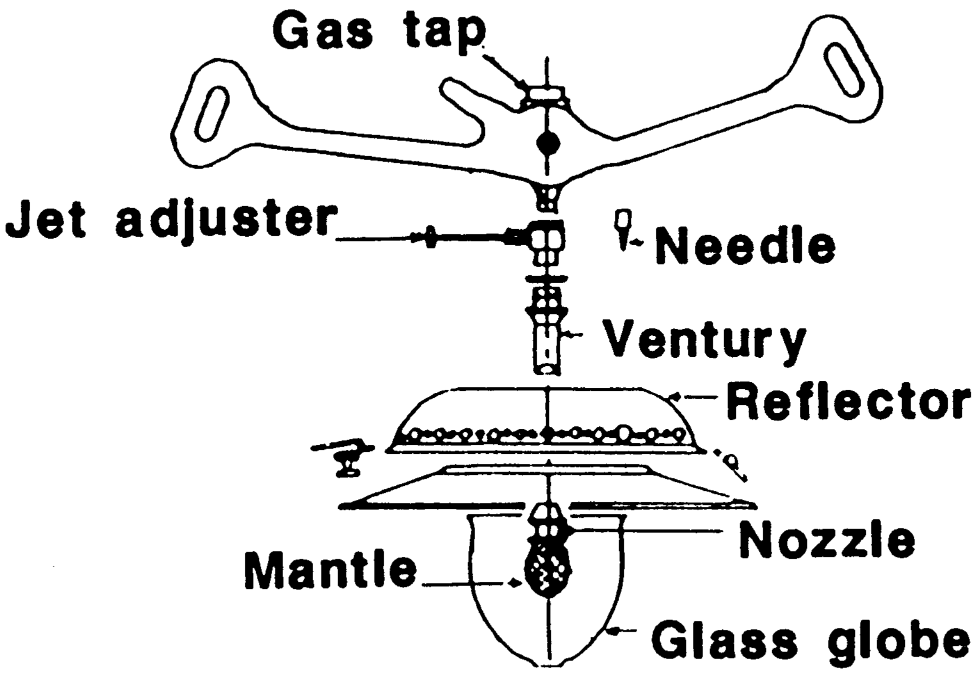


Figure 6.6 *Biogas light (made in India)*

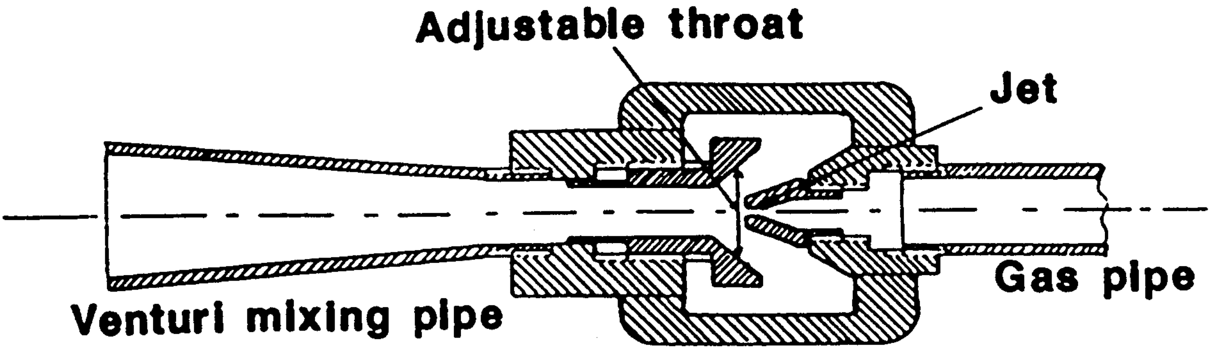


Figure II.6 *Tapered throat design of gas burner*

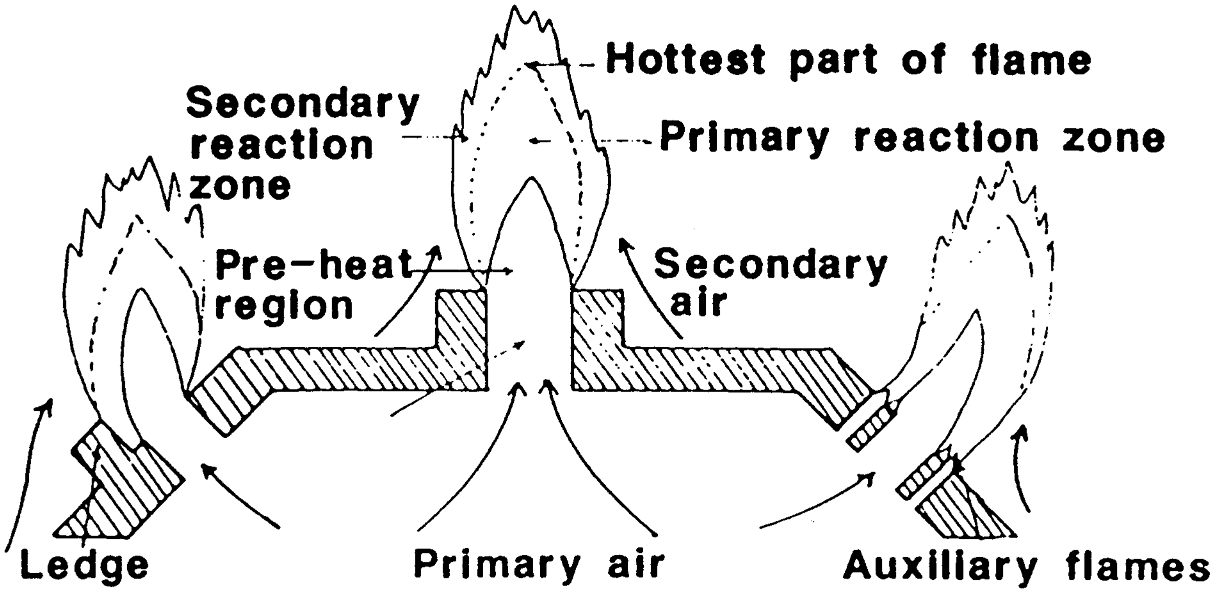


Figure II.7 *Details of gas flame and means of stabilisation*

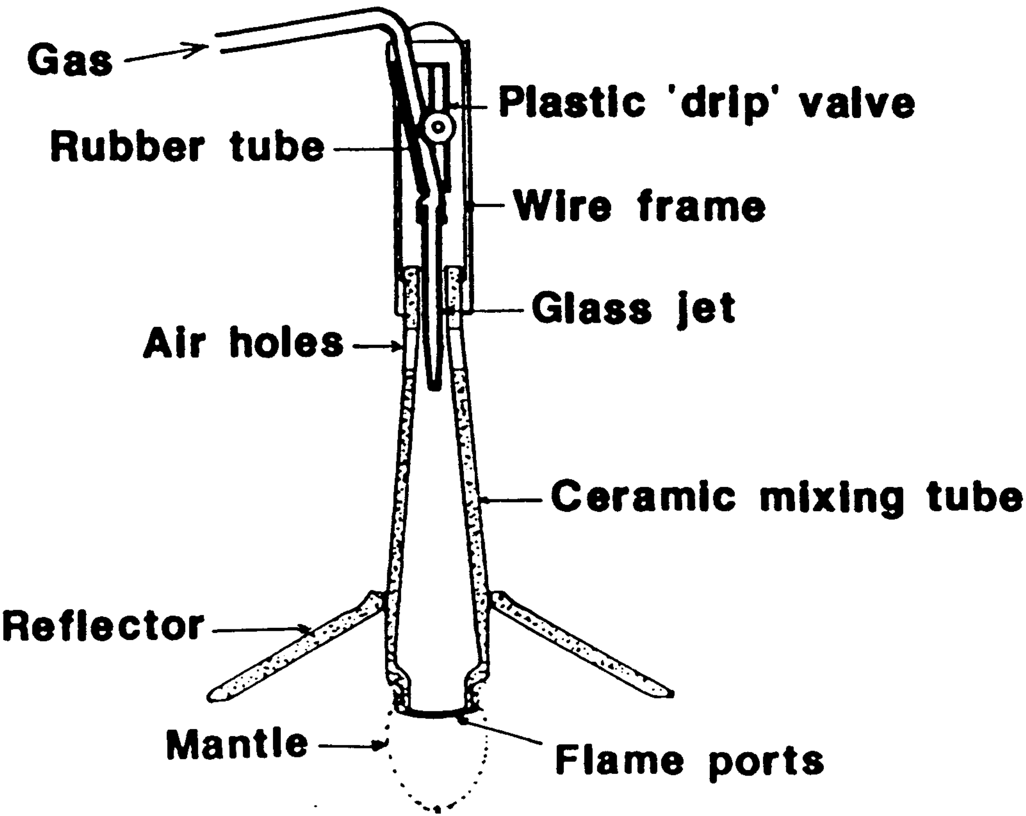


Figure II.8 *Ceramic gas lamp—made in China*

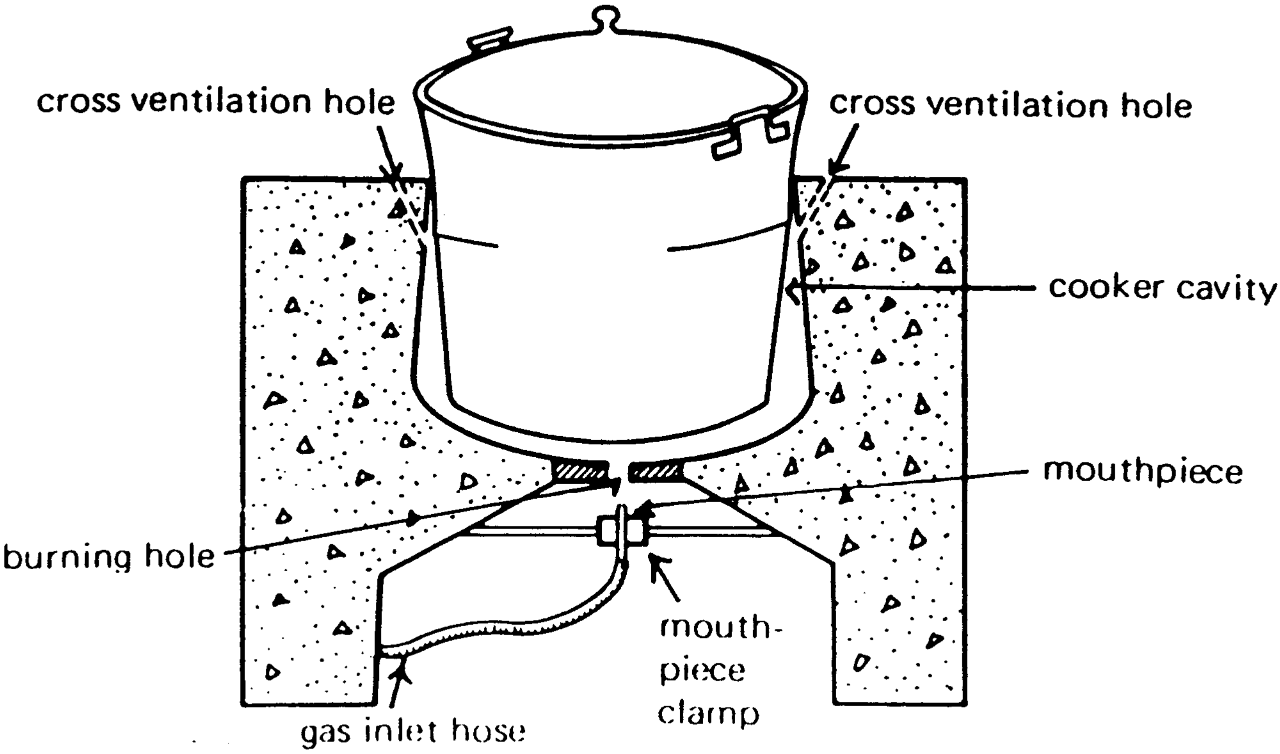


Fig. 7-13. The biogas stove.

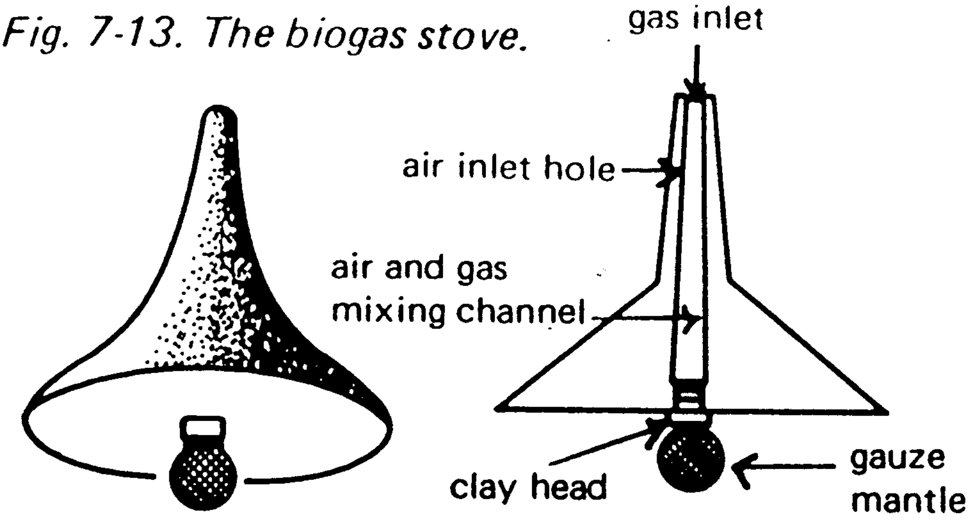


Fig. 7-14. The clay hanging lamp.

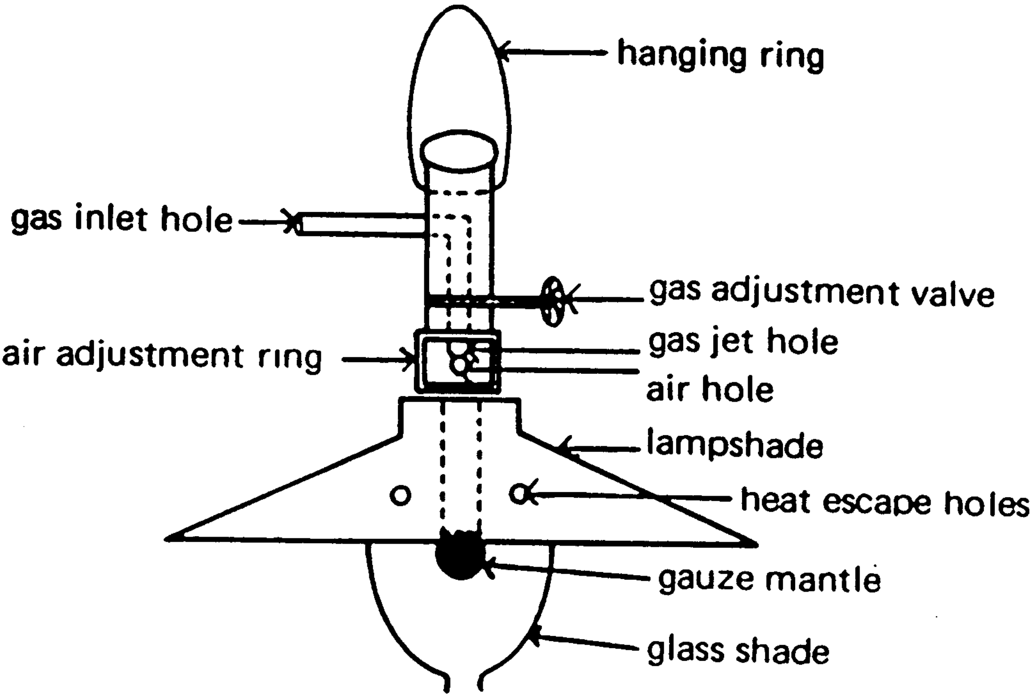


Fig. 7-15. 'Red Star' hanging lamp.

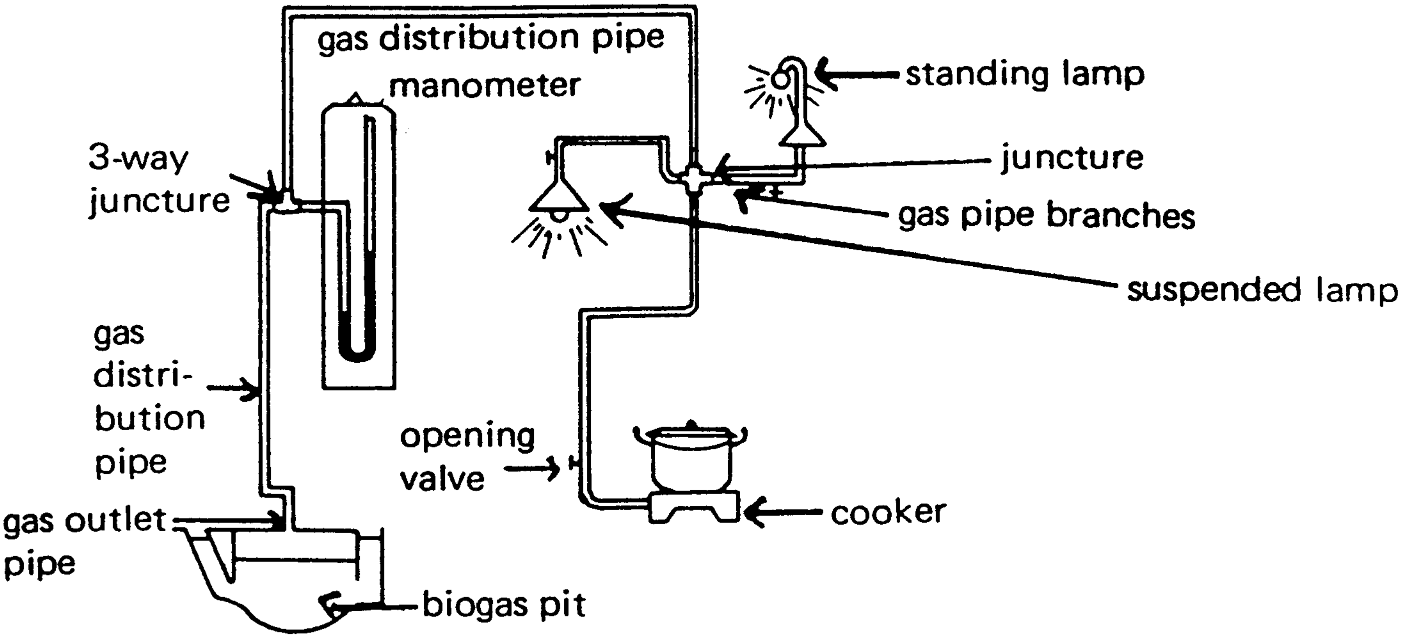


Fig. 7-16. *Rough plan of equipment installation for using biogas.*

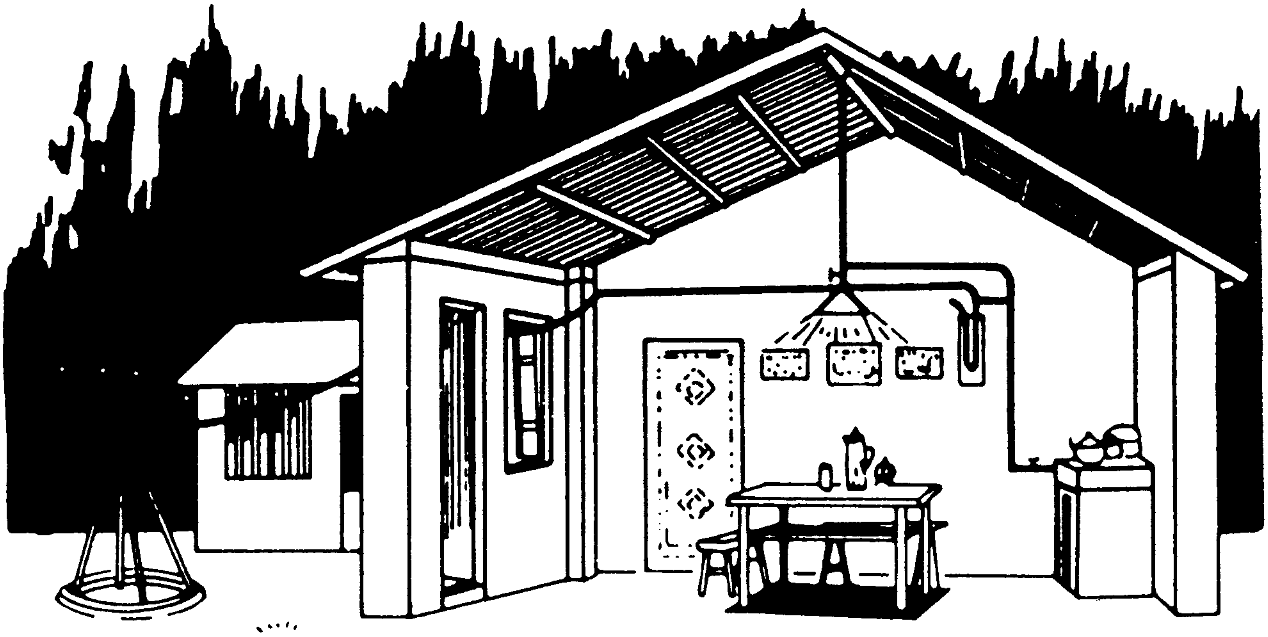


Fig. 7-17. *Wall attachment of biogas distribution pipes.*

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Postscripts

Now that I have written an entire book on how I overcame the scum accumulation problem, along with descriptions of how I solved attendant worries, I feel that I have produced something which will spell the difference between a hit-or-miss, experimental methane plant which would sooner or later require basic design changes of digester unit, gas holder, etc., and an efficient, functional design along tested specifications.

My findings are the result of down-to-earth, practical experimentation in the true sense of the word invention. The suggested techniques and plans will point the way and suggest alternative features, such as heating systems, while allowing the reader a certain latitude in application.

According to patent laws I may apply for patents on certain aspects of this work within twelve months of the book's distribution. I reserve these rights.

Since few methane power plants have been built thus far in the U.S., meaning that little or no research material is available on large-scale units, it would be of considerable benefit to have and maintain a listing of working plants. Information to be recorded should include dimensions, methods of heating and loading, raw materials tested and used, capacities and types of gas holders used, etc., and should be accompanied by photographs. This material would be used for record purposes only, unless authorization to publish and reproduce details is granted. Pooling information in the early stages of development could lead to dissemination of information on a worldwide basis for the benefit of all mankind, which is really what this book is all about. Write to me at 1223 North Nopal Street, Santa Barbara, California, 93103, or to my permanent address:

L. JOHN FRY
c/o Santa Barbara National Bank
P.O. Drawer JJ
Santa Barbara, Calif. 93102

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