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CHINESE DOME BIODIGESTER CONSTRUCTION AND TECHNOLOGY TRANSFER

SOLAR ENERGY LABORATORY

BAMAKO, MALI

Prepared for:

Solar Energy Research Institute
Golden, Colorado
Contract No. TS-2-02064-1

Prepared by:

M & E Pacific, Inc.
Consulting Engineers
190 S. King Street
Honolulu, Hawaii 96813

April 1982

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CHAPTER I

INTRODUCTION

OBJECTIVES

The objectives of the Chinese dome biodigester project are to design and construct a Chinese-type dome biodigester at the Solar Energy Laboratory in Bamako, Mali, Africa. In addition, the work is also to include the establishment of basic biogas monitoring systems, instruction of Malian engineers in digester construction and operation, and development of a long-term biodigester research program for establishment of optimum operating parameters and methods appropriate to the materials, environment, and local conditions of Mali.

Specifically, the scope of work for this project includes:

1. To determine the most appropriate Chinese dome biodigester design relevant to the availability of local construction materials and local construction techniques.
2. To direct the site excavation, work crew mobilization, digester construction, and pressure testing.
3. To analyze the organic fermentation substrate and direction of organic loading with correction of any resulting biological imbalances.
4. To develop and implement a biodigester technology seminar for Malian engineers.
5. To develop and implement a long-term biogas research program.

PROJECT LOCATION AND HISTORICAL BACKGROUND

The Republic of Mali is a large (1,204,000 km^2) land-locked country located in the central region of West Africa (Figure I-1). It shares borders with seven other former French colonies: Algeria, Mauritania, Senegal, Guinea, Ivory Coast, Upper Volta, and Niger. Most of Mali lies in the West African savanah region, known as the Sahel, and exhibits a gradual transition from forest land in the south to a perennial desert in

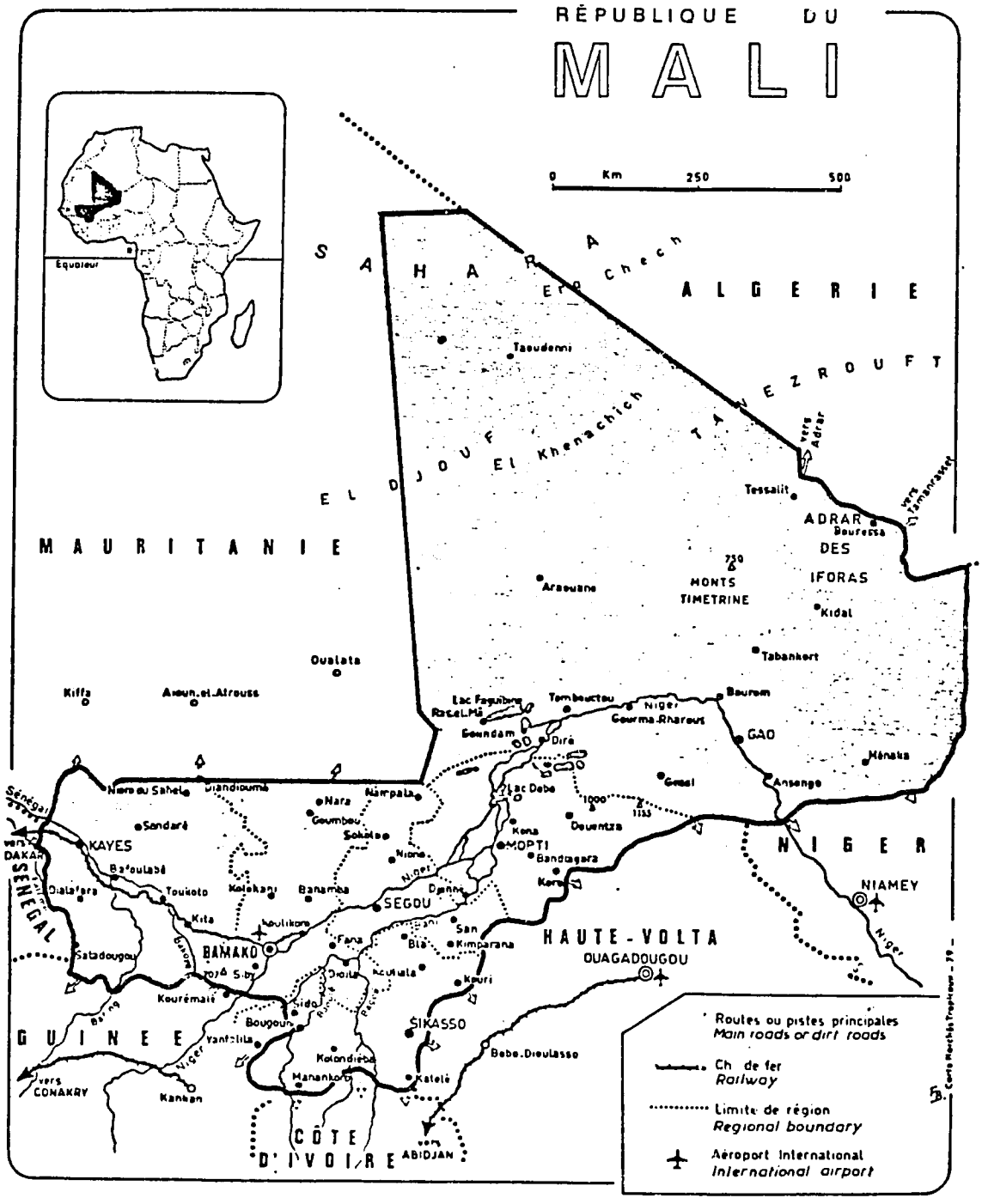

FIGURE I-1

LOCATION MAP

the north. Rainfall in the Sahel is variable, with most of the rain generally occurring between June and September. Annual rainfall ranges from 160 to 1300 mm (Figure I-2), depending on location.

The vast majority of Mali's land is in the barren and arid zone of the Southern Sahara. Evaporation potential exceeds rainfall during all seasons, except in the far south. Natural vegetation and the agricultural use of land are directly related to the season and the distance from a source of water. In South Mali there are a few deciduous forests which are succeeded by bush and grasslands in the center of the country. Except during the rainy season, the savanah vegetation is sparse and the dry soil supports little more than thorny bushes.

Two rivers, the Niger and the Senegal, flow through Southern and Southwestern Mali and are the life blood of the country. These rivers provide water for domestic needs, irrigation, transportation, and fishing resources. All of Mali's major towns and the capital, Bamako, are located along the rivers. Only one-fifth of the 0.3 million Malian people, however, live in urban areas. Mali is primarily an agrarian and pastoral society. Agricultural land, however, comprises only 1.5 percent of the total land area and is situated almost exclusively along the rivers. The major agricultural products include millet, sorghum, peanuts, and rice along with relatively large standing herds of cattle and goats. Fresh and dried fish from the Niger River are an important protein source in the local diet and are an export product.

Livestock management is a major agricultural occupation in Mali. Standing herds total approximately five million cattle and ten million goat and sheep. The herds are field grazed during the day, but are returned to compounds at night. In the driest season of the year, field grazing may last four or five days before the herds are returned to the compound because of the extended travel distance to grazing areas. During prolonged droughts livestock herds are often decimated by thirst and lack of forage. In addition to utilizing the herds as a source of meat, wool, and leather, the livestock manure is sometimes used as a cooking fuel in conjunction with wood and other forest residues. This practice precludes using the manure as a fertilizer and leads to reduced land fertility.

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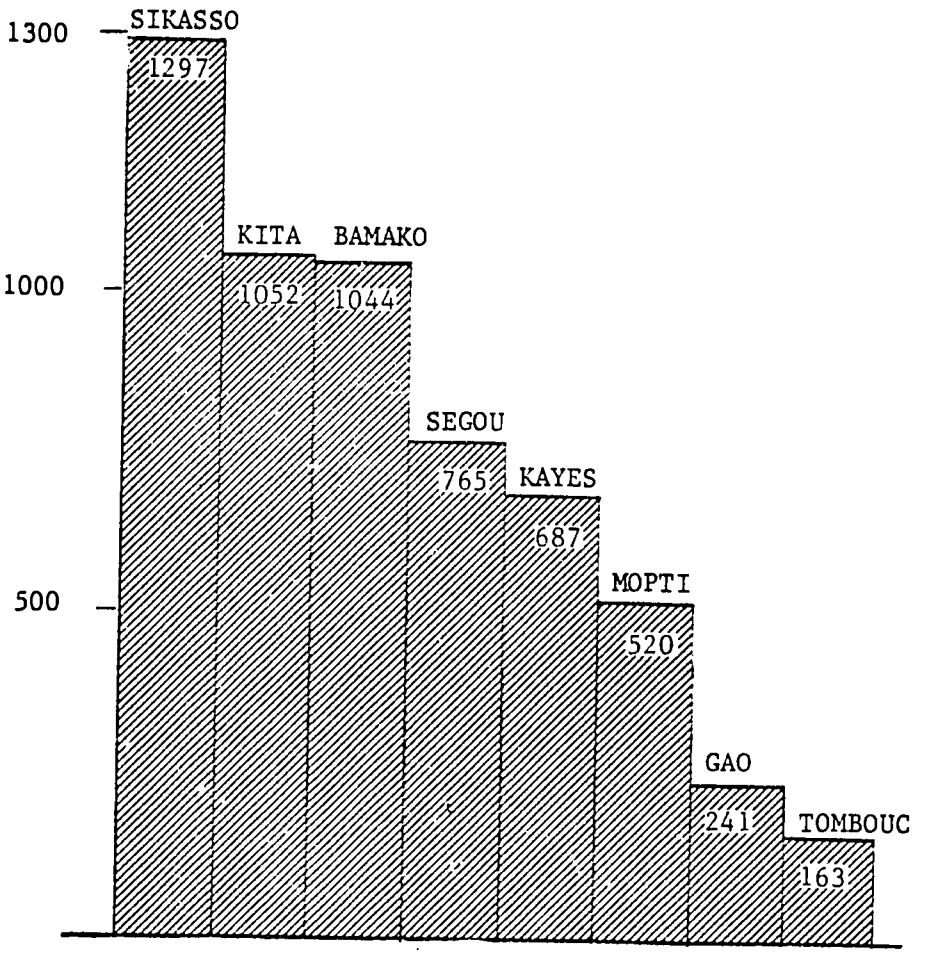

FIGURE I-2

AVERAGE ANNUAL RAINFALL (1975 TO 1976) IN EIGHT MALIAN CITIES

(Millimeters)

Droughts, a growing population, poor business management, and problems in exploitation and management of natural resources are some current obstacles slowing economic development in Mali. Deposits of bauxite, uranium, iron, copper, manganese, and phosphate are known to exist in the northern desert region but are not presently mined because of Mali's inadequate transportation and power facilities. To overcome these problems, numerous foreign governments and international development organizations are currently assisting Mali's effort to become self-sufficient in food production, improve livestock breeds and exports, improve transportation and communication facilities, increase educational opportunities, and improve rural energy availability and use patterns.

The Solar Energy Laboratory (SEL), located in Bamako, is the major Malian organization involved in bettering the quality of rural and urban life through development of improved energy utilization methods and by development of alternative and renewable energy sources. This organization was created in 1964 and conducted important work in flat-plate solar collectors and solar stills. During the late sixties and early seventies the productivity of SEL declined because of widespread economic and social changes occurring throughout the country.

The laboratory has since been revitalized and is currently conducting both research and extension efforts in a variety of renewable energy programs, including:

- Wind turbines and pumps
- Wood stoves
- Solar stills
- Photo voltaic generators
- Biomass

The present research focus is supported jointly by the Malian Government and the United States Agency for International Development (USAID). The design and construction of the Chinese dome biodigester is part of this renewable energy program at SEL. With livestock herds totaling approximately five million cattle and ten million sheep and goats, the opportunities to generate biogas fuel and liquid fertilizer are

promising, though cultural practices of livestock management and scarcity of water may hamper the implementation of these renewable energy innovations.

CHINESE DOME BIODIGESTERS

Biogas is produced by microbiological fermentation of organic materials within a narrow temperature range, water content, and acidity in an airtight container (see Appendix A). The biogas is 50 to 70 percent methane, with the balance mostly carbon dioxide. The container or reactor in which the fermentation takes place is known as the biodigester.

The Chinese dome biodigester is a below-ground, fixed roof reactor constructed with brick, stone, or concrete. The other major type of biodigester used in agricultural applications is the floating gas holder digester and is commonly referred to as the Indian gobar gas design. The Indian biodigester gas cover is fabricated from sheet steel and floats on the fermenting liquid contained by the masonry walls and bottom. This digester is constructed partially above ground and often employs internal baffles to reduce hydraulic short-circuiting.

The Chinese dome design biodigester has exhibited several advantages over the Indian design. The absence of steel in the cover reduces the cost and permits easier construction in rural areas using indigenous building materials. In addition, elimination of the steel floating cover reduces the corrosion problem in the digester and therefore reduces maintenance. The underground Chinese dome biodigester is also better insulated and easier to load in comparison to the Indian design.

The Chinese biodigester has the following major components: inlet section, outlet section, digestion chamber, gas storage volume, and manhole entrance (Figure I-3). The size and configuration of the components may vary with local needs and construction preferences.

The inlet section consists of a funnel or cylindrical shaped tank fitted with a 0.20 to 0.25 mm I.D. pipe which slants into the digester. The upper end of the inlet tank extends just above ground elevation, with the lower end of the inlet pipe protruding into the digester at or below mid-height. The introduction of substrate (raw digestion material) at the

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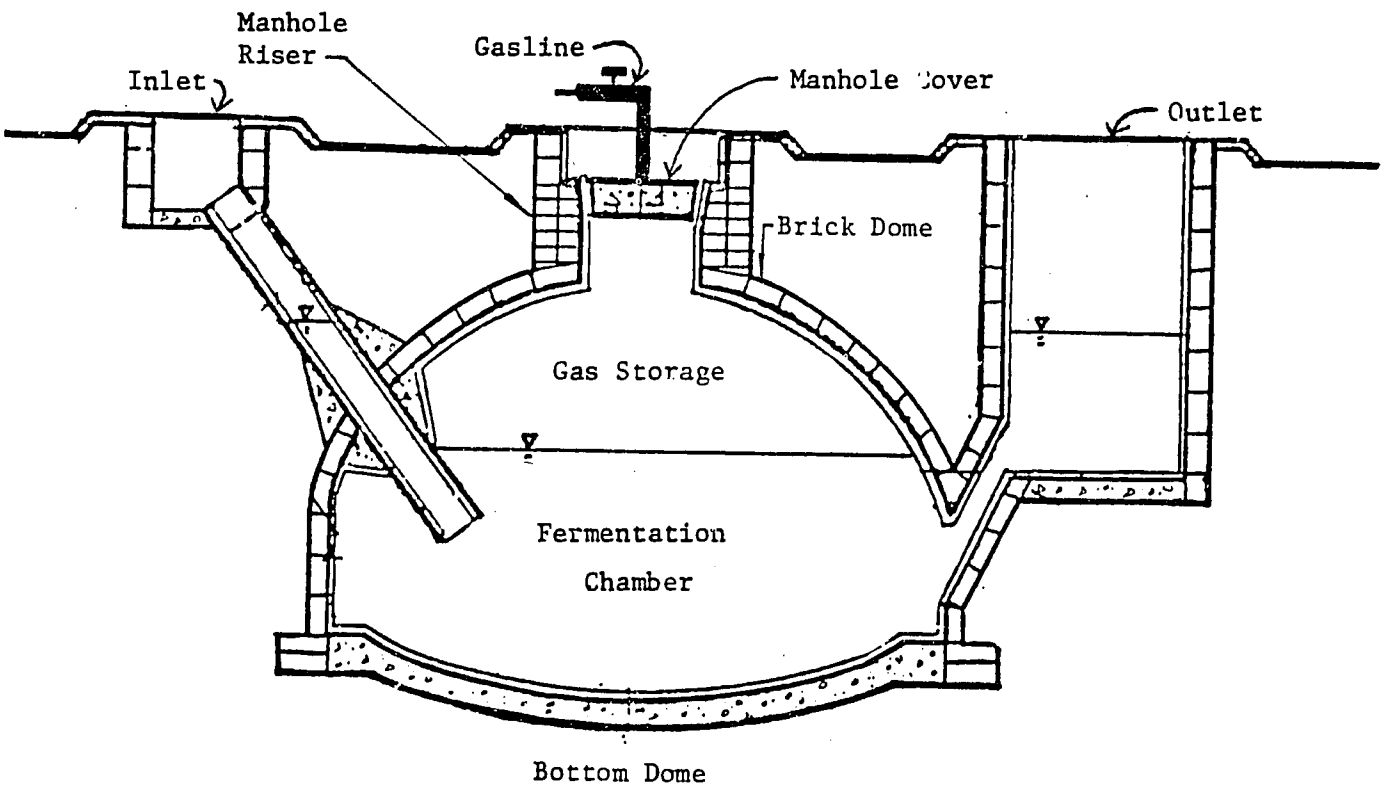

FIGURE I-3

CHINESE DOME BIODIGESTER

middle of the digester facilitates natural mixing of the fermenting material. The inlet may be connected directly to latrines and livestock sheds or may be used as an entrance port for materials brought to the digester site.

The outlet section consists of a cylindrical tank connected to the digester with a pipe or brickwork portal. The upper end of the outlet section extends just above ground elevation, while the lower end is at mid-height of the digester, opposite the inlet section. Although locating the outlet at mid-digester height complicates annual digester cleaning, it reduces hydraulic short circuiting associated with a bottom outlet design and thus improves the fermentation process.

The digestion tank of the Chinese dome digester is composed of a brickwork cylindrical shell resting on a concaved bottom floor and an upper hemispherical brickwork dome. The digestion chamber is entirely underground to improve thermal insulation and to facilitate gravity feeding of substrate. Backfill on the upper dome maintains the thin shell in compression and permits fabrication with brick masonry without reinforcing.

The manhole cover is cast with concrete in the shape of a frustum of a cone and is fitted into a concrete and brick frame located in the manhole riser above the center of the upper dome. The cover is fitted into the frame with a clay gasket to prevent gas leakage. Immediately after setting the bevel shaped cover into the manhole the space above the cover is filled with water to keep the clay saturated to maintain a gas tight vessel.

Typical construction methods for the Chinese dome biodigester are described in Appendix B.

CHAPTER II

DOME BIODIGESTER CONSTRUCTION AT SOLAR ENERGY LABORATORY, BAMAKO, MALI

CHINESE DOME BIODIGESTER DESIGN

The Chinese dome biodigester design used at the project site at the Solar Energy Laboratory in Bamako, Mali, was adapted from a standard brickwork dome digester design by the Southwestern Institute of Architectural Design, Sichuan, People's Republic of China. The design choosen for installation (Drawings 1 to 5) was a 6-cubic meter volume brick and cement mortar reactor. It included a funnel-shaped inlet, cylindrical outlet, concrete inlet pipe, brick floor and walls, brick dome, brick manhole riser, and cast concrete manhole cover.

The 6-cubic meter reactor was choosen as the demonstration unit because it represented the smallest size biodigester for practical application in rural settings. Under normal organic loading conditions (see Chapter IV, "Digester Loading"), the daily gas production rate in China was approximated as 0.25 to 1.00 cubic meters per cubic meter of fermenting liquid under mesophylic temperature conditions (15 to 30°C). Thus, with a 6.0 cubic meter total volume and a 5.0 cubic meter liquid volume, approximately 1.25 cubic meters of gas can be expected daily (using a 0.25 gas production rate). Daily gas consumption in rural regions of China has been estimated at 0.2 cubic meters per capita; therefore, the digester should provide the normal fuel requirements for a family of six.

The 6-cubic meter Chinese design was modified (shown on As-Built Drawings 4 and 5), both in dimensions and in construction materials, in order to conform to the excavation already completed at the project site and to better utilize locally available construction materials. The reactor volume was increased to approximately 7.75 cubic meters because the substrate (see Chapter IV) was found to contain less fermentable material than the pig manure normally used in China. Thus, additional volume was required to obtain the same gas production rate as demonstrate in China. The floor of the inlet, the outlet, and the main digester tank

were constructed with thin concrete slabs because of the stable laterite earth foundation. The digester dome was built lower in the ground than the standard design to provide greater insulation from the extreme temperature variations at the project site. Finally, the outlet tank diameter was decreased to lessen the exposed liquid surface and reduce water loss through evaporation.

DIGESTER EXCAVATION

An excavation at the project site was completed prior to the arrival of the project engineer. The excavation was located on the SEL test field. The dimensions of excavation, as found, are provided on Figure II-1. The size and configuration of the excavation, however, were incorrect for the 6 cubic meter digester design or the modified 7.75 cubic meter design. Therefore, the pit dimensions were modified to those shown on Figure II-2.

The earth and subsoil at the project site are composed of laterite. The top 0.5 m is fractured laterite and was removed manually by the two-man excavation crew using picks and shovels. Below the surface crust, the subsoil was a consolidated laterite and could only be removed by chipping with stone chisels and hammers.

Changes in the excavation dimensions required three days to complete. String lines, a level, and a plumb bob were used to determine the center of the pit. The walls were then recut to be vertical and provide the required diameter. The inlet and outlet were modified. A 250 mm horizontal bench was added to the periphery of the floor as a footing for the cylindrical walls. Finally, an iron stake was driven into the center of the floor for use as a guide in the wall and dome construction.

WORKMEN AND CONSTRUCTION MATERIALS

One mason and two mason's helpers were assigned to the digester construction program. The mason had approximately ten years of experience as a bricklayer, but had no prior experience in dome digester construction. To reduce errors on the project, each phase of the digester construction program was carefully explained prior to initiation of the

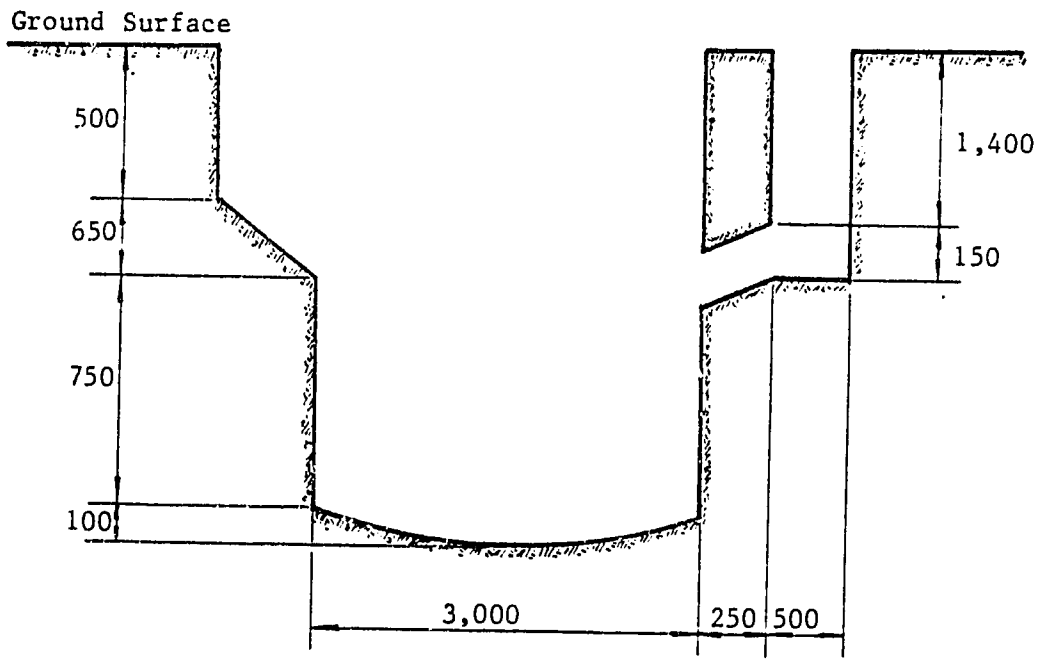

FIGURE II-1

EXISTING EXCAVATION FOR DIGESTER AT THE SOLAR ENERGY LABORATORY, BAMAKO, MALI

(All Dimensions in Millimeters)

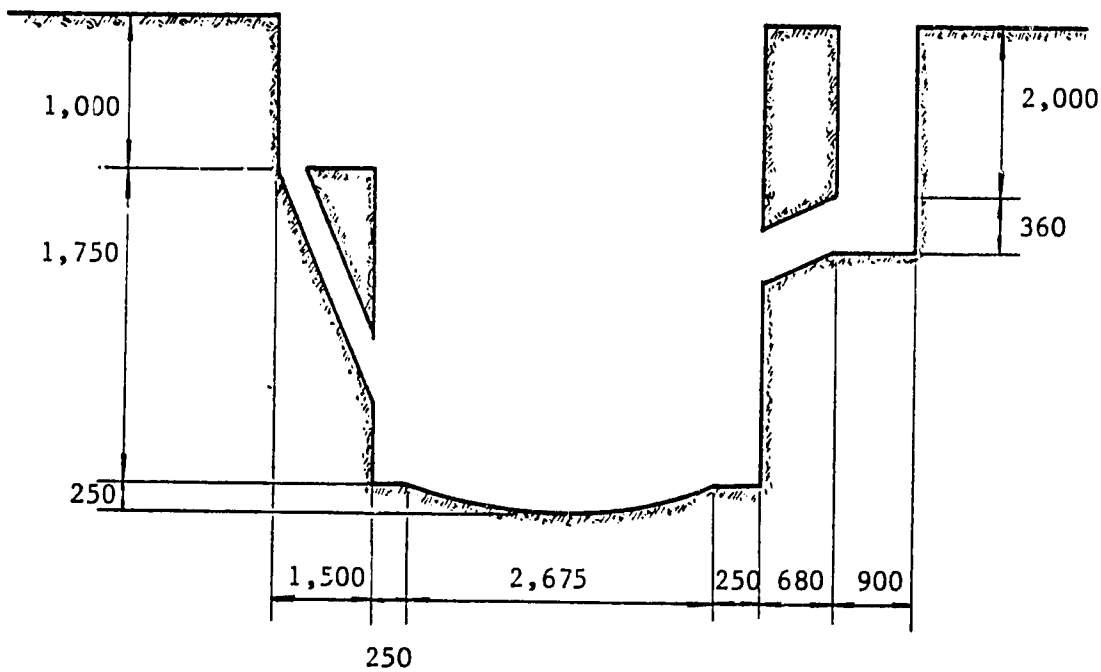

FIGURE II-2

MODIFIED EXCAVATION DIMENSIONS

(All Dimensions in Millimeters)

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work. The mason's helpers were instructed on the type and amount of cement, sand, concrete, mortar, aggregate, and water required. Following a few days of intensive supervision and demonstration, the mason and his helpers evolved into an efficient and skilled work crew, indicating that Chinese digester construction can be accomplished with indigenous African construction skills.

Locally available materials included brick, sand, gravel, clay, and lime. Cement was locally available but of unknown quality; therefore, cement was imported from Senegal for this demonstration digester. Future tests may indicate that local cement is suitable for digester construction. The bricks were composed of fired clay, but were inconsistent in size and strength, with numerous cracks and breaks.

Sand and gravel were of good quality and were sieved before use. Lime was obtained as chunks of CaO with many impurities, but following crushing and slaking the lime proved to be of acceptable quality. The clay was fine river clay, obtained in large dry chunks admixed with organic materials. Following crushing and sieving, however, the clay proved to be of exceptionally high quality.

DIGESTER FLOOR

The original Chinese design called for a brick floor. The stable laterite at the project site, however, provided an excellent footing; therefore, a thin concrete slab was substituted for the brick. The slab was laid by hand to a thickness of 50 mm. The concrete was a cement-aggregate mix with the following composition:

2 parts gravel:1 part sand:1 part cement

After partial drying, the surface was smoothed with hand trowels and a 10 mm thick liquid cement paste was applied to the surface as water proofing. Approximately 150 kg of cement were used in the digester floor and the bases of the inlet and outlet.

The newly poured slab was covered with plastic sheeting and grass mats to reduce water loss and slow the drying process. The slab was allowed to cure for 24 hours and was wetted several times prior to initiation of the vertical wall brickwork.

DIGESTER WALLS, INLET AND OUTLET

The walls of the Chinese dome digester and inlet and outlet structures were built with bricks and cement mortar. The bricks were oriented with the 60 mm x 240 m side down and approximately 10 mm of mortar under and between adjacent bricks. The mortar was prepared with the following composition:

2 parts screened sand:1 part cement

Two courses of brick were laid and their exterior surfaces were plastered with 10 mm of cement mortar. Two 1 m sections of 200 mm inside diameter unreinforced concrete pipe were then lowered into position at the inlet. The two sections of pipe were supported from the surface by rope and were cemented together at their joint. Stones and pieces of broken brick were used to wedge the pipe sections into the inclined trench from the inlet. The base of the pipe extended 300 mm into the digester and was 250 mm above the digester floor. Additional courses of brick were then added to the digester wall up to a total height of 810 mm.

The method of bricklaying for the wall and inlet and outlet structures was as follows:

1. Two courses of bricks were laid.
2. The exterior surface of the bricks was plastered with mortar.
3. The annular space between the excavation wall and the plastered surface of the bricks was backfilled and tamped firm.
4. The next two courses of bricks were laid and the entire process repeated.

The inlet and outlet pit walls were constructed following the completion of the digester walls. The pipe from the inlet to the digester passed through the inlet pit floor and penetrated the digester wall below mid-height. The passage between the digestion chamber and the outlet pit was constructed with bricks in the shape of a trapezoid with dimensions as shown on Figure II-3. The outlet passage was located opposite the inlet pipe.

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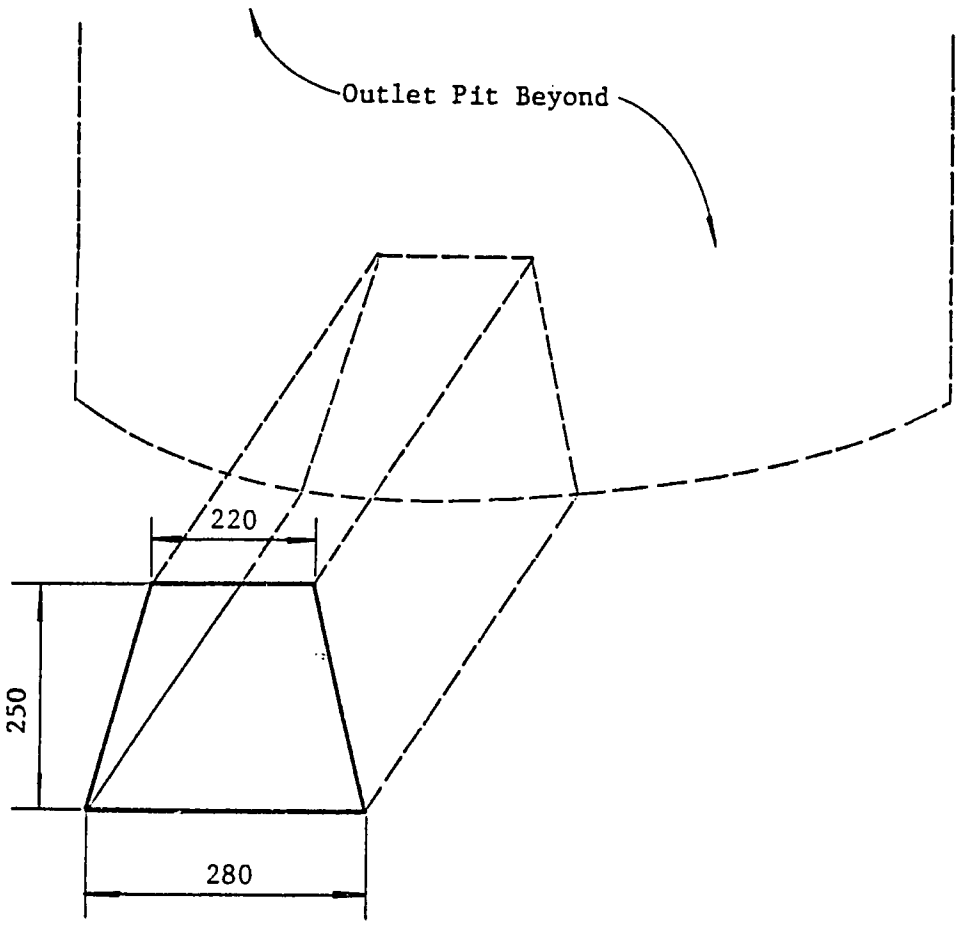

FIGURE II-3

ENTRANCE OF PASSAGE FROM DIGESTION CHAMBER TO OUTLET PIT

1 Dimensions in Millimeters)

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A circular and vertical digestion chamber wall was achieved by use of a string guide and a plumb bob. The string was attached to a 10 mm diameter iron rod set into the concave center of the digester floor at a height coinciding with the base of the digester wall. The string pivoted around the rod so that a constant radius was maintained in the base course. A plumb bob and level were then used to maintain the radius and assure level and vertical placement of subsequent courses of brick.

Approximately 175 kg of cement were used in the mortar for the digester walls, inlet pit, outlet pit, inlet pipe attachment and external plastering. The work described above required five days to complete.

DIGESTER DOME

The dome of the Chinese design biodigester is the principal structural feature that sets it apart from other biodigesters and is also the most difficult to construct. In order to form a perfect hemisphere, a constant radius of curvature must be maintained while working without the benefit of a solid form and largely against the force of gravity. Special techniques have been developed by the Chinese to build domes, and these methods, with some modifications, were applied in construction of the biodigester at SEL in Bamako.

Before construction of the dome, a ring beam (see Appendix B, Figure B-2) was added to the top and outside of the digester side wall to transfer the horizontal thrust of the dome to the surrounding native soil. The ring beam was an unreinforced concrete and rubble mix 150 mm thick that was laid on top of the tamped backfill behind the wall and extended over the top of the wall to form an inclined surface. The angle of inclination of this surface matched the radius of curvature of the dome and thus formed the footing of the dome.

Bricks for the dome were laid in the same orientation as in the wall. Because of the inclination, however, the bricks required support until the mortar set and the ring of bricks was locked into position. Therefore, each brick of a row in the dome was held in position by a 10 mm diameter, 400 mm long piece of rebar bent into a "C" shape. The "C" clamp was spread open until its jaw could hold a newly placed brick and mortar to

the bricks of the previous row. One "C" clamp was used for each brick in a ring of the dome. After a ring was completed, the triangular spaces between adjacent bricks were filled with broken bricks and mortar, which acted to lock the entire ring into position. Each new ring was set at the correct radius of curvature by using a string guide from the center pin. Close adherence to the specified 1500 mm radius of curvature resulted in a smooth dome.

The brick work was continued until a 600 mm diameter opening remained in the top of the dome. The last ring of bricks in the dome formed the footing of the manhole riser (discussed in the next section).

The outside of the dome was plastered with a 10 mm thick mortar covering. After drying, the space above the dome was backfilled with damp earth and tamped. Backfilling continued up to the height of the base of the manhole riser opening. The inside of the digester was then scrubbed with water and a wire brush to remove loose cement as a preparation for the inside sealing (discussed in a later section).

The dome section of the digester required seven days to complete and approximately 200 kg of cement were used in its construction.

MANHOLE COVER, RISER AND SUPPORT RING

The manhole cover and the cover support ring inside the riser were cast in concrete onsite. The form for the manhole cover was cut from 16 gauge sheet metal, as shown on Figure II-4, and was shaped into a frustum of a cone. The two ends were overlapped and spotwelded. Minor deformations in the form were pounded out with a hammer and the edges were filed smooth. The inside of the form was then coated with grease.

Reinforcing for the manhole cover consisted of two 500 mm diameter rings made from 10 mm diameter malleable iron bars, which were set one above the other, 100 mm apart. Eight lengths of 10 mm diameter straight rod were wired to the ring for rigidity. The 25 mm I.D. gas pipe and the two liftout handles, as shown on the revised plans of As-Built Drawing 5 were wired to the straight rods.

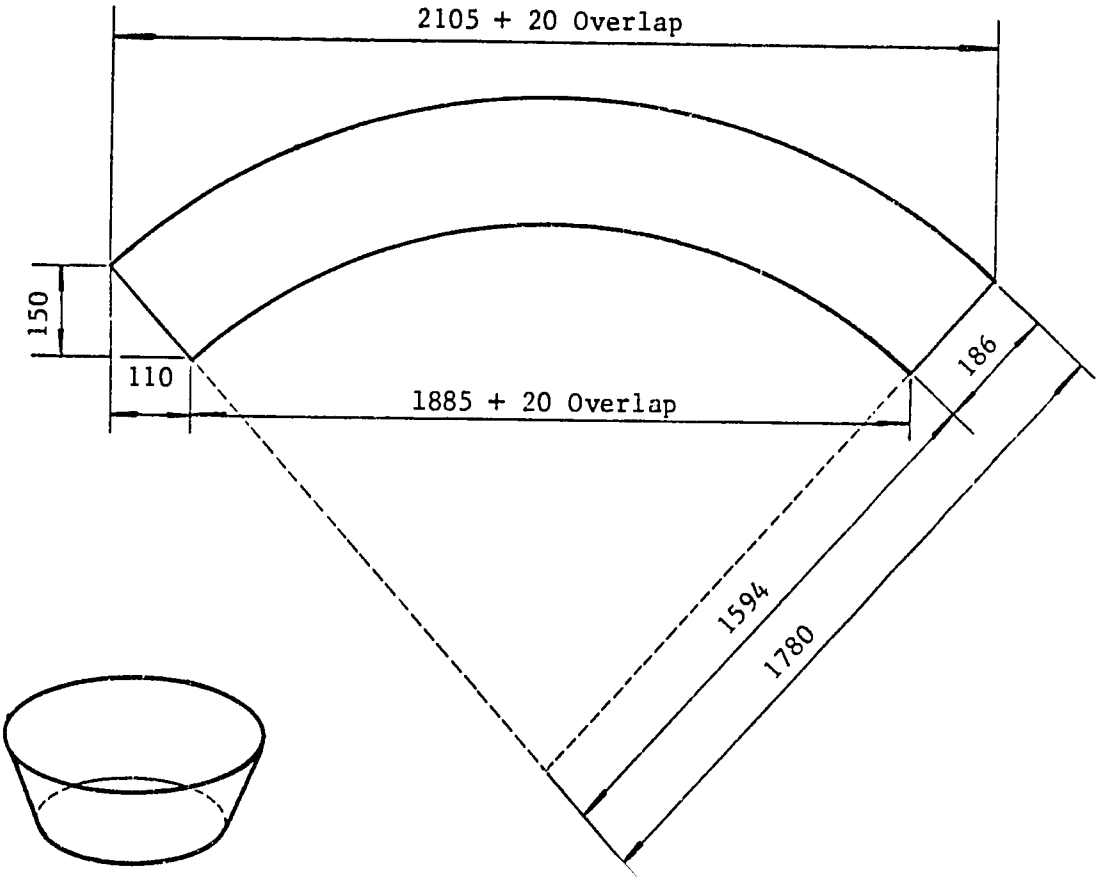

FIGURE II-4

SHEET METAL LAYOUT FOR MANHOLE COVER FORM

(All Dimensions in Millimeters)

The manhole cover was cast by placing the reinforcing inside the form and slowly pouring in concrete having the following composition:

1 part gravel:1 part cement

The concrete was tamped repeatedly and the surface was smoothed. The casting was then allowed to cure for two days before the form was removed.

The manhole riser was constructed around the 600 mm opening in the top of the dome. The riser was built with brick and mortar, with the first ring of bricks oriented on their 120 by 240 mm side as a footing. The following courses of bricks for the riser were oriented on their 60 by 240 mm side and formed a 700 mm diameter ring. A 50 mm ledge was left at the base of the riser as an aid to future cleanout efforts. Additional rings were added until the riser extended 450 mm over the dome.

The outside of the manhole cover form was then greased and placed in the center of the riser. It was supported by a bamboo tripod. Wet paper was wedged between the manhole riser wall and the bottom of the form. Concrete was then packed into the annular space to form the beveled support ring for the manhole cover. The manhole riser diameter was increased to 720 mm and the riser brickwork was completed to a height of 940 mm above the dome.

Following two days of curing, the form for the cover support ring was removed and irregularities in the support ring surface were repaired with mortar. The 145 kg manhole cover, connected to a sturdy pole with ropes and supported by four men, was slowly lowered into position on the support ring to check the fit. The cover was found to sit snugly in the support ring, with all gaps less than 5 mm. This space was required for the clay gasket in order to seal the top of the digester.

The outside of the manhole riser was plastered with a 10 mm thick layer of cement mortar. The remaining excavated space above the dome was backfilled and tamped.

The manhole cover, support ring, and manhole riser required five days to complete and consumed 150 kg of cement.

INTERNAL SEALING OF THE DIGESTER

Internal sealing of the digester for gas and waterproofing was a four-step process. First, a cement slurry coating was applied to the entire inside surface of the digester, inlet, outlet, and manhole riser. This was followed by two 10 mm thick layers of cement mortar. These layers were tightly packed with hand trowels following partial drying to eliminate all crevices and air pockets. Finally, a layer of cement slurry was applied by brush to form a continuous sealing coat. The internal sealing was allowed to cure for four days before the manhole cover was replaced and the digester pressure tested (discussed in a later section).

The sealing work took two days to complete. An electric fan, directed into the inlet pit, and a light bulb suspended from the manhole improved the working conditions within the almost completed biodigester. Approximately 100 kg of cement were used in the four internal sealing coats.

CHAPTER III

BIOGAS PIPING SYSTEM

GAS LINE DESCRIPTION

The gas piping system refers to all gas lines, fittings, and safety equipment between the manhole cover and the gas appliances. The 25 mm I.D. galvanized steel pipe emerging vertically from the manhole cover was connected to a 90° elbow and then to a 25 by 15 mm I.D. galvanized reducer. A 15 mm I.D. bronze ball valve was attached to this section and was followed by a short section of 15 mm I.D. galvanized pipe. A 15 mm I.D. nylon reinforced neoprene hose was stretched and clamped over the end of this pipe. The flexible pipe was installed in a shallow trench leading to a mud-walled, grass-roofed hut where the manometer, safety equipment, and gas appliances were located. Figure III-1 shows a schematic of the gas piping system.

MANOMETER, FLAME TRAP AND PRESSURE RELIEF VALVE

Valves and other gas line equipment were minimized to keep the digester gas system simple and low cost. Although manometers are easily and cheaply constructed (as explained in Appendix A), a Dwyer manometer from the SEL warehouse was installed on a side loop of the gas line. The manometer was filled with colored water and could measure a maximum pressure of 914 mm (36 inches) of water column.

The manometer was followed by a flame trap/backflow preventer. This apparatus, shown on Figure III-2, was combined with a pressure relief valve. The flame trap was a simple water barrier backflow preventer. The system operated by allowing gas to enter the main chamber of the apparatus only when the gas pressure was greater than the head of water maintained in the chamber (usually 100 mm). No backward flow (and therefore no back flame) was possible because of the water in the chamber. Gas in the chamber was free to move upline through the remaining gas pipe to any appliance when the last ball valve was opened.

The pressure relief valve was a simple hydraulic device that contained no mechanical parts. Gas entering the flame trap forces water

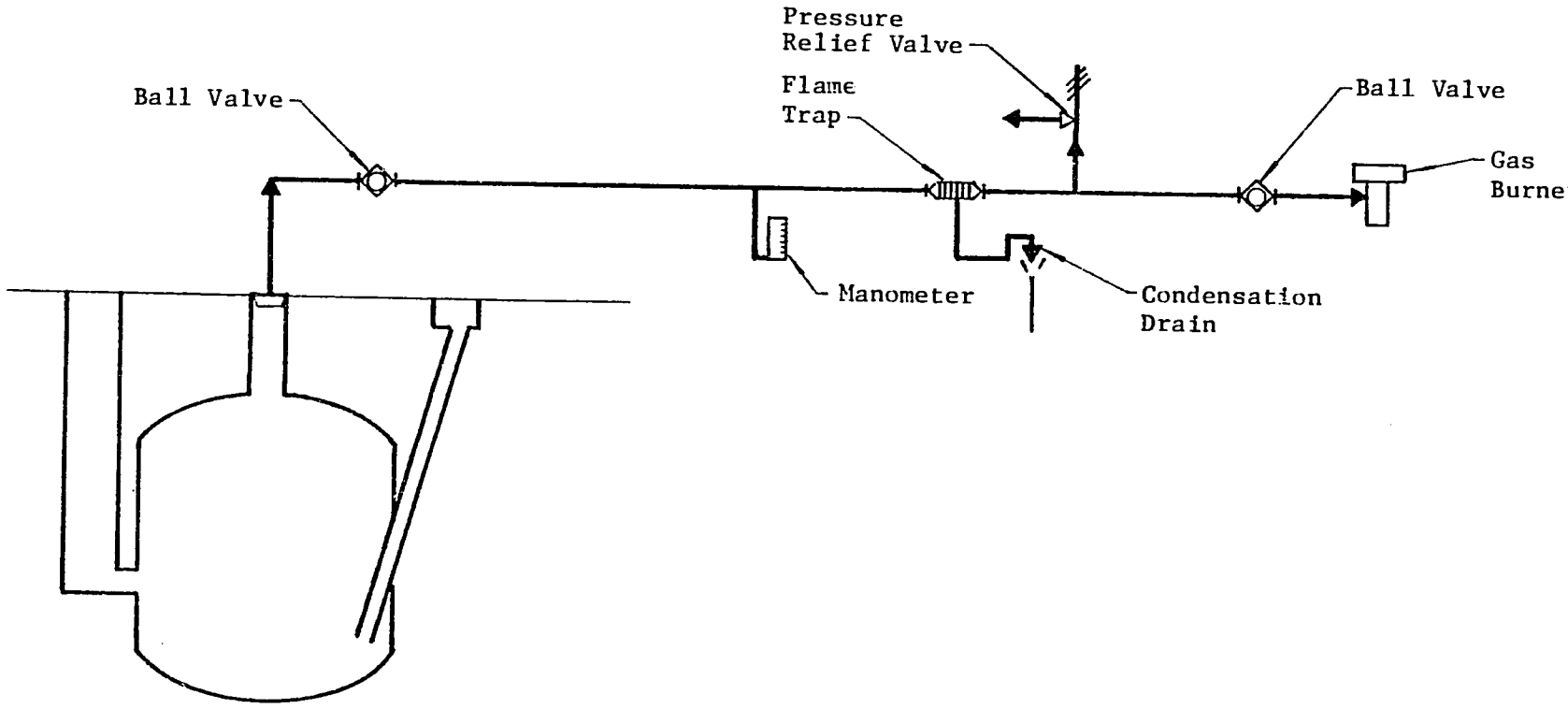

FIGURE III-1

SCHEMATIC OF GAS LINE BETWEEN CHINESE DOME BIODIGESTER AND GAS BURNER

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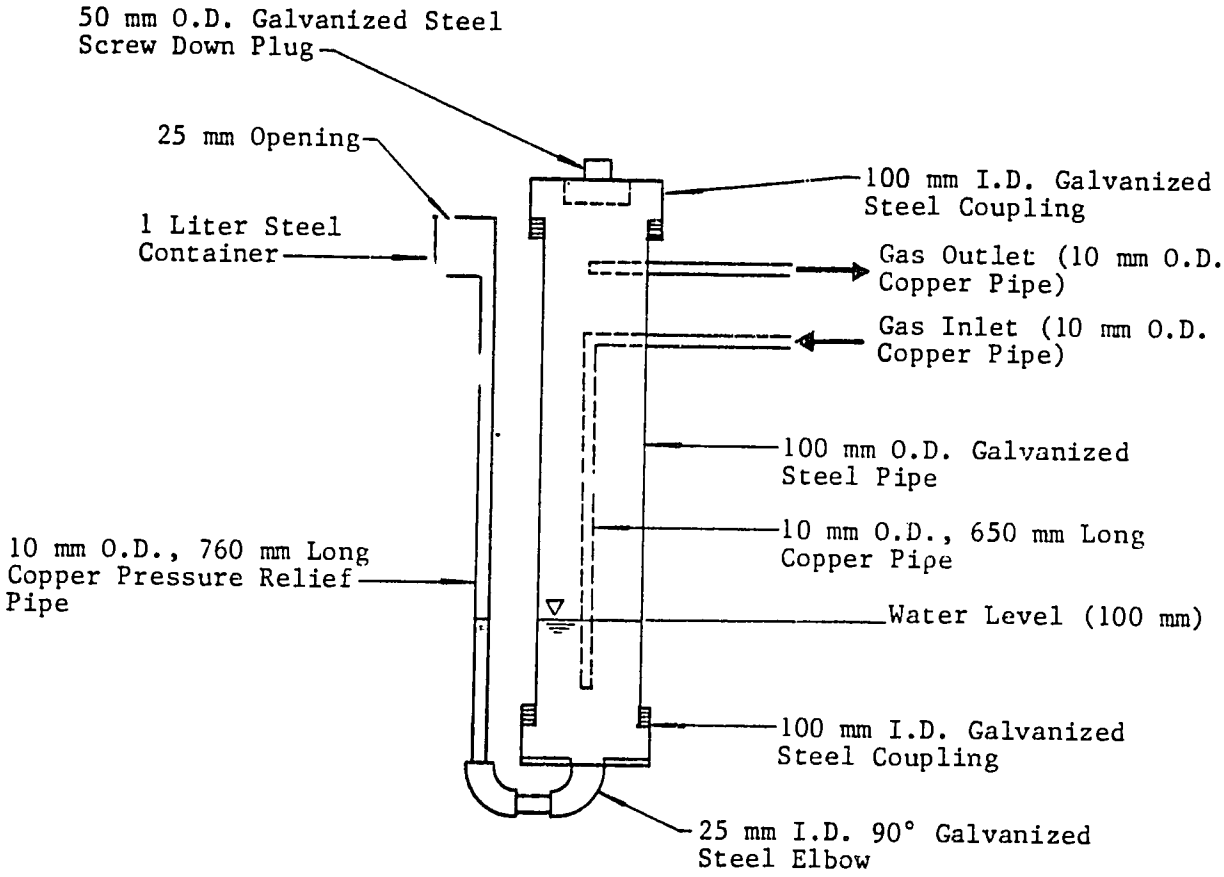

FIGURE III-2

FLAME TRAP AND PRESSURE RELIEF VALVE

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up through the pressure relief tube to a level equal to that of the manometer. If the valve to the gas appliances is closed and the pressure builds up in the system, water is forced higher up in the pressure relief tube. When the gas pressure reaches approximately 760 mm (30 inches) of water column, sufficient water has been forced up the relief tube to allow gas to escape up the tube. The water that overflows the tube is trapped by the container on top of the relief pipe. As the gas pressure falls below approximately 650 mm of water column, the water in the upper reservoir flows back into the relief tube, thereby terminating the flow of escaping gas.

BIODIGESTER AND GAS LINE PRESSURE TESTING

Prior to loading the Chinese dome biodigester with organic substrate, the digester and gas lines were checked for leaks. The manhole cover was set into the support ring after a 20 mm thick layer of clay was applied to the beveled surface of the ring. Water was added to the space above the cover to keep the clay seal moist and to observe any gas leaks through or around the cover.

Water was then fed into the digestion chamber through the inlet pipe until the manometer indicated that both the inlet and outlet portals were covered and the air, trapped above the water, was being compressed. The water flow was halted and the concrete was allowed to absorb water overnight. The following morning, water was once more added to the digester until the manometer indicated that the air above the water was at a pressure of 500 mm of water column. The level of water in the outlet pit and the manometer were then observed for changes. Both the water level and the manometer level dropped, indicating that leakage of gas and water was occurring.

Short sections of the gas piping system were isolated and tested for leaks by immersion in soapy water. Two gas leaks were located and repaired. In addition, air bubbles were observed at the perimeter of the manhole cover. Clay was packed into the bubbling spaces until all leakage was stopped. The digester was repressurized by adding water. The manometer level and water level in the outlet were again observed. Both

levels dropped, but at a much slower rate than in the first test. Water was then added to the digester at such a rate that the level of water in the outlet pit remained constant. The rate of water addition to maintain a constant level was found to be 0.9 liter/minute. Gas pressure fell only slightly during this test, indicating that the major digester leakage was due to water passing through the floor or sidewall and not because of gas seeping through the dome.

The digester manhole cover was reopened and the water in the digester pumped out. Upon careful inspection of the interior, small cracks and an open crevice were located in the outlet passage, but no other obvious sources of leakage were observed. The cracks and crevice were repaired with mortar and the entire inner surface was recoated with a cement slurry. Following overnight curing, the dome and walls were coated with a clay-lime mix as a final precaution against additional gas or water leaks. The clay-lime mix was prepared as follows: one part slaked lime (with 30 percent water content) was mixed with 19 parts crushed and screened clay. The mix was wetted and kneaded into a paste and was then applied to the dome and walls in a 3 to 5 mm thick layer.

Water was then added to the top edge of the concave floor and all entrances were closed so that the clay-lime sealing could cure in a high humidity environment. Curing continued for four days, after which the inside of the digester was reexamined. The clay-lime seal was firm, had no crevices, and appeared to form a good seal.

The manhole cover was replaced and sealed. The digester was refilled with water and pressurized to 500 mm of water column. Both pressure and water level remained constant overnight, indicating that the leaks had been sealed.

CHAPTER IV

ORGANIC SUBSTRATE ANALYSIS, BACTERIOLOGICAL SEED, INITIAL DIGESTER LOADING AND BIOGAS ANALYSIS

ANALYSIS OF ORGANIC SUBSTRATE

Cow manure was the organic fermentation substrate suggested for use in the biodigester by the Solar Energy Laboratory staff. Arrangements were made for a weekly pick-up of manure from the Sotuba Livestock Research Institute, which is located approximately 10 km from the SEL. Representative samples of manure from the weekly manure delivery were collected and analyzed. Parameters for analysis were limited to those easily performed with locally available equipment and essential for determining organic loadings. These parameters included:

- Percent total solids
- Percent water
- Percent volatile solids

All analyses were conducted in accordance with the methods provided in Standards Methods for the Examination of Water and Wastewater, 14th Edition, APHA-AWWA-WPCF, 1975, and are described in detail in Appendix C. Table IV-1 is a list of the analytical results of six replicated samples of the raw cow manure. The analytical results and visual inspection indicated that the raw manure was very dry when received from Sotuba. The moisture content of the raw substrate made it suitable for aerobic composting. The percent volatile solids, however, was relatively high and indicated that anaerobic digestion would be possible following rehydration of the substrate.

TABLE IV-1

ANALYSIS OF RAW COW MANURE SUBSTRATE

% Total Solids	= 34.8%
% Water	= 65.2%
% Volatile Solids	= 74.1%

BACTERIOLOGICAL SEED

The biodigestion process depends largely on the fermentation substrate and the bacterial population performing the fermentation. As indicated in the previous section, the cow manure substrate was found to be an acceptable fermentation material based on its 74 percent volatile solids content. The manure contains numerous bacterial groups, some of which will develop into the required anaerobic population for methane fermentation. Unfortunately, this process often takes from two to five weeks. The long start up period can be significantly shortened by culturing anaerobic seed organisms prior to construction of the biodigester. The bacterial seed is then added to the fresh manure during the initial digester loading and gas production usually occurs within several days, depending upon the amount of seed and the size of the digester. This process is discussed in greater detail in Appendix A.

Two 200-liter metal drums were prepared for anaerobic seed culturing by removing their tops and cleaning their inner surfaces with detergent and water. Thirty kilograms of raw manure were added to each drum and the drums were then filled with water to within 100 mm of their tops. Two liters of 5 percent lime water were also added to each container. The contents of each drum were stirred, loosely covered, and allowed to sit in a sunny place for approximately 25 days. At the end of that time an active anaerobic bacterial population had developed and was ready for introduction to the digester.

DIGESTER LOADING

Following successful pressure testing of the biodigester, the manhole cover was removed and organic loading began. Four organic loading rates, ranging from 0.5 to 4.0 kg V.S./M^3-day, were selected for testing in the Chinese dome biodigester. The research program and experimental procedures are discussed in a subsequent section. The initial digester loading was based on a 0.5 kg V.S./M^3-day organic loading rate and a 50-day hydraulic retention time. The liquid volume of the 7.75 cubic meter reactor was estimated to be 5.5 cubic meter. Table IV-2 is a summary of the organic loading calculations.

TABLE IV-2

ORGANIC LOADING CALCULATIONS

Given: Liquid Volume = 5.5 M^3
HRT = 50 Days
Organic Loading Rate = 0.5 kg V.S./M^3 Day

Manure = 35% Total Solids
74% Volatile Solids

1. Total volatile solids added per day:

$$0.5 \text{ kg V.S.}/_{M^3\text{-Day}} \times 5.5 \text{ M}^3 = 2.75 \text{ kg V.S./Day}$$

2. Total volatile solids added to 5.5M^3 Water for Digester Startup:

$$50 \text{ Days} \times 2.75 \text{ kg V.S./Day} = 137.50 \text{ kg V.S.}$$

3. Total raw manure added to 5.5M^3 Water for Digester Startup:

$$137.50 \text{ kg V.S.} \times \frac{1.00 \text{ total solids}}{0.74 \text{ V.S.}} \times \frac{1.00 \text{ raw manure}}{0.35 \text{ total solids}} =$$

530.9 kg Raw Manure

4. Daily raw manure addition at 0.5 kg V.S./M^3 -Day:

$$2.75 \text{ kg V.S./Day} \times \frac{1.00 \text{ total solids}}{0.74 \text{ V.S.}} \times \frac{1.00 \text{ raw manure}}{0.35 \text{ total solids}} = \frac{10.62 \text{ kg raw manur}}{\text{Day}}$$

5. Daily water addition to 10.62 kg raw manure:

$$\frac{5.5 \text{ M}^3}{50 \text{ Day}} = 0.11 \text{ M}^3/_{\text{Day}} \quad \text{Water in Manure} = 10.62 \text{ kg} \times 0.65 = 6.9 \text{ kg}$$

THEREFORE: 110 kg-6.9 kg = 103.1 kg Water per Day

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530.9 kilograms of raw manure were weighed and loaded into the digester via the manhole. The two drums of bacterial seed were then poured into the inlet, and the manhole cover was reset into its support ring using a clay gasket. Vigorous gas production was observed within two days of loading.

INITIAL BIOGAS PRODUCTION

No gas flow meters were available at the Solar Energy Laboratory; therefore, the initial gas production rate provided here is an estimate based on the known gas storage volume, the temperature, and the pressure. The gas storage volume in the digester was approximately 2.25 cubic meters. The pressure and internal temperature of the digester following the first day of gas production were approximately one atmosphere (gauge) and 40°C respectively. Since the external temperature was also 40°C, the approximate first-day gas production was 4.5 M^3, with a gas production rate of 0.82 M^3/M^3-day. This is expected to increase to about 5.5 M^3/day, or a gas production rate of about 1 cubic meter of gas per cubic meter of liquid digester volume.

Samples of this initial gas were collected and analyzed for methane content using an apparatus built on site. The methane test equipment and the test procedures are described in Appendix C. The gas was found to consist of 56 percent methane and 44 percent carbon dioxide and trace gases.

The first and second day gas was flamed off in a test burner. Although no calorific tests were conducted, the burning gas exhibited a hot, blue flame and appeared suitable for use in any properly modified gas burning equipment.

CHAPTER V

TECHNOLOGY TRANSFER

CHINESE DOME BIODIGESTER CONSTRUCTION TECHNOLOGY TRANSFER

The dual objectives of the project were construction of the dome biodigester and instruction of SEL engineers in the construction and operation techniques. These goals were achieved by participation of Solar Energy Laboratory engineers in each phase of the digester construction program and through an operation technology seminar series.

Five copies of the Chinese biodigester plans were distributed to the engineers of SEL. One SEL engineer, Mr. Yaya, was permanently assigned to the Chinese dome biodigester program and each step on the construction job was discussed with him. During modification of the construction plans and throughout the subsequent construction period, frequent consultations and hands-on instruction played important roles in assisting Mr. Yaya and fellow SEL engineers to learn the techniques of Chinese biodigester construction and to gain confidence in their own ability to design and construct dome digesters. Increasing responsibility for design, construction management, and actual fabrication was transfered to Mr. Yaya as the project progressed. This approach resulted in a successful field training program and learning experience, considering the short (five weeks) duration of the project.

BIODIGESTER SEMINAR

Knowledge of the biodigester process is essential for the successful operation of the dome digester and for future biogas projects. An understanding of the biological and physical processes occurring within the digester permits engineers to calculate and design specific biogas systems for any waste treatment project, rather than simply following empirical recommendations developed for other regions and environmental conditions.

The seminar series was divided into five parts, outlined in Table V-1, and was presented in 15 one-hour classroom, laboratory, and

TABLE V-1

BIODIGESTER TECHNOLOGY SEMINAR OUTLINE

I. Overview of Biogas Process and Definition of Important Terms.

1. Volatile Solids
2. Hydraulic Retention Time
3. Organic Loading Rate

II. Develop Understanding of the Biodigester Biology and Efficiency Equations.

1. Gas Production Rate
2. Organic Conversion Efficiency
3. Gas Yield Coefficient

III. Laboratory Analytical Methods for Biodigester Monitoring.

IV. Scientific Report Preparation.

V. Problem Solving Sessions and Examination.

field sessions. Three members of the SEL staff and four technician-scientists from the Malian Agricultural Research Station at Samako participated in the classes. The first part of the seminar program concentrated on bringing all class members to an equivalent starting point in biogas biology for subsequent lectures and on introducing the pertinent technical terms. These terms and digester performance equations, introduced in a later lecture, formed the basic tools used to explain digester design and analysis (definitions are provided in Appendix C). Following the introduction of the terms and performance equations, several class sessions were devoted to examples of digester analysis and problem solving.

The next phase of the seminar program was devoted to laboratory techniques required to analyze biodigester substrates and monitor biodigester performance. Class members learned equipment and sample preparation and performed the following basic tests:

1. Percent water in substrate
2. Percent volatile solids in substrate
3. Fermentation substrate preparation
4. Ammonia nitrogen in substrate
5. Percent methane in digester gas
6. pH of digester supernatant

Test procedures are included in Appendix C.

In order to assist the engineers in future research efforts, lecture time was devoted to the method of scientific report preparation. This seminar was particularly well received, for it provided a standardized format for reports and will ultimately increase the effectiveness of the Solar Energy Laboratory as a research institution.

The final lectures of the biodigester instruction program were used for problem solving and application of the analytical techniques to typical biodigester design problems for Mali. A quiz, shown with answers in Table V-2, was administered to the class members to determine the effectiveness of the lecture series. The average score on the examination was 90 percent, which indicated the success of the sessions.

TABLE V-2

BIOGAS QUIZ

1. Question: Give the equation for organic removal efficiency.

   Answer: $\frac{\text{V.S. IN-V.S. out}}{\text{V.S. In}} \times 100 = \%$ V.S. removed.

2. Question: A sample of manure was found to contain 35% dry solids and 55% ash after heating to 550° C. Find the % V.S.

   Answer: 100 - 55% = 45% V.S.
   The % dry solids is not required when the % ash is known.

3. Question: Given: Methane yield coefficient = 0.3 m^3 CH_4/kg V.S. removed
   Digester liquid volume = $10m^3$
   Loading rate = 1.5 kg V.S./m^3 day
   Organic removal efficiency = 45%
   Find the daily CH_4 production

   Answer: 10 m^3 x 1.5 kg VS/m^3 - day = 15 kg VS added per day

   $$\frac{15 \text{ kg V.S.}}{\text{Day}} \times 0.45 = 6.75 \text{ kg VS removed/day}$$

   $$\frac{6.75 \text{ kg VS Removed}}{\text{Day}} \times \frac{0.3 \text{ m}^3 CH_4}{\text{kg VS Removed}} = 2.0 \text{ m}^3 CH_4/\text{day}$$

4. Question: Given: 5 cows produce 57 kg manure/day
   Manure is 65% water
   Manure is 45% volitile solids
   Loading rate = 1.5 kg VS/m^3- day
   HRT = 20 days

   Find: 1. size of the digester required (liquid volume only).
   2. amount of water to be added to the daily manure feed.

   Answer: 57 kg/day x 0.35 = 19.95 kg solids/day
   19.95 kg/day x 0.45 = 8.98 kg V.S./day

   $$\frac{8.98 \text{ kg V.S./Day}}{1.5 \text{ kg V.S./m}^3\text{-day}} = 5.99 \text{ m}^3 .$$

   1) Liquid volume $\approx$ 6.0 m^3

   $$20 \text{ day} = \frac{6.0 \text{ m}^3}{\text{x m}^3/\text{day}} \times 0.30 \text{ m}^3/\text{day}$$

   57 kg/Day x 0.65 = 37.05 kg water/day in manure

   $$\frac{37.05 \text{ kg/Day}}{1000 \text{ kg/m}^3} = 0.037 \text{ m}^3/\text{day}$$

   2) 0.30 m^3/day - 0.037 m^3/day

   $$= \frac{0.26 \text{ m}^3 \text{ water added}}{\text{day}}$$

CHAPTER VI

SEL BIODIGESTER RESEARCH PROGRAM

OBJECTIVES OF THE PROGRAM

A three-phase biogas research program for the Solar Energy Laboratory was established to guide biodigester studies and extension efforts (see Appendix C). The first and most important phase was the determination of an optimum organic loading rate and hydraulic retention time, consistent with local organic substrates, gas and fertilizer utilization expectations, and local operating constraints. This phase includes four operational experiments scheduled to last approximately one year. In addition to determining the most appropriate operational parameters, the experimental program is designed to provide SEL engineers with experience and confidence in biodigester operation and analysis. Following the completion of the first phase experimentation, a scientific report will be written and the results used for future extension projects. In addition, the results will be simplified for use in an illustrated user manual written in local languages.

The second and third phases of the program were designed to examine alternative construction materials for biodigesters and gas utilization possibilities respectively.

TESTING PROGRAM

Four basic tests were designed to determine the optimum organic loading rate. In order to simplify the experimentation and analysis of data, the hydraulic retention time was fixed at 50 days. The long hydraulic retention time (HRT) also had the effect of reducing the daily water requirement, which is an important consideration in the arid Sahel gion. The four organic loading rates were 0.5, 1.5, 2.5, and 4.0 kg M^3-day. The basic tests consist of routine analysis of influent and luent volatile solids, pH, effluent temperature, quality and quantity gas, and ammonium content of influent and effluent. All test edures and terms are described in detail in the research program,

included as Appendix C. To facilitate the program, an inventory was conducted of the pertinent analytical equipment at SEL and a list of additional required equipment was prepared. This additional equipment has been ordered.

CHAPTER VII

PROJECT SUMMARY AND CONCLUSIONS

COMPLETION OF OBJECTIVES

All objectives for the Chinese dome biodigester project in Bamako, Mali, were successfully completed within the timetable provided in the project proposal. Excavation, design modification, and construction of the dome biodigester proceeded on schedule, with only minor delays for material procurement. Following completion of the digester, pressure testing revealed a minor leak in the digestion chamber. The leak was carefully repaired and the digester was loaded with cow manure and anaerobic seed. Vigorous gas production was observed within two days.

Instruction of the Malian engineering staff at SEL in biodigestion technology was structured into 15 one-hour sessions. The seminars, laboratory work, and field instruction periods were lively and often generated question, answer, and problem solving sessions lasting well after the end of regular classtime. Homework problems and a final examination revealed that the material had been understood and assimilated.

A detailed biodigester research and application program was designed to assist local engineers in determining optimum operating criteria and to provide a structured plan in order that classroom lectures will be reinforced by practical experience. The first phase of the research plan calls for tests to examine organic loading rates and will include both field and laboratory work. Additional research phases will examine alternative and less costly biodigester construction materials and appropriate gas utilization technologies.

CONCLUSIONS AND RECOMMENDATIONS

Biodigestion of livestock and human wastes provides an effective means of (1) preserving and improving scarce organic residue for agricultural fertilizer, (2) conserving limited irrigation water by using digester effluent as combined irrigation and fertilizer. (3) improving rural sanitation by isolation of waste materials and attenuation of

pathogenic and parasitic populations, and (4) generating a viable alternative energy source.

The Chinese dome biodigester, in comparison to the Indian design agricultural biodigesters, is particularly appropriate for use in Mali and other Sahel regions because its underground construction dampens the diurnal temperature variations and reduces evaporative losses. In addition, the masonry construction techniques and required construction materials are readily available in the region.

The biodigester technology transfer classes and research plan have provided the basis for an effective biogas technology program at SEL. Following the one-year research experience, SEL engineers will be prepared to instruct potential local users in biodigester construction and operation and thus permit promulgation of the biodigestion technology.

Although the Chinese dome biodigester is seen as constructable with local technology and materials, several environmental and social problems may limit application of the process.

1. Most cattle herds are relatively small and, due to shortages of forage, are field grazed during the day and padlocked only at night. This reduces the available feedstock for fermentation.

2. The arid climate rapidly dries manure on the ground and increases the requirement for make-up water prior to biodigestion. The value and alternative use of scarce water resources must be weighed against its use in biodigesters.

3. Many small scale livestock herders are semi-nomadic. Permanent biogas installations may require untenable changes in their culture.

The principal users of the biodigestion technology are anticipated to be medium- and large-scale livestock producers. They will be able to make the necessary capital investments, have permanent installations, and have relatively large energy needs for pumping and electricity, which could be met with biogas fuel. Excess electrical generating capacity may form the nucleus of additional small-scale industries in the rural sector. Digester effluent may be used to increase the productivity of grazing land to close the cycle.

Small, family sized biodigesters (as used in China) are not foreseen as immediately practical in Mali or adjacent Sahel nations. Capital investment, feedstock availability, competent operational labor, and incentive are largely lacking.

It is essential to integrate the operation of the biodigester into traditional patterns of farming so that the residues from agricultural operations feed into the digester and the digester sludge and effluent are used as fertilizer. Unless these systems are coordinated, no matter how perfectly the technicalities are worked out for Mali, the biodigester program will not survive.

Water scarcity in the Sahel region may be a serious obstacle to biodigester implementation. It is suggested that semi-solid biodigestion of organic wastes be investigated as an alternative biofermentation process. New digester designs and digestion techniques will be required. The new approaches must also be appropriate for the environmental, social, and economic conditions of the Sahel.

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A P P E N D I X A

The Small Biogas Plant:

Operation and Use

APPENDIX A

THE SMALL BIOGAS PLANT: OPERATION AND USE

I. What is a Biogas Digester?

Biogas is a mixture of methane, carbon dioxide, and traces of other gases and is produced as a result of anaerobic (without oxygen) biological decay of carbonaceous wastes. The biological process, known as anaerobic digestion, can be controlled in a biogas digester to produce biogas fuel and stabilized organic residue for fertilizer.

A biogas digester is a reactor to contain the organic wastes and methane producing bacteria and to capture the evolved gases. There are two basic biodigester designs: the fixed dome and the floating cover. The fixed dome or Chinese design employs a single masonry or cast concrete structure to contain the fermenting wastes and to collect the evolved gases. The floating cover or Indian design uses a masonry or concrete base to contain the fermenting material and a floating sheet metal gas storage chamber.

In addition to the structure of a biogas digester, there are two major modes of operation. The first, batch-fed, refers for a digester which is filled completely with fermentable materials and starter bacterial seed which is then allowed to digest for 40 to 60 days. Following fermentation, the batch-fed digester is emptied and refilled with fresh manure. The second mode, continuous-fed, refers to a biodigester which receives daily or semi-weekly additions of fermentable materials and discharges equal volumes of digested materials at the time of feeding. In general, the batch-fed digester produces higher quality gas and fertilizer, but the continuous-fed digester is easier to operate.

II. The Starter

Biogas is evolved by the action of the methane-producing bacteria. These bacteria are present in the manure, but there are not enough of them to produce biogas in large amounts, nor are they necessarily the most suitable. For this reason it is better to add to the slurry some bacteria of known ability to do the work efficiently. This medium is known as the starter. The starter usually comes from sludge of a working digester. When starting a biogas plant far from a working biogas plant, it would be necessary to culture a starter to avoid transporting large quantities through long distances. A starter may be cultured by adding a few gallons of sludge or mud from a sump area of a livestock pen to a clean, open 55-gallon drum or similar container. Fresh manure, mixed 1:1

with water, is then mixed in to within 10 or 20cm of the top. The drum is then loosely covered and allowed to ferment for 3-4 weeks until the digester is ready for loading.

III. Establishing a Small Biogas Plant

The quantity and kind of waste organic materials available will determine whether it pays to build a biogas plant or not. There should be enough to produce the amount of biogas and/or sludge required. The biogas plant should be large enough to handle all the organic wastes in order to control pollution. The amount of available raw materials and the retention time will determine the size of biogas plant to be constructed. The ambient temperature, available space, the kind of sub-soil, the height of the water table and flood level will determine the design of the biogas plant to be constructed.

Construction of the underground biodigester has several advantages over above-ground units. Underground digesters permit gravity feeding of the fermentation materials, the subsoil provides structural support and the earth provides insulation to maintain an even digestion temperature. In areas of periodic flooding or high groundwater tables, however, underground digesters may be inundated and filled with sand and debris. Biodigesters in these regions must be constructed above or partially above-ground. Additionally, in areas with rock or adobe substrata, excavation may be difficult and necessitate an above-ground design.

IV. Operation of a Biodigester

An understanding of the biological processes which occur inside the biodigester aid in achieving successful fermentation and a continuous supply of high quality gas.

A. Basic theory

The fermentation process is relatively complicated one involving two main stages:

Stage 1: Bacteria break down complex organic materials, such as carbohydrate and chain molecules, fruit acid material, protein and fats. The disintegration produces acetic acid, lactic acid, propanoic acid, butanoic acid, methanol, ethanol and butanol, as well as carbon dioxide, hydrogen, H_2S, and other non-organic materials.

In this stage the chief micro-organisms are ones that break down polymers, fats, proteins and fruit acids, and the main action is the butanoic fermentation of polymers.

Stage 2: The simple organic materials and CO_2 that have been

produced are reduced to methane by micro-organisms, the chief ones being the methane-producing or methanogenic micro-organisms of which there are many varieties. This stage may be represented by the following overall reaction:

$(c_6H_{10}O_5)n + nH_2O$ through the action of methane bacteria -- $3nCH4 + 3nCO_2$ + heat

Individual reactions include:

i. Acid breakdown into methane.

$$2C_3H_7COOH + H_2O \text{ -- } 5CH_4 + 3CO2$$

ii. Oxidation of ethanol by CO_2 to produce methane and acetic acid.

$$2CH_3CH_2OH + CO_2 \text{ -- } 2CH_3COOH + CH_4$$

iii. Reduction with hydrogen of carbon dioxide to produce methane.

$$CO_2 + 4H_2 \text{ -- } CH_4 + 2H_2O$$

Thus, complex organic materials are broken down through the action of micro-organisms to produce imple organic acids, alcohols, CO_2 etc., which are ıen utilized by micro-organisms with the release of ethane.

This is a complex biological and chemical process and a balance must be maintained between the two stages. If the first stage proceeds at a much higher rate than the second, acid will accumulate and inhibit the fermentation in the second stage.

B. Necessary conditions for fermentation

Since this fermentation is the result of the action of many sorts of anaerobic micro-organisms, the better the living environment of these micro-organisms, the faster the production of biogas. If proper conditions cannot be maintained, biogas production will slow or cease altogether. Optimal living conditions for these micro-organisms are:

1. Airtightness

None of the biological activities of anaerobic micro-organisms, including their development, breeding and metabolism, requires oxygen; in fact they are very sensitive to the presence of oxygen. The breakdown of

organic materials in the presence of oxygen will produce carbon dioxide; in airless conditions it will produce methane. If the biogas pit is not sealed to ensure the absence of air, the action of the micro-organisms and the production of biogas will be inhibited and some will escape. It is therefore crucial that the biogas pit be watertight and airtight.

2. Suitable temperature

The temperature for fermentation in the pit will greatly affect the production of biogas. Under suitable temperature conditions the micro-organisms become more active and gas is produced at a higher rate. Methane can be produced within a fairly wide range of temperatures, depending on prevailing conditions. Three types of fermentation are possible: at high, medium and ordinary temperatures. For high temperature fermentation, the temperature should be 50-55°C; for medium, 30-35°C; and for ordinary temperature, 10-30°C.

3. Necessary nutrients

There should be plentiful material for the normal growth of the micro-organisms, and they must be able to extract their nutrients from the source of fermentation. The main nutrients are carbon, nitrogen and inorganic salts. A specific ratio of carbon to nitrogen must be maintained, between 20:1 and 25:1. This ratio will vary for different raw materials, and sometimes even for the same ones. The main source of nitrogen is human and animal excrement, while the polymers in crop stalks are the main source of carbon.

4. Water content

There must be suitable water content as the micro-organisms' excretive and other metabolic processes require water. The water content should normally be around 90 percent of the weight of the total contents. Both too much and too little water are harmful. With too much water the rate of production per unit volume in the pit will fall, preventing optimum use of the pit. If the water content is too low, acetic acids will accumulate, inhibiting the fermentation process and hence production; also, a rather thick scum will form on the surface. The water content should differ according to the difference in raw materials for fermentation.

5. Maintaining a suitable pH balance

The micro-organisms require a neutral or a mildly alkaline environment with a pH of between 7 and 8.5. For normal fermentation, the concentration of volatile acid, measured

Table A-1. Approximate values for the carbon/nitrogen ratios of some of the common materials used for biogas pits

Material	Carbon as a percentage of total weight %	Nitrogen as percentage of total weight %	Carbon/ nitrogen ratio
Dry straw	46	0.53	87:1
Dry rice stalks	42	0.63	67:1
Maize stalks	40	0.75	53:1
Fallen leaves	41	1.00	41:1
Soya bean stalks	41	1.30	32:1
Wild grass: i.e. weeds etc. (in China often narrow, thin leaved)	14	0.54	27:1
Peanut vine stalks	11	0.59	19:1
Fresh sheep manure	16	0.55	29:1
Fresh cow/ox manure	7.3	0.29	25:1
Fresh horse manure	10	0.42	24:1
Fresh pig manure	7.3	0.60	13:1
Fresh human manure	2.5	0.85	2.9:1

Table A-2. Water content of common fermentation materials

Type of Material	Human manure	pig manure	Solid pig manure	Liquid Horse manure	Common wind-dried manure	Dried rice stalks
Water content: %	80	82	96	76	30-40	10-20

Table ·3

Materi

Genera s
manure
livest .k

Pig ma

Horse .n

Rice h

Fresh :a.

Flax s ..

Straw

Leaves 'r

Potato
leaves n
etc.

Sunflo
and st k

Sludge

Waste t
wine o
making a

C. Initial charging of the biodigester

Upon completion of the biodigester, the unit must be
with fermentable materials and starter bacterial seed
Generally, pile-rotted vegetative mass is the first m
added to the unit. This is accomplished by feeding t
the inlet and outlet compartments. Next, manure and
latrine wastes are added. Finally, water and starter
added to bring the fermenting material up to the prop
operating level.

Gas production usually commences within a few days af
loading. The initial gas is generally rich in carbon
and will not ignite. This gas must be released throu
gas line pet cock.

Following one to two weeks' production of burnable ga
regular schedule of feeding the biodigester must be i

At weekly or fortnightly intervals in summer an every
days in winter remove fermented material from the exit
compartment and replenish fresh material through the
compartment. This should be a mixture containing not
stalks and vegetable matter but a suitable quantity o
and animal manure. If the biogas pit is linked to a
livestock per human and animal manure flows naturally
pit, making it only necessary to supplement this with
pile-rotted vegetable matter and water. In changing
material one should first outlet, then inlet material
extract so much material and manure that the openings
inlet and outlet compartments are exposed, as this wi
gas to escape. The quantity of material removed shou
equal the amount put in. If there is a temporary lac
material for fermentation, one should simply put in
enough water to maintain the previous water level and

For each unit volume of methane, twice the volume of oxygen will ensure complete combustion under stoichiometric conditions. The oxygen content of air is roughly one-fifth, so complete combustion of a unit volume of methane requires ten unit volumes of air. Since biogas contains 60-70 percen methane, complete combustion of a unit volume of biogas required six or seven unit volumes of air. Fulfilling these conditions will release the maximum amount of heat.

In using biogas as fuel you should try to achieve a ratio fo biogas to air that will allow complete combustion, in order to yield the best results. During complete combustion of biogas the flame is forceful, pale blue in color, and makes a hissing sound. If it wavers and is pale blue in color, there is too little air (oxygen) and incomplete combustion. If the flames are short, yellow and unsteady, then there is insufficient biogas and too much air - these conditions produce low temperatures and bad results.

The most efficient use of biogas is in cooking and other direct heat applications. About 60 percent of the heating value of biogas is utilized with a properly designed burner. A good burner has a mixing chamber for the premixing of air with biogas prior to combustion. However, a very simple burner can be made out of a piece of iron pipe. plugged at one end and perforated along the length with one or two rows of holes 1/8" to 3/16" in diameter and ½" to 3/4" apart. The efficiency is lower but it is cheap and easy to make, especially for people in the rural areas.

LPG appliances such as gas stoves, water heaters and gas mantle lamps are readily converted to use biogas by enlarging the injector orifice to about 1/8" diameter. Flat irons using gas or charcoal can also be converted to use biogas for ironing clothes. With gas refrigerators, the heating assembly is by-passed and biogas is piped directly for heating with a ¼" diameter orifice.

Biogas can completely replace gasoline in internal combustion engines. Conversion to giogas is accomplished by simply changing the carburator. A biogas carburator can be fabricated from a one-inch diameter copper tube 6 to 8 inches long fitted with a 3/8" copper tubing inlet at the midsection and a butterfly valve at one end of the tube to control the biogas-air mixture. The power developed by the engine is not as high as when gasoline is used but the same rpm is maintained.

The approximate consumption of biogas is as follows:

cooking burner	6-10 cu. ft/hr.
flat iron	5-6 cu. ft./hr.
gas mantle lamp	2-3 cu. ft./hr.

Therefore, one can control the pressure and ensure safety of the biogas pit. When the pressure within the pit is too high the water in the U-shaped tube will flow up into the safety bowl or bottle, and allow excess methane, or biogas to escape through the safety valve, thus automatically reducing the pressure within the pit. And when the pressure within the pit has been reduced to what is tolerable, the water will once again flow into the U-shaped tube and so maintain the gas pressure within the safe zone, avoiding damage to the pit from excess pressure within.

VI. Safety Considerations with Biogas

Biogas normally contains about 60 percent methane, 35 percent carbondioxide and 5 percent trace gases. In closed areas, a 15 percent concentration of biogas with air is highly explosive and must be avoided. Additionally, since the environment in the digester is anaerobic, clean out of the digester must be conducted with great caution due to the possibility of suffocation through lack of oxygen.

VII. Use of Biodigester Sludge and Effluent as Fertilizer

Organic substances such as human, animal and agricultural wastes, through fermentation, can produce not only a kind of excellent gas fuel -- bio-gas, but also a large quantity of digested sludge and effluent as organic fertilizer, thus coordinating the relationship among fuel, feed and fertilizer, and promoting the development of agriculture and animal husbandry in the rural area.

Sludge is the solid residue removed periodically from the bottom of the biodigester and the solid materials settled out of the liquid discharge. Studies in India, China and the USA confirm that sludge is an excellent organic fertilizer and soil conditioner. It releases nutrients slowly at a rate which crops can utilize and adds organic matter to soils which improves water retention and root penetration. The liquid discharge from the digester contains some partially digested materials and may have a foul odor. It can, however, be applied to crops as a liquid fertilizer or may be used instead of fresh water in charging the digester. Table 4 is an approximate range of nutrient contents of the digested materials for agricultural application.

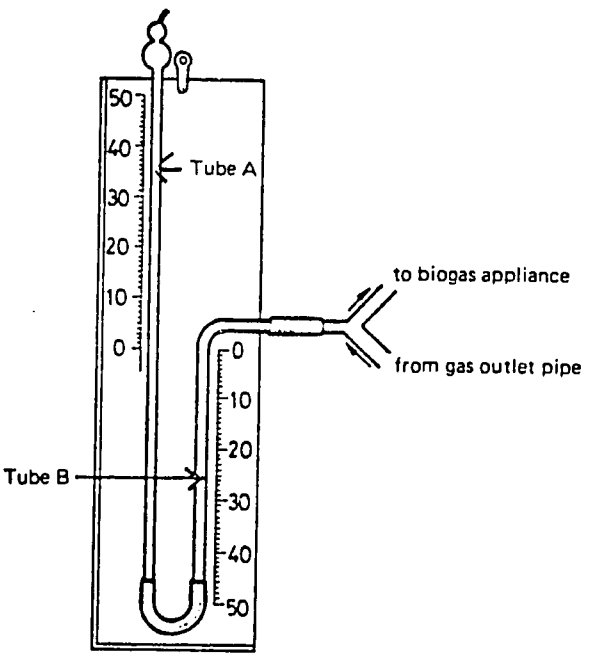


FIGURE A-1. A MANOMETER

Table A-4. Approximate range of nutrient contents of digester manure

Digester manure	Organic matter (%)	Humic acid (%)	Total nitrogen (%)	Total phosphorus (P_2O_5) (%)	Total potassium (K_2O) (%)
Effluent	--	--	0.03-0.08	0.02-0.06	00.5-0.10
Sludge	30-50	10-20	0.8-1.5	0.4-0.6	0.6-1.2

•

VIII. The Improvement of Rural Sanitation by Disposal of Human and Animal Excreta in a Biodigester

In regions, e.g. China, where human and livestock wastes are directly conveyed to a biodigester, the following public health benefits have been observed:

1. Control of feces: All the animal and human excreta are fed into the digester to produce bio-gas through fermentation. This has opened up a new method of managing feces in the rural areas.

2. Control breeding of flies and mosquitoes: Since feces and livestock manure are no longer exposed to open air, the breeding of flies is minimized and the incidence of diseases spread by them has dropped. As a result of the disposal of sewage, the breeding of mosquitoes has also been controlled.

3. Improvement of household hygiene: Biogas is convenient and hygienic compared with wood, or cow dung cake stove.

4. Disposal of feces: Feces which are disposed through fermentation and disinfection in the digester are free from hazard so that the spread of hookworm disease, Schistosomiasis, hepatitis and intestinal infectious diseases has been kept under control.

IX. Summary

Biodigesters have been shown to be a new source of fuel, fertilizer and improved sanitation for rural communities. The units are relatively easy to build with locally available materials and can be operated without extensive training. The installation and operation of biogas digesters in developing nations has the potential to reduce dependence on scarce fossil fuels and fertilizers and to improve the quality of rural life.

A P P E N D I X B

Construction Notes

for the

Chinese Dome Biodigester

APPENDIX B

CONSTRUCTION NOTES FOR THE CHINESE DOME BIODIGESTER

I. Site Selection and Excavation

Biodigesters are located near to the source of fermentable biomass. Where possible, siting should be selected so that both latrine and livestock wastes may be fed by gravity to the biodigester. The site should be free of tree roots and should be above the year-round high water table level.

The selected site should be cleared and leveled. A circle delineating the digester outer diameter and approximately two times the backfill (15-20cm) is then marked on the ground with lime using a center stake and a string guide. Four additional stakes, at right angles to each other, are driven-in outside of the layout circle. The central intersection of diagonal strings tied between these stakes is used to identify the center of the excavation, as shown in Figure 1.

Excavation follows layout of the digester diameter. Where firm soil conditions permit, the pit is dug with vertical walls. Excavated materials must be cleared away from the edge of the pit. The bottom is shaped in accordance with the dimensions provided in the plans. The bottom earth is then compacted. Crushed brick and pebbles are then laid in a 15-20cm deep bed over the floor and are compacted. A small iron or steel ring is embedded in the floor material for attaching the guide string for wall and dome construction. The bed is then covered with mortar which is tamped and leveled to the radius of curvature provided in the plans.

II. Wall Construction

Construction is assumed to be conducted with brick and mortar. If precast concrete slabs or cast-in-place concrete is used, techniques appropriate to these materials must be applied. A base ring of mortar is placed at the periphery of the bottom and bricks (oriented in the vertical position with ½ brick facing in) are laid with mortar. The outside of the wall must be carefully mortared to assure no gaps. After three courses of brick are in place and beginning to set, earth is backfilled and compacted to close the space between the brick and the excavation wall. The vertical bricks are continued in this manner up to the height indicated in the design.

The inlet and outlet structures are set into the wall during its construction. Generally, these structures consist of concrete or clay pipes. The elevations and angles of inclination of these pipes must be as provided in the plans. The pipes must be supported by rope and timber until set in the wall.

When the vertical wall reaches the height designated in the plans, a ring beam is constructed to support the dome. Where available, reinforcing is used in construction of the ring beam, as shown in Figure 2. The ring beam is inclined according to the radius of curvature provided in the design. A concrete and stone or broken brick abutment is then constructed between the ring beam and the native soil. This abutment is used to transfer the horizontal thrust of the dome to the surrounding native soil.

In areas where no reinforcing materials are available, the ring beam may be constructed with brick. The brick are oriented at ¼ brick thickness with their exposed flat side matching the line of curvature of the dome.

III. Dome Construction

Dome construction is accomplished without a form. Bricks are laid in interlacing courses with good quality masonry mortar. The courses are set in place by adhering to the radius of curvature and packing bricks tightly. Bricks are oriented horizontally, with the flat, ½ brick surface out. A U or L shaped iron or steel clip is used to hold the first few bricks or every course. Following each full circle, pebbles or broken bricks are fitted into the gaps between the bricks. As with the walls, the outer surface of the dome is mortared. Following the set of the mortar, earth is backfilled (in thin layers) and compacted over the dome. This backfill provides a working surface for workmen completing the inner rings and acts to hold the dome in compression.

The innermost course shall be constructed of ½ bricks. After the mortar has set, the superstructure for the manhole cover is constructed.

IV. Inner Surface Sealing Coat

The inner surface of the entire digester requires multiple layers of sealing to assure gas and water tightness. The base coat consists of a wet mix of cement and lime (in a ratio of 1:02). This mix is brushed over the complete inner surface following a thorough cleaning to remove loose mortar.

The base coat is followed by a layer of cement, lime and sand plaster (in a ratio of 1:02:03) to a thickness of 0.5cm. After partial drying (2-3 hours), the surface is pressed hard with a trowel. A middle layer, with the same consistency of the previous plaster, is then applied. The surface plastering consists of a 0.5cm layer of a cement, lime and sand (in a ratio of 1:0.4:3). This layer is pressed and then smoothed with a trowel. Finally, the surface is coated 2 or 3 times with a wet cement and lime mortar (in a ratio of 1:02).

The biodigester must be maintained in a damp condition and allowed to cure for 5-7 days before filling.

B

V. Casting the Manhole Cover

The manhole cover may be cast in an excavated earthen form or constructed wood or steel form. Reinforcing bar is required for the cover handles and to secure the 12mm I.D. galvanized gas pipe.

The cover is fitted to the digester following backfilling and tamping of the earth cover. In order to assure a gas tight fit, the cover support ring is covered with a clay gasket. After the manhole cover is fitted, water is placed over it to keep the gasket wet and to determine if the seal is gas tight.

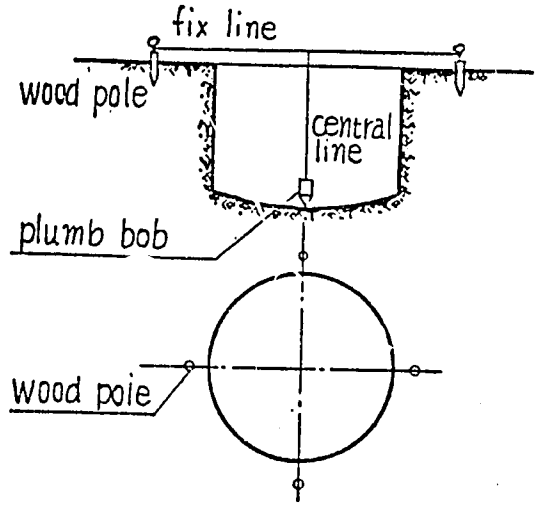


FIGURE B-1 STAKING THE DIGESTER EXCAVATION

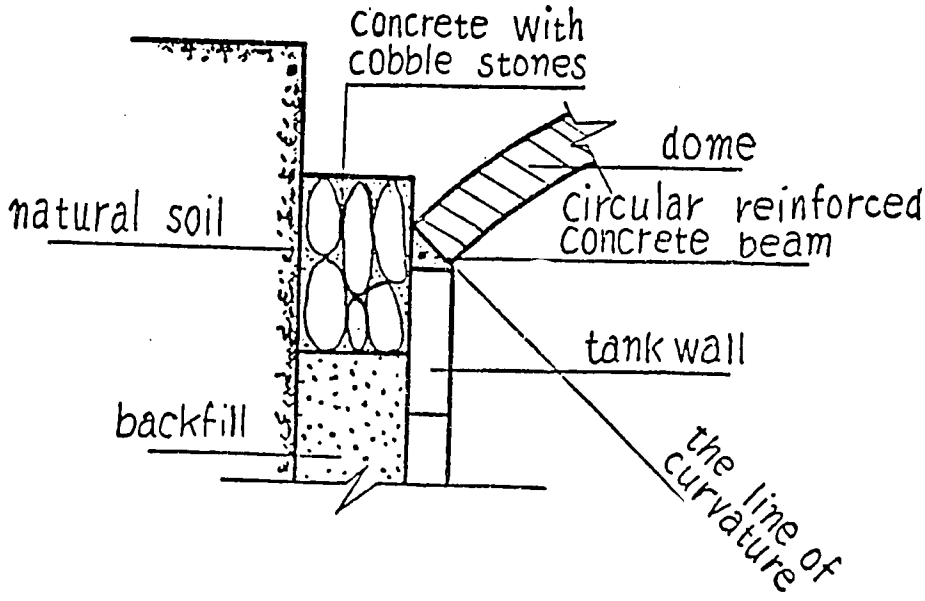


FIGURE B-2 RING BEAM

A P P E N D I X C

Three-Phase Biogas Research Program

APPENDIX C

THREE-PHASE BIOGAS RESEARCH PROGRAM
SOLAR ENERGY LABORATORY, BAMAKO, MALI

OBJECTIVES

I. Determination of optimum organic loading rate and hydraulic retention time, consistent with local organic substrates, gas and fertilizer utilization expectations and local operating constraints. Simplification of results of testing and publication of a local user operational manual.

II. Economic and pilot scale examination of locally available materials for use in digester construction.

III. Examination of local priorities for gas usage, digester sizing and loading requirements to achieve continuous biogas supply. Experimentation with biogas fueled refrigation, water pumps, etc.

PHASE 1: DIGESTER PERFORMANCE OPTIMIZATION

Performance of an anaerobic digester is controlled by a combination of digester geometry, organic loading regime and local environment. The most important factor in controlling the fermentation process is the organic loading. Geometry and environment are relatively unimportant in optimizing performance when hydraulic short-circuiting is avoided and local temperatures favor the biological process. Thus, the primary focus of research in Phase 1 is directed at determining the optimum organic loading conditions; that is, the organic loading rate and the hydraulic retention time.

TESTING AND DIGESTER OPERATION INSTRUCTIONS

The existing Gobar gas digester (GG) and the newly constructed Chinese Design Digester (CD) will be operated at varying organic loading rates and a constant hydraulic retention time (HRT) of 50 days. The loading rates will begin at 0.5 Kg V.S./m^3-Day and will be increased to 4 Kg V.S./m^3-Day. HRT is to be held constant at 50 days to (1) minimize water usage, (2) maximize fertilizer value of effluent, and (3) assure biostabilization of pathogens. The basic tests will consist of routine analysis of influent and effluent volatile solids, pH, effluent temperature, quality and quantity of gas, and ammonium content of influent and effluent. A list of analytical procedures, definitions, required instruments, and materials is included in the Appendices.

TEST 1: Operating Parameters

Loading Rate = 0.5 Kg V.S./m^3-Day

HRT = 50 Days

PROCEDURES

1. Mix and load daily digester feed for GG and CD according to the operating parameters provided.

2. Collect a 50 milliliter sample of feed two days per week and conduct the following tests:

   a. Volatile solids analysis

   b. pH determination

   c. Ammonium determination

3. Measure total daily gas production and analyze the gas for the CH_4 content two times per week.

4. Remove a volume of effluent equal to the influent. Collect a 50-milliliter sample and conduct the following tests two times per week.

   a. Volatile solids analysis

   b. pH determination

   c. Ammonium determination

   d. Temperature

NOTES FOR TEST 1

1. Digester feeding will be conducted daily on a regular schedule.

2. Analytical tests will be conducted on the same day the samples are collected.

3. Samples are to be well mixed and representative of influent and effluent.

4. All data will be recorded in a notebook with legible, neat and clear entries.

5. Data will be used to plot the following curves:

   a. Influent and effluent V.S. (mg/l) versus days.

   b. Influent and effluent ammonium (mg/l) versus days.

   c. Gas production rate and methane production rate versus days.

   d. Gas yield coefficient versus days.

6. Test will be continued for 50 days, maintaining the same loading rate.

TEST 2: Operating Parameters

Loading Rate = 1.5 Kg V.S./m^3-Day

HRT = 50 Days

Conduct Test 2 in the same manner as Test 1. Record, analyze and plot data. Test will continue for 50 days using the given operating parameters following one month of start-up feeding at 1.5 Kg V.S./m^3-Day. The one-month delay is required for stabilization of the process.

TEST 3: Operating Parameters

Loading Rate = 2.5 Kg V.S./m^3-Day

HRT = 50 Days

Conduct Test 3 in the same manner as Test 1. Record, analyze and plot data. Test will continue for 50 days using the given operating parameters following one month of start-up feeding at 2.5 Kg V.S./m^3-Day. Delay is required for stabilization of the process.

TEST 4: Operating Parameters

Loading Rate = 4.0 Kg V.S./m^3-Day

HRT = 50 Days

Conduct Test 4 in the same manner as Test 1. Record, analyze and plot data. Test will continue for 50 days using given operating parameters following one month of start-up feeding at 4.0 Kg V.S./m^3-Day. Delay is required for process stabilization.

PREPARATION OF SCIENTIFIC REPORT AND USER MANUAL

Upon completion of the four tests, the data will be organized into the form of tables which compare the operation of the two digesters under equivalent organic loading conditions. The following operational efficiencies will be calculated and compared.

Organic Removal Efficiency
Methane Production Rate
Methane Yield Coefficient

The information derived from this exercise will then be used to determine the optimum operating condition for each digester and to compare and contrast the operation of both units.

The curves plotted during the testing phase will be included in the report as supporting evidence, while the tables of data will form part of the appendices.

Prior to writing the report a literature review of all available biogas material will be initiated. The purpose of the literature review will be to (1) enable the Engineer conducting the tests to understand the results and compare them with similar tests by other authors and (2) assist the Engineer in developing further tests and modifications to improve the digester operational performance.

THE SCIENTIFIC REPORT

The format for the scientific report will be as follows:

TITLE

ABSTRACT - A short (less than 200 words) summary of Project and Results.

INTRODUCTION AND LITERATURE REVIEW - A brief background of the project objectives, location and related material by other authors for comparison.

METHODS AND MATERIALS - A detailed description of all digester components of this study, all analytical procedures used, digester feed analyses and feeding procedures.

RESULTS - A detailed list and short explanation of the results of all tests. Some of the tables of data made during the tests may be inserted in this section.

DISCUSSION - The discussion section points out the important features of the results section and permits the author to evaluate the project. Errors in method and suggested improvements are included in this Section of the report. The curves plotted during the testing phase are to be used in the discussion section to reinforce hypotheses and to illustrate concepts. Information by other authors cited in the literature review is to be contrasted with the results of the present testing program.

CONCLUSION - This is a short section outlining the conclusions that the chief engineer has drawn from the results of the testing program.

REFERENCES - This section is an alphabetical list of the other sources of information used in writing the report. The citing will be as follows:

Author, Date published, Title, Journal or Publisher, Volume and Issue Number, Place published.

APPENDICES - All data collected during the testing program will be organized into tabular form and included in the appendices. Any nonstandard tests or other procedures will be concisely described and included in this section.

PREPARATION OF A USER MANUAL

Following the completion, review and editing of the scientific report a manual for local users of biogas technology will be prepared. This manual will differ substantially from the scientific report in that it will contain no research findings or conclusions, but rather simple formulas for local users to follow in operating biogas digesters. The Engineer will convert the results of the testing program and biodigester construction experience into an easily understood and illustrated manual. Manure loading rates will be converted to volumes of manure and water required. A section on digester construction will be written with simple plans for a minimum cost and minimum difficulty digester. Also, a final section will be included on gas utilization.

PHASE II AND PHASE III RESEARCH

The Phases II and III biogas research programs for the Solar Energy Laboratory in Bamako, Mali, will be developed after the successful conclusion of Phase I. This delay is required for two important reasons. First, the Chief Engineer of the biogas program must gain considerable expertise and experience in digester operation prior to evaluating alternative designs and materials. Second, the locally available manure feedstocks for anaerobic fermentation must be thoroughly tested to determine maximum potential gas production prior to initiation of a research program into gas utilization possibilities. Upon completion of Phase I the Chief Engineer will be well qualified to develop and carry out Phases II and III.

DEFINITION OF TERMS

ANAEROBIC FERMENTATION - Biological conversion of an organic substrate to methane, carbon dioxide and trace gases in an oxygen-free, aqueous environment.

HYDRAULIC RETENTION TIME (HRT) - The length of time a daily volumetric addition remains in a reactor given ideal plug flow conditions.

$$HRT = \frac{\text{Liquid volume}}{\text{Daily volume added}}$$

ORGANIC LOADING RATE - Kilograms of volatile solids added per cubic meter of reactor per day.

SUBSTRATE - Materials used by bacteria as feed.

VOLATILE SOLIDS - The fraction of the dry solids which combusts upon heating to 550°C. The volatile solids are considered equivalent to the biologically available substrate (feed).

DRY SOLIDS - The fraction of fresh manure remaining after removal of water at 102°C.

FIXED SOLIDS - The mineral fraction remaining after the volatile solids determination.

GAS PRODUCTION RATE - The volume of biogas or methane produced per cubic meter of digester per day.

GAS YIELD COEFFICIENT - The volume of biogas or methane produced per day divided by the kilograms of volatile solids destroyed per day.

ORGANIC CONVERSION EFFICIENCY - The difference of volatile solids added in the influent and volatile solids removed in the effluent; that is, the amount of volatile solids destroyed in fermentation.

INFLUENT - Manure and water added to the digester via the inlet.

EFFLUENT - Material removed from the digester via the outlet.

ANALYTICAL PROCEDURES

CRUCIBLE PREPARATION:

1. Wash and rinse crucibles (use 3 per sample).
2. Mark with letter or number on bottom using pencil.
3. Place in muffled furnace for one hour at 550°C.
4. Cool in desiccator to room temperature.
5. Measure and record weights. Use immediately or store in desiccator. NOTE: Do not touch crucibles by hand, but rather use tongs.

VOLATILE SOLIDS AND PERCENT WATER DETERMINATION FROM MANURE SOLIDS:

1. Use 3 prepared crucibles for each sample.
2. Weigh and record marked, empty crucibles-- Weight 1.
3. Place approximately 10 g. well mixed and representative sample in each crucible and record weight-- Weight 2.
4. Dry at 102°C for 6 to 8 hours, cool in desiccator to room temperature and record weight--Weight 3.
5. Combust in muffled furnace at 550°C for 2 hours. Cool to room temperature in desiccator and record weight--Weight 4.
6. Calculations are as follows:

   a. Weight 2 - Weight 1 = Fresh Sample Weight

   b. $\frac{\text{Weight 2 - Weight 3}}{\text{Weight 2}} \times 100 = \%\ \text{Water}$

   c. $\frac{\text{Weight 3 - Weight 4}}{\text{Weight 3}} \times 100 = \%\ \text{Volatile Solids}$

VOLATILE SOLIDS AND PERCENT WATER DETERMINATION WITH LIQUID SAMPLES (INFLUENT & EFFLUENT)

1. Use 3 prepared crucibles for each sample.
2. Weigh and record marked crucibles. Use immediately--Weight 1.
3. Pipet exactly 10 ml well mixed sample into each crucible.
4. Dry 6 to 8 hours at 102°C. Cool to room temperature in desiccator. Weigh and record--Weight 2.

5. Combust for 2 hours in muffled furnace at 550°C. Cool in desiccator to room temperature. Weight and record--Weight 3.

6. Calculations are as follows:

   a. Weight 2 - Weight 1 = Dry Solids

   b. $\frac{10g - \text{Weight Dry Solids}}{10g} \times 100 = \%\ \text{Water}$

   c. (Weight 2 - Weight 3) X 100 = Volatile Solids, g/l

PERCENT METHANE DETERMINATION

Assumptions:

1. Biogas is composed of only CH_4 and CO_2.

2. CO_2 combines completely with N_aOH.

3. Reaction takes place at constant temperature and pressure.

Reaction:

$$CO_2 + N_aHCO_3$$

Method (see Figure C-1)

1. Purge gas holder with biogas for at least 2 minutes while keeping both clamps open.

2. Close top clamp, then close bottom clamp. Turn off gas flow.

3. Equalize pressure by opening top clamp for one-half second.

4. Add 2N N_aOH slowly to gas holder, keeping pressure equal.

5. When no additional N_aOH will flow to gas holder at equal pressure the reaction is complete.

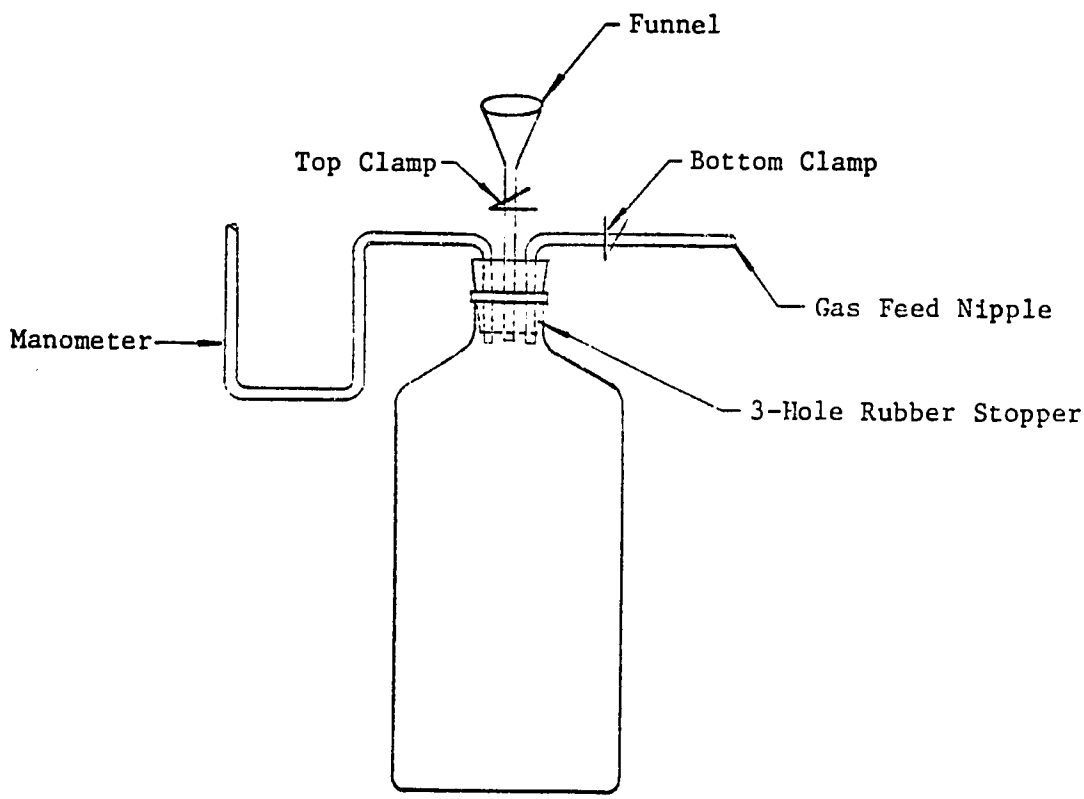
6. N_aOH solution may be used over approximately 10 times.

7. Calculations are as follows:

   a. Volume filled with $N_aHCO = V_{CO_2}$

   b. Total volume of gas holder = V_T

   c. Volume of methane = V_{CH_4}



Graduated Gas Holder/Reaction Vessel

FIGURE C-1

METHANE DETERMINATION APPARATUS

d. $V_T - V_{CO_2} = V_{CH_4}$

e. $\frac{V_{CH_4}}{V_T} \times 100 = \%\ CH4$

8. Wash out apparatus with distilled water.

AMMONIUM DETERMINATION

Standard solution = 100 ppm NH_4^+, use Reagent Grade NH_4CL and follow directions provided with ammonium electrode.

Calibrate Meter:

1. Add 1 ml standard solution to 100 ml distilled water. Add 1 drop 10N N_aOH and place electrode in solution.

2. Set calibration control to 1.0 on X^- scale. 1.0 = 10ppm NH_4^+

3. Add 10 ml standard solution to 100 ml distilled water. Add 1 drop 10N N_aOH and place electrode in solution.

4. Set calibration control to 10.0 on X^- scale. 10.0 = 100ppm NH_4^+.

TESTING LIQUID SAMPLES:

1. Place exactly 50 ml well mixed sample in beaker.

2. Add 1 drop 10N N_aOH. Place on magnetic stirrer with stirring bar.

3. Immediately place electrode in sample and read ppm NH_4^+ from X^- scale. ppm = mg/l.

4. Wash electrode with distilled water and place in 10ppm NH_4^+ solution with no N_aOH for storage until next use.

EQUIPMENT REQUIREMENTS

ITEM	CATALOG NO.	QUANTITY	PRICE (1977)
Crucible (30 ml)	7-965E	36	$ 45.20 (case)
Tongs	15-208	2	15.00 (each)
Muffle Furnace	10-550-185	1	375.00 (each)
Desiccator	8-634-B	2	38.47 (each)
Volumetric Flask (1000 ml)	10-210G	2	11.65 (each)
(500 ml)	10-210F	2	19.22 (two)
(100 ml)	10-210C	6	36.96 (two)
Wet Test Gas Meter	11-166-4	1	765.00 (each)
Pipet (Large Tip) 10 ml	13-671-108D	12	29.70 (twelve)
25 ml	13-671-108E	12	34.34 (twelve)
Wash Bottle (500 ml)	3-409-10E	4	5.37 (four)
Aspirator Bottle (500 ml)	2-972C	6	34.32 (six)
(2000 ml)	2-972E	3	11.20 (each)
Polyethylene Distilled Water Bottle	2-963	1	27.75
Beaker (150 ml)	2-555-25A	24	14.88 (twelve)
(400 ml)	2-555-25C	12	19.08 (twelve)
Spatulas	14-375-10	6	13.50 (six)
	14-375-20	6	2.50 (each)
Porcelain Stand	14-667	2	18.50 (each)
Buret Clamps	5-772	6	4.75 (each)
	5-777	6	6.50 (each)
Hosecock Clamps	5-847	12	2.75 (each)
Tygon Tubing	14-169-1R	1	31.75 (each)
Tubing Connector	15-316B	1 box	11.75 (box)
	15-315B	1 box	8.34 (box)
Rubber Stopper (Size 4)	14-130F	1 lb	4.35
	14-135F	1 lb	4.35
	14-140F	1 lb	4.35
(Size 8)	14-130M	1 lb	4.35

EQUIPMENT REQUIREMENTS, (Cont'd.)

ITEM	CATALOG NO.	QUANTITY	PRICE (1977)
Graduated (1000 ml) Cylinder	8-572G	6	$ 46.93 (total)
(500 ml)	8-572F	8	48.31 (total)
Cork Borer	7-850-10	1	31.50 (each)
Sharpener for Cork Borer	7-850-10	1	10.00 (each)
Glass Tubing	11-377-5	1 box	58.75 (box)
Glass Cutter	11-340	2	4.20 (each)
Stirrer	14-511-1B	1	65.50 (each)
Magnetic Stir Bar	14-511-64	15	2.20 (each)
Stir Bar Retriever	14-511-86	2	4.35 (each)
Thermometer	14-985-5B	10	3.30 (each)

Source: Fisher Scientific Co., 1977

A P P E N D I X D

Structural Analysis

of

Biodigester Dome

APPENDIX D

STRUCTURAL ANALYSIS OF BIODIGESTER DOME

ASSUMPTIONS:

1. Internal gas pressure is low, 0.05-0.10 Kg/cm^2, and is neglected.
2. Thickness of shell is small in comparison to radius of curvature.
3. Boundary condition of spherical shell is assumed to be flexible.
4. Loads are applied about the polar axis and the shell is assumed to be closed.
5. Combined live, backfill and masonry load is assumed to be 2500 Kg/M^3.

TOTAL LOAD ON DOME:

1. Average depth of backfill over dome = 1.3 M.
2. Surface area over dome = 4.98 M^2.

Total Load = $(1.3\ M)(5.3\ M^2)(2500\ Kg/M^3) = 17{,}225\ Kg$

CRITICAL LOAD OF DOME:

$P_c = 1/10\ E\ \left(\frac{h}{R}\right)^2$ FROM: Biogas Technology and Utilization, Sichuan Provincial Office of Biogas Development, 1979

WHERE:

P_c = Critical Load, Kg

E = Modulus of Elasticity for Malian Brick-Masonry Shell = $7.04 \times 10^8\ Kg/M^2$

h = Thickness of shell = 0.06 M

R = Radius of Curvature = 1.5 M

$$P_c = 1/10(7.04 \times 10^8\ Kg/M^2)\left(\frac{0.06M}{1.5M}\right)^2 = 1.13 \times 10^5\ Kg$$

FACTOR OF SAFETY:

$$\frac{1.13 \times 10^5\ Kg}{17.225\ Kg} = 6.5$$

10

A P P E N D I X E

Digester Design Assistance

for the

Center for Renewable Energy

University of Dakar, Dakar, Senegal

APPENDIX E

DIGESTER DESIGN ASSISTANCE FOR THE CENTER FOR RENEWABLE ENERGY UNIVERSITY OF DAKAR, DAKAR, SENEGAL

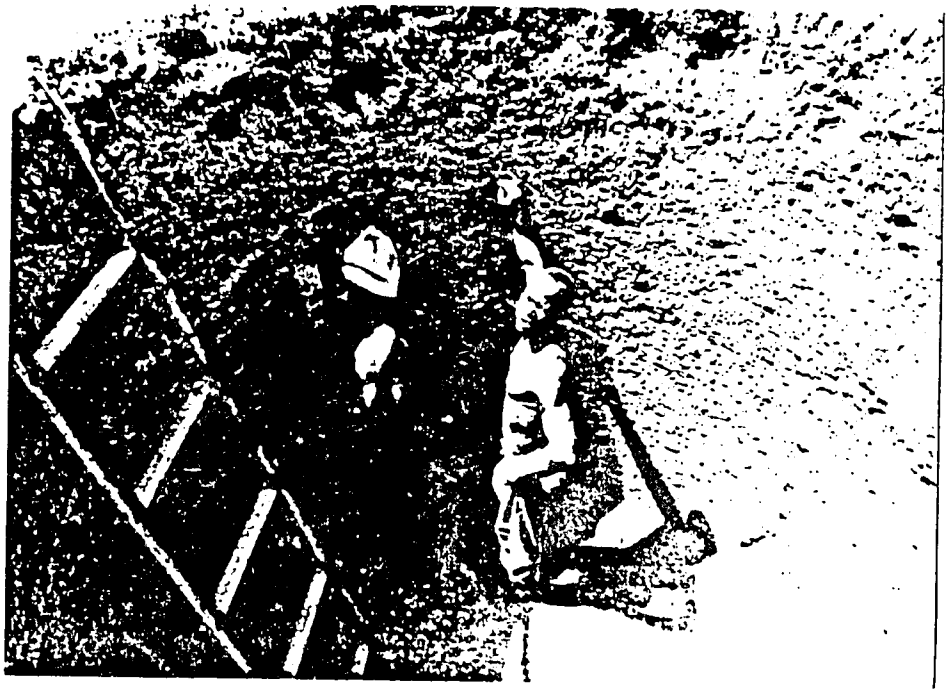
Following the successful completion of the SEL Biodigester Project and upon the request of Terence Hart, Chief Engineering Consultant for SEL, the biodigester consultant was sent to the Center for Renewable Energy in Dakar to assist Gerard Madon, Chief Mechanical Engineer, in a revision of a biodigester design. The biodigester under consideration is planned for construction in Sotuba, Mali, under a grant from the United Nations.

One day of consultation resulted in preliminary plans for a 44-cubic meter (liquid volume) circular, reinforced concrete digester with a 4-meter diameter. The unit is to digest wastes from approximately 65 head of cattle and will have a 50-day hydraulic retention time and a 1.5 Kg Volatile Solids/M^3-Day loading rate. A 50 cubic meter welded steel floating gas reservoir set into a reinforced concrete basin was also suggested. A diaphragm pump will be used to load and empty the digester and a blower will be utilized to push the biogas 100 m to a cafeteria kitchen for use in gas stoves

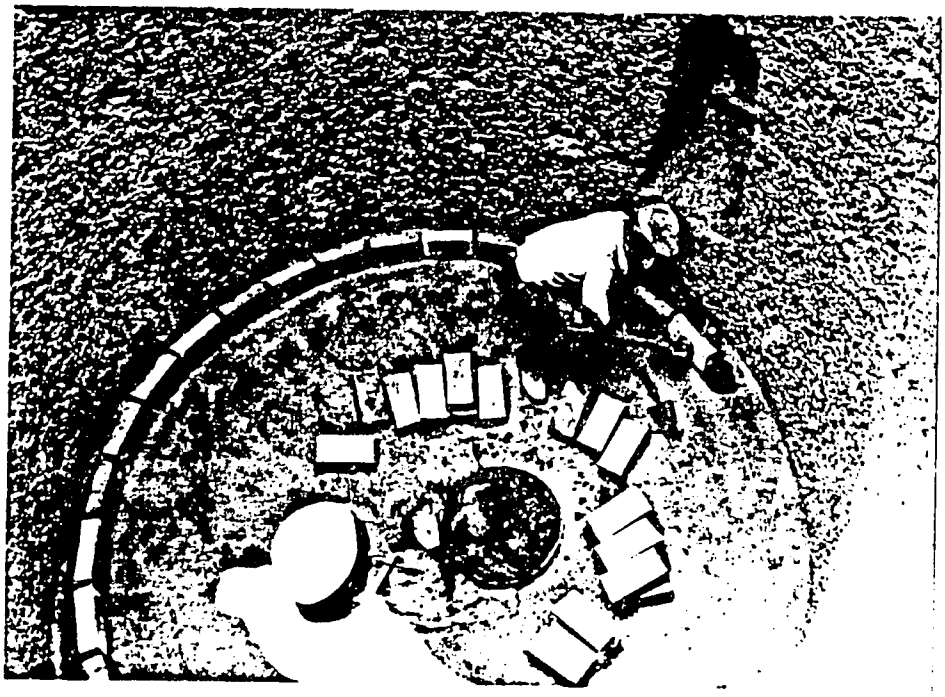
A P P E N D I X F

Photo Record

of Project

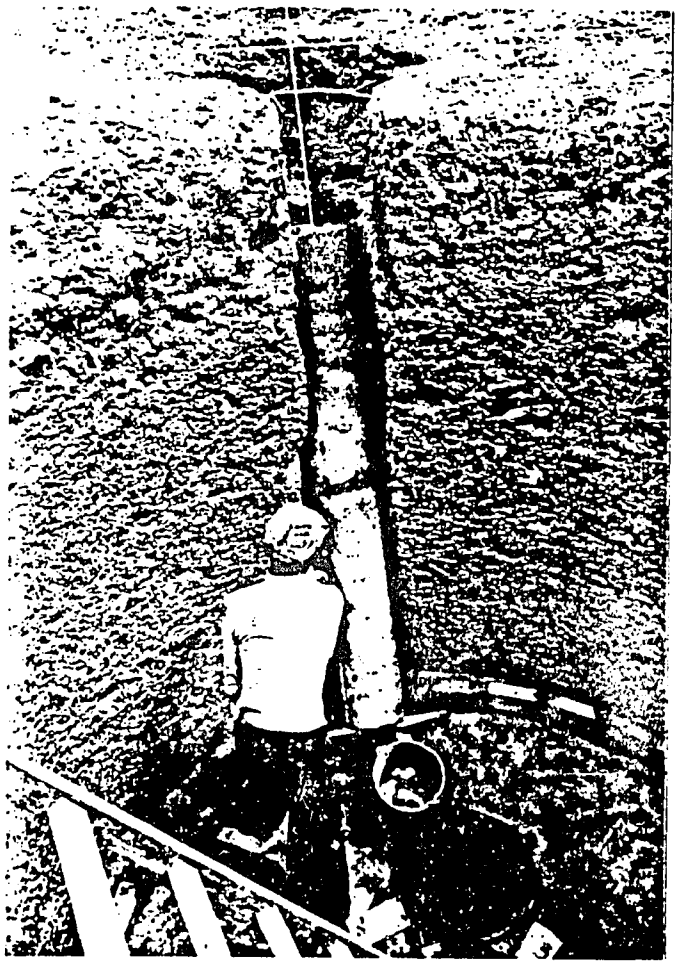


No. 1 Stone cutters modifying existing excavation.



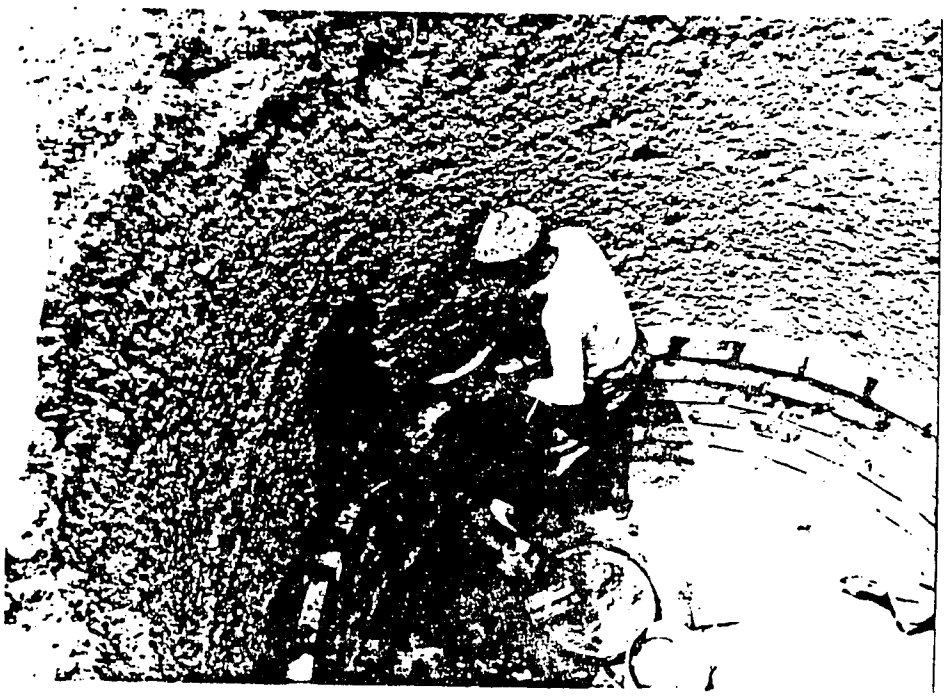
No. 2 Mason laying in first course of brick on floor slab.

14

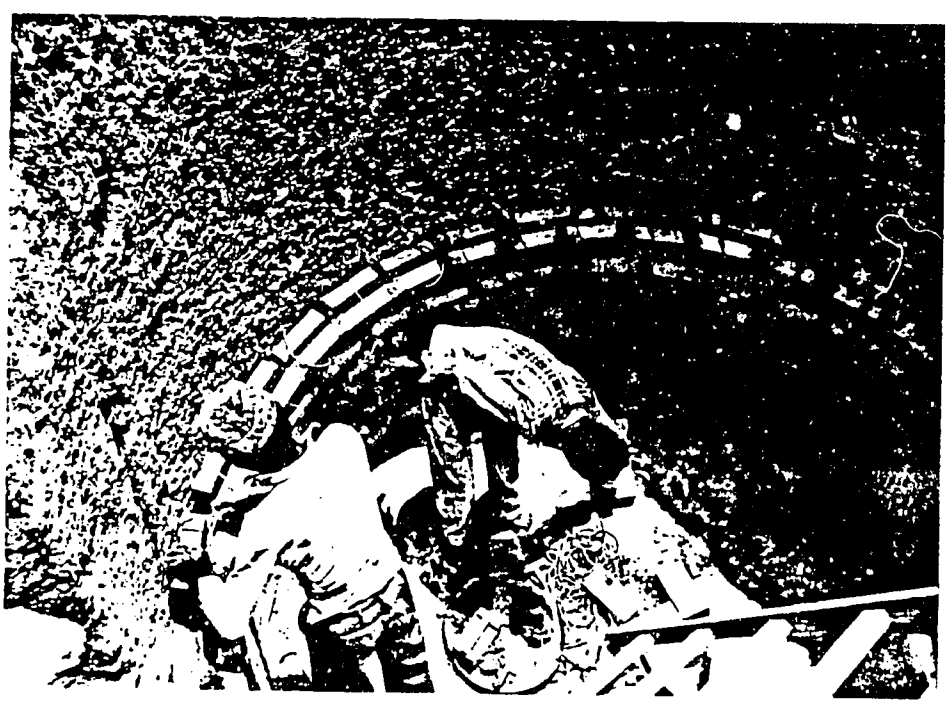


No. 3 Cementing the inlet pipe into the inclined trench.

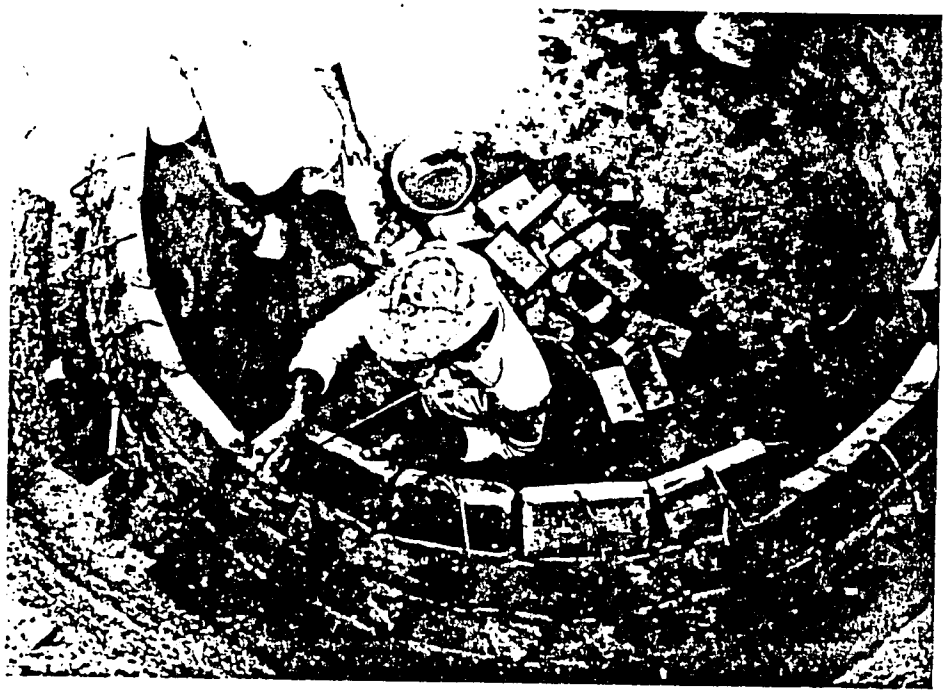
15



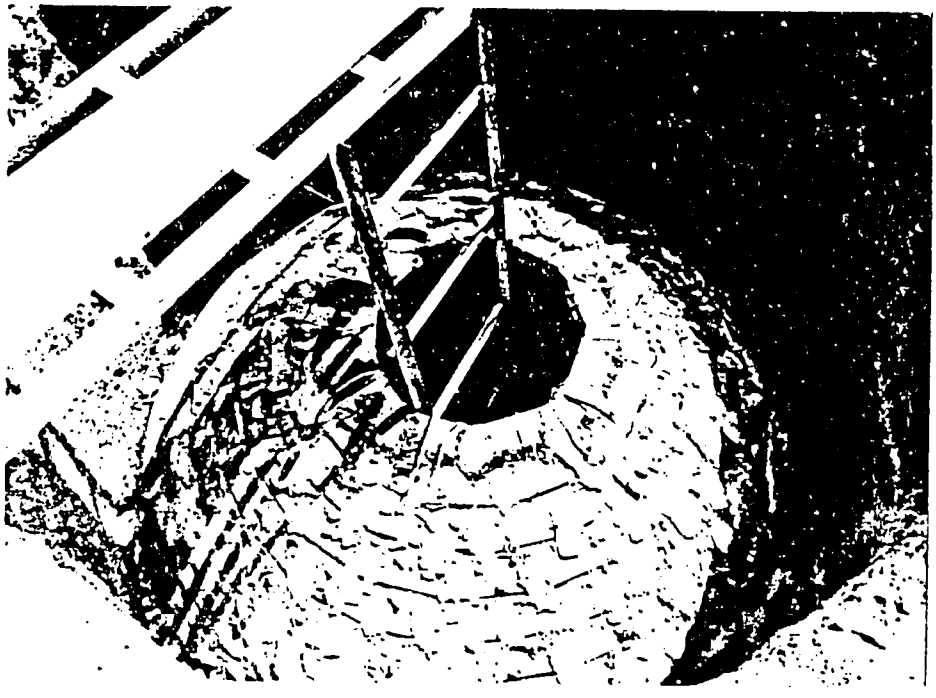
No. 4 Completed outlet passage brickwork (left) and mason tamping backfill (right).



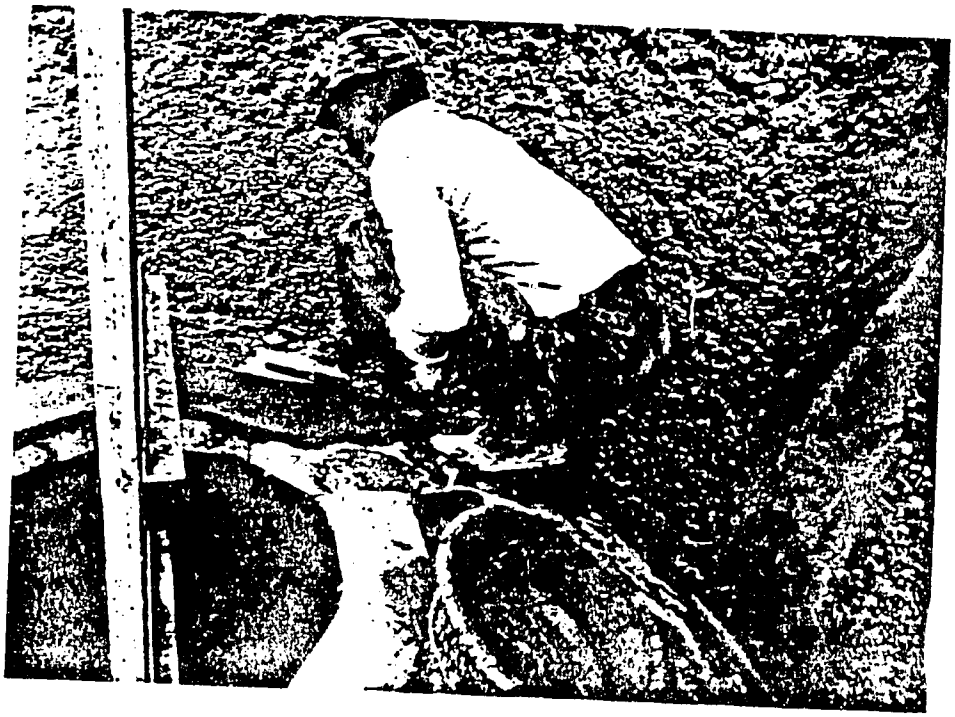
No. 5 Mason removing "C" clamps from the first ring of bricks in the dome.



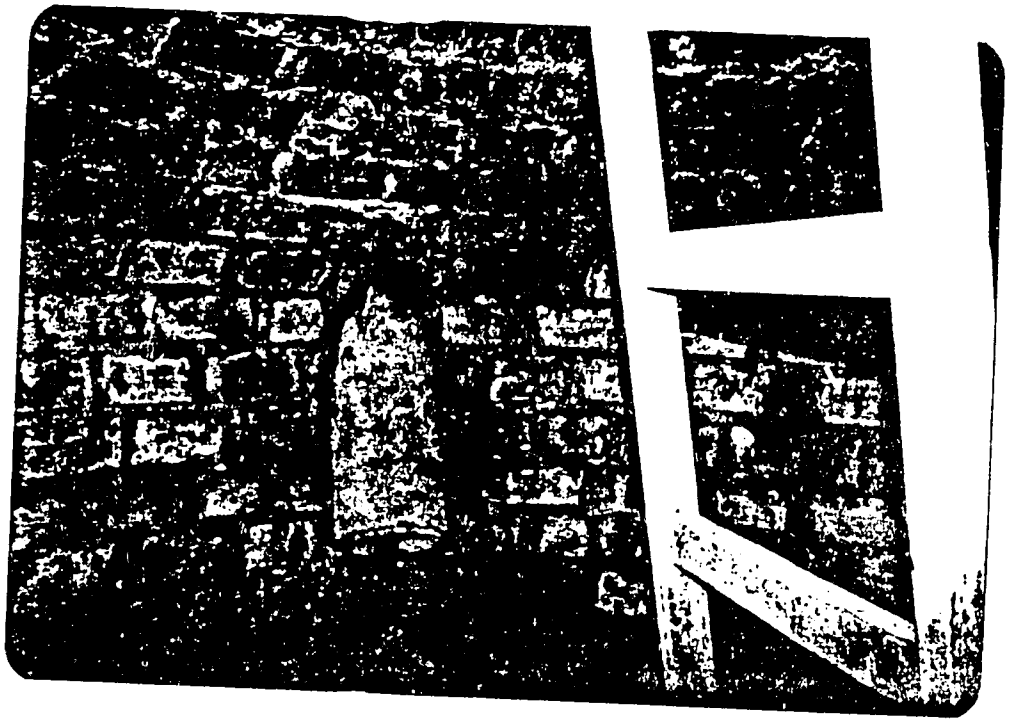
No. 6 Mason measuring the radius of curvature to set new ring of bricks at the correct inclination (Note "C" clamps holding freshly laid bricks.)



No. 7 Completed dome brickwork.

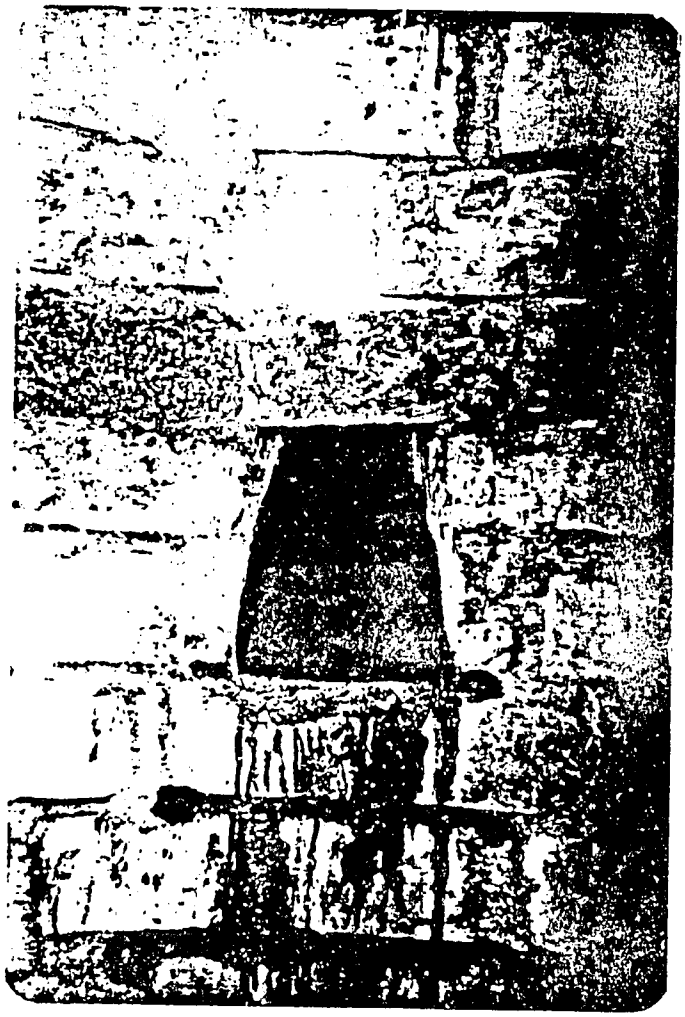


No. 8 Mason applying external plastering on dome.



No. 9 View of completed inlet pipe and lower portion of dome prior to plastering.

18



No. 10 View of completed outlet portal prior to plastering.

19'

No. 11 Bottom view of manhole riser and manhole cover support ring.

80

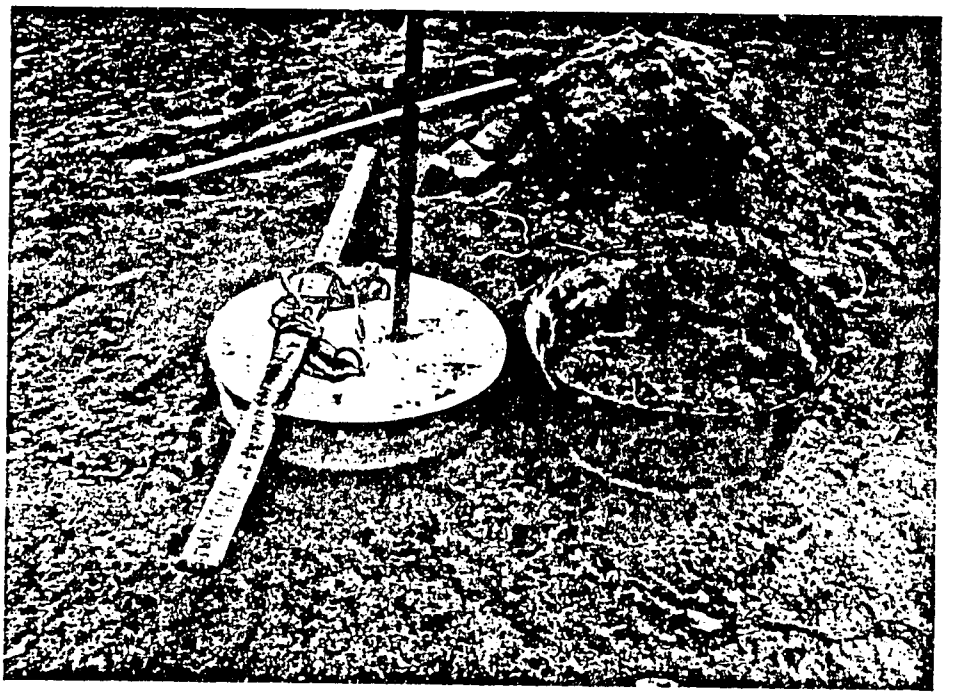
No. 12 Tamping dome backfill.

81

No. 13 Manhole riser. Left to right: mason's helper, mason Keita, SEL engineer Mr. Yaya.

No. 14 Manhole riser. Center, in white: Chikna Traore, SEL Director.

83

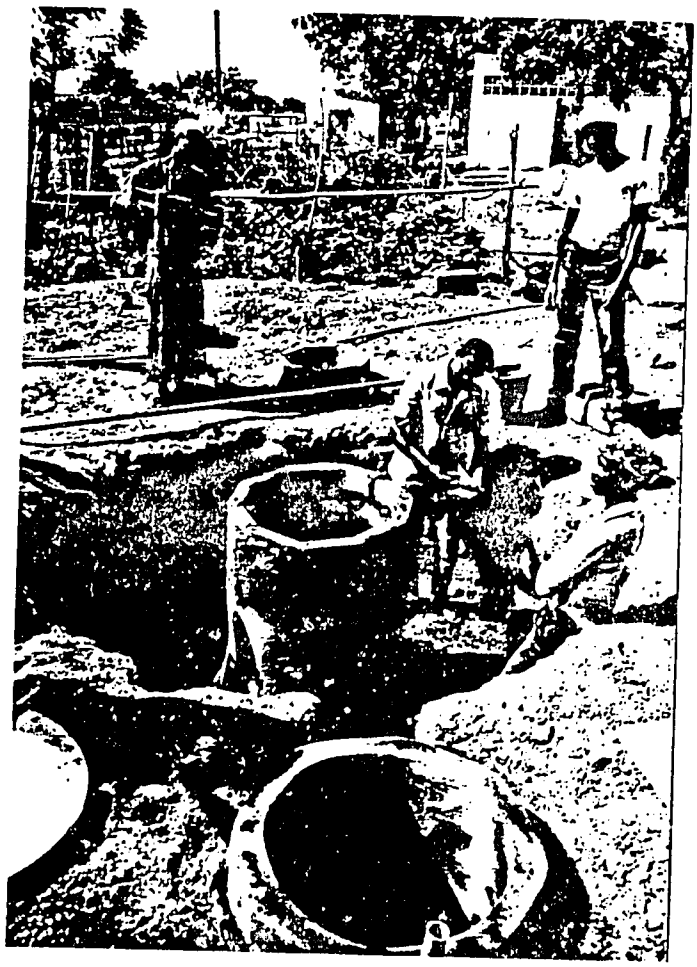


No. 15 Manhole cover and form

84'

No. 16 Casting of manhole cover support ring.

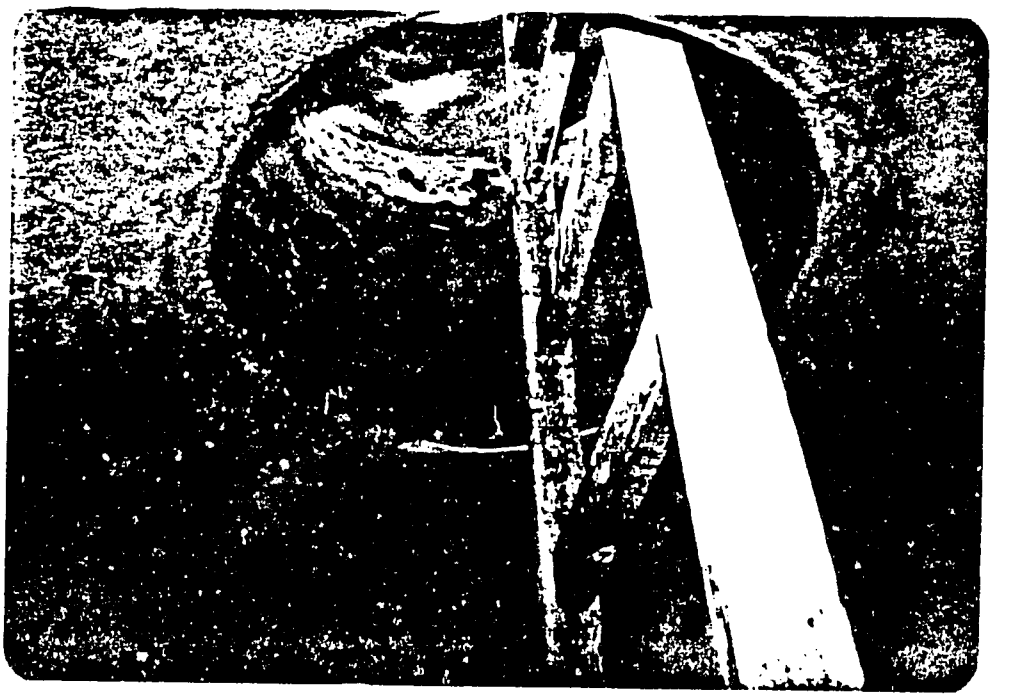
85



No. 17 Plastering outside of manhole riser.

No. 18 Application of cement slurry to inner surface of manhole riser.

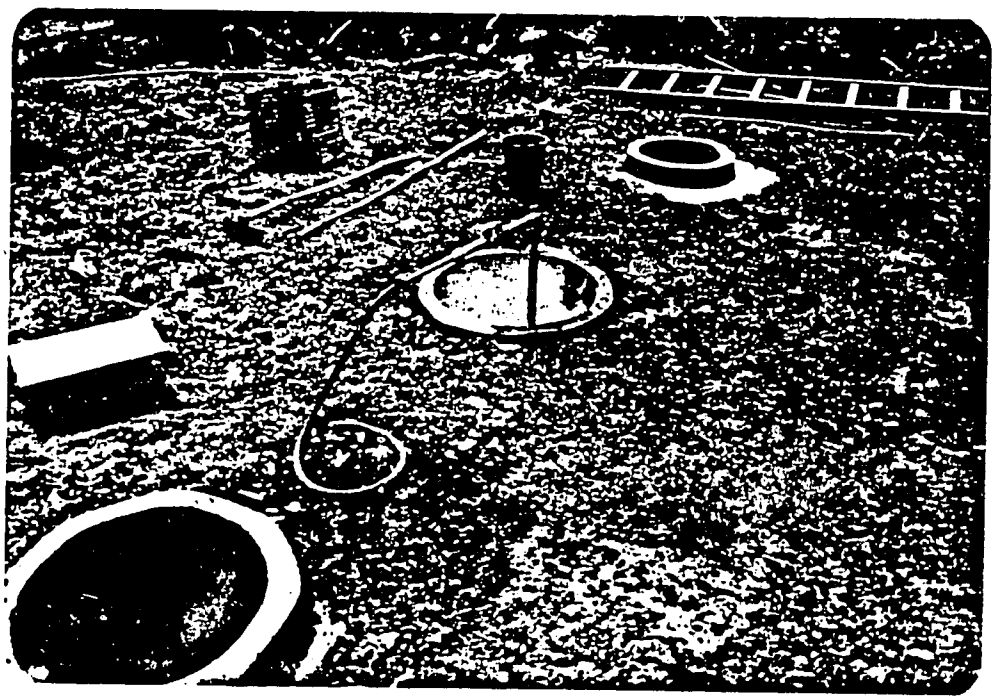
87



No. 19 Bottom view of sealed dome and manhole riser.

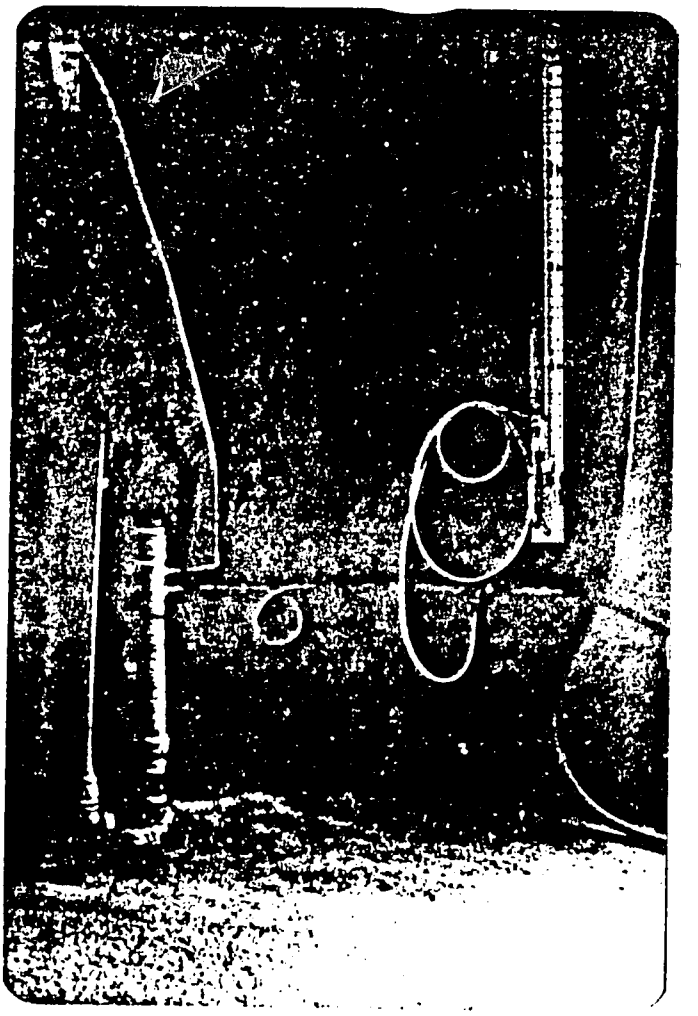
No. 20 Workmen loading cow manure into manhole for initial charging of the reactor.

No. 21 Application of the clay gasket to the manhole cover support ring.



No. 22 Completed and operative Chinese Dome Biodigester. Inlet in foreground, manhole cover (underground) with gaspipe in center, outlet in background.

89



No. 23 Gas system. From right to left: Pipe from digester, manometer, backflow preventer/pressure relief valve, gas pipe to appliances.