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BIOGAS PLANTS WITH PLASTIC FILM GASHOLDER

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ABSTRACT

In this paper, some methods for the construction of simple family-and farm-size digesters with horizontal and vertical flow are described. In all cases, plastic film is used as the gasholder. Imported film lasting 10 years or local ones giving 1 to 2 years life may be used. It depends on site specific factors which methods and techniques are the most appropriate. The processing and maintenance of the film is discussed. The construction of the digester body is seen to be easier and requires less skill than for fixed dome digesters.

INTRODUCTION

The intensive development of biogas plants in Thailand dates from 1973, the year of the world energy crisis. The predominant digester type until 1980/82 was the KVIC type with floating drum as gasholder. Evaluations between 1979 and 1981 concluded that Chinese fixed-dome digesters may be cheaper to construct because their design does not require the expensive floating mild steel drum. [1, 2] However, the fixed-dome designs constructed in Thailand were still expensive and unlike the floating drum design need well trained and skilled constructors, if they are not to develop gas leaks and be abandoned by the farmers.

Until the problems of the training of masons, guaranteeing the reliability of fixed dome digesters, and proper follow up services are satisfactorily solved, designs which require less skill in construction and which involve lower investment costs, may have a higher chance for widespread use. A solution may be offered by replacing the floating-steel drums with plastic film, fixed directly at the digester walls to a water jacket around the digester.

MODE OF CONSTRUCTION FOR DIGESTERS WITH PLASTIC FILM GASHOLDERS

1 Digester Pit and Ring Canal

These digesters can be constructed partially or fully underground as shown in the figures below. The plug-flow type, which should be about seven times longer than wide, has advantages in areas with a high water table because it is shallow. The other advantage is better flow characteristics inside the digester.

The slope of the digester wall depends on the soil properties. Laterite soil, for example, is very stiff and does not need a reinforcing wall even in deep cavities with a slope of 90 degrees. The sludge can also come in direct contact with the laterite soil without so reducing the soil properties that the slope will fail. But it is advisable to line the vertical walls with plastic film, ferrocement or merely with a ca.3 cm thick layer of plaster reinforced with chicken wire. Clay soils are more complicated. If the digester is simply lined with a plastic film or chicken wire reinforced plastic, the walls cannot resist any soil pressure. Thus, the angle of the walls has to be such that active soil pressure is avoided. The angle would vary between 40° for soft clay and about 65° for stiff clay. This is important for empty digesters, i.e. for construction or cleaning periods. If the digester is filled, the pressure of the slurry against the wall is sufficient to maintain the stability of the wall on a long-term basis (Figure 1).

Digesters with plastic film lining should be constructed with a ring canal (see Figure 2). The gasholder covers the whole digester. The weight of the canal has to be determined to compensate for the uplifting force of gas pressure and wind attack. There also has to be a safety factor against sliding. Ground hooks may be needed if the weight of the canal and the water contained are not high enough. Digesters with a plaster interior may alternatively have hooks inside, to be inserted deep into the soil. In this case, the gasholder covers the digesting slurry only.

2 Fabricating Plastic film for Use as Gasholder

PVC* film may be processed with a hot air gun or, preferably, a high frequency welder. In the latter case, the seam has the same tensile strength as the film itself if the sheets overlap by at least 2 cm. If a hot air gun or glue is used, the film has to overlap by at least 5 cm. The strength of this joint may be 40 to 60% of the film only.[1] PVC film of 0.2 to 0.3 mm thickness is being processed by high frequency welding machines in many countries of the third world. Figure 6 shows a high frequency welding machine in Bangkok joining red mud plastic film of 1.2 mm thickness. Conditions (frequency, pressure, time) have to be adjusted, particularly for

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* Poly vinyl chloride

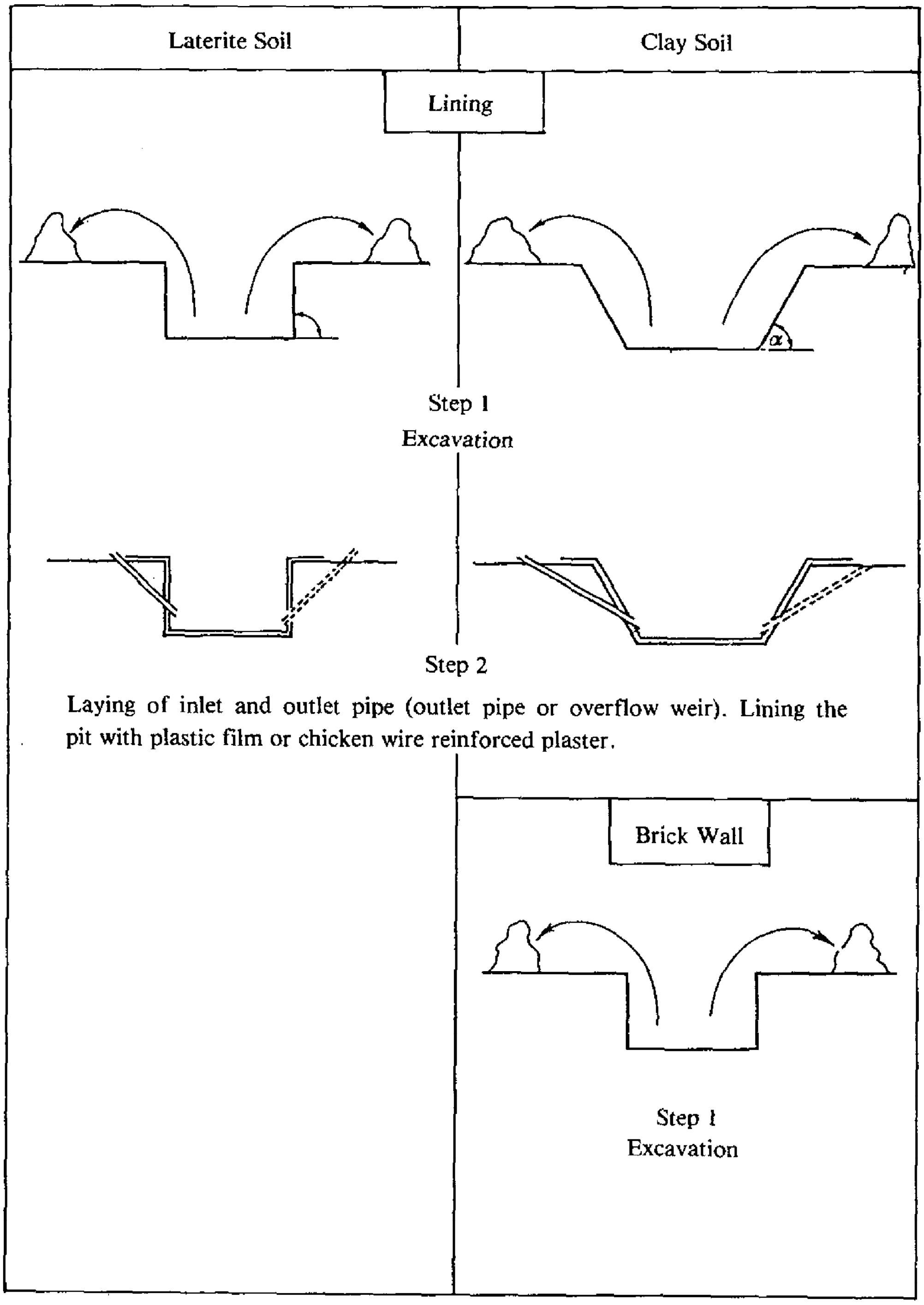


Fig. 1 Construction of the Digester Pit and Methods of Lining

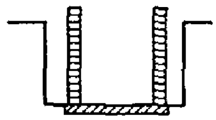
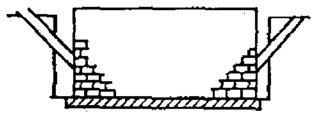
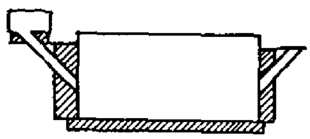
Laterite Soil	Clay Soil
	  Step 2 Cast basement and do the brick work, insert inlet and outlet pipes  Step 3 Refill soil, make inlet and overflow

Fig. 1 (continued)

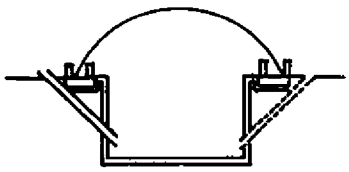
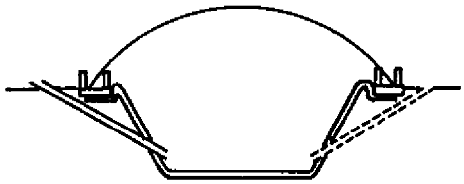
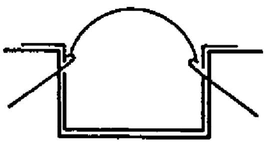
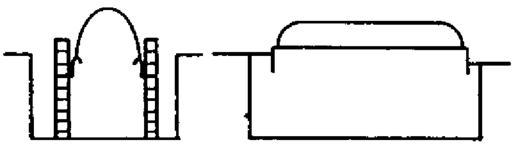
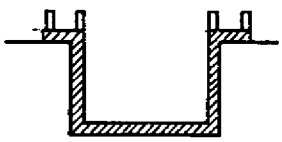
<table>
<tr><th>Laterite Soil</th><th>Clay Soil</th></tr>
<tr><td>1.
</td><td></td></tr>
<tr><td colspan="2">Construct a ring canal around the pit. The gasholder can be fixed in different ways in this canal (see Fig. 3)</td></tr>
<tr><td>2.
</td><td>
Insert hooks inside at certain distances during construction of the walls</td></tr>
<tr><td>3.</td><td>
The digester including the ring canal is cast in place. This work requires form work</td></tr>
</table>

Fig. 2 Construction work to fix the Plastic Film Gasholder

this thick material. Processing the gasholder is cheaper and material consumption is lower when no loop (see Figures 3 to 5) is necessary. Such technologies are suggested for the fixed film gasholders in Figures 3 and 4. The easiest and cheapest solution is given in Figure 4.1, where the film is "sandwiched" between bricks and the floor of the ring canal. Chinese experience suggests this method is good for gas pressures of up to 2 cm water gauge (WG).[4]

The solutions presented in Figure 4.2 to 4.5 are more expensive but can withstand higher gas pressures.

In Figure 3, another simple solution is presented which may be used for digesters with vertical walls. The plastic film is sandwiched between two rectangular frames made of wood or steel (see Figures 3 and 5) and fixed to a brick wall around the shoulder of the digester.

The corner of the gasholder may be welded according to Figure 5, to give the gasholder a neat look. This has to be done on the side which finally goes inside. Step 1 demonstrates how the corners are folded and welded. Welded film is shown in Figure 7. In steps 2 and 3 of Figure 5, it is demonstrated that surplus corners may be cut off. In step 4, the final appearance inside is presented. The film then has to be turned inside out and the edge sandwiched in the appropriate frame.

EXAMPLE FOR DIGESTERS WITH PLASTIC FILM GASHOLDER

1 Family Scale Digesters

Figure 8 shows the three plug-flow digesters constructed by the Asian Institute of Technology at Tabkwang Research Station with small burnt bricks. The construction process is given in Figure 2.2. They have a digester volume of 0.9 m^3 each and produce 1.8 $m^3/m^3.d$ when loaded regularly at 4.7 kg TS/m^3 .d, which corresponds to the manure of about 14 pigs. At a loading rate of 3.5 kg $TS/m^3.d$ (corresponding to about 10 pigs), the gas production is at 1.4 $m^3/m^3.d$, still sufficient for one family's cooking. The floating drum gasholders were installed instead of gas flow meters to measure the gas produced. They are not necessary for field application. However, the gas storage volume of the RMP* film has to be adjusted to the needs of the farmer. Another digester of the vertical type, shown in Figure 3 was constructed by the GTZ in the Ivory Coast. This is fed continuously with cow manure. The digester pit is dug into laterite soil and lined with plaster reinforced with chicken wire.[5]

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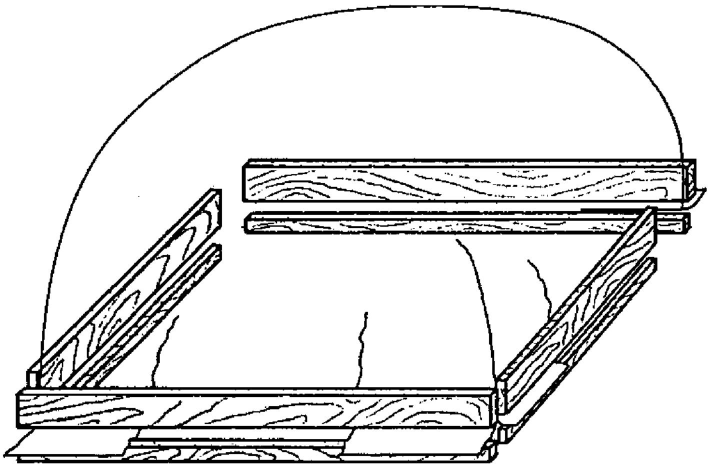
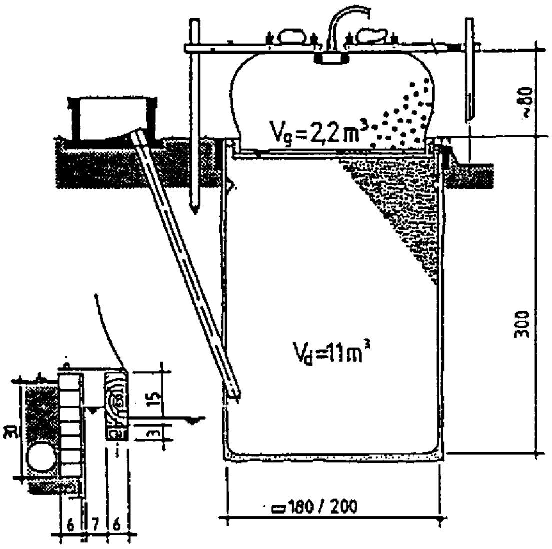
* Red Mud Plastic PVC



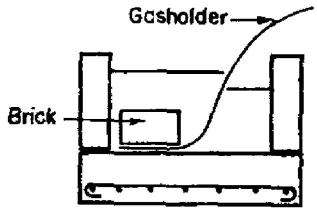
The frame may be made out of wood and nailed together. Some weights may be put on top of the film to increase the gas pressure as shown in the drawing below



The plaster penetrates into the digester in order to collect the gas bubbles at the edge

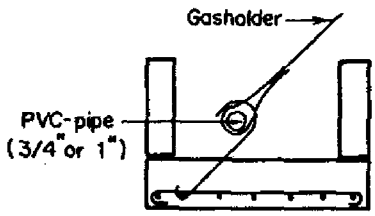
Fig. 3 Methods to fix the plastic film gasholder to a frame

1.

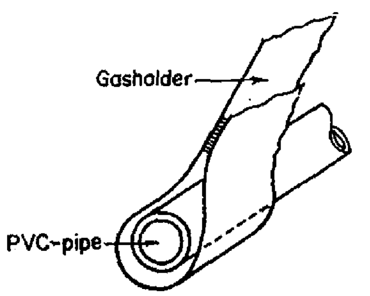


Put one or two layers of bricks on the edge of the film, a loop at the edge of the film is not necessary

2.

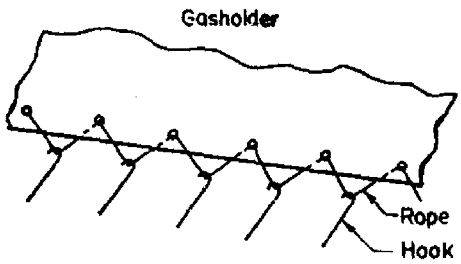


During casting of the basement of the ring canal, fix hooks at a distance of 75 to 150 cm to the steel rods



In this case, the plastic film has to have a loop along the edge, through which a PVC (3/4" pipe, or 1") is being pierced. The loop has to be cut where the hooks are located.

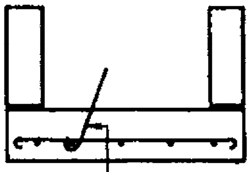
3.



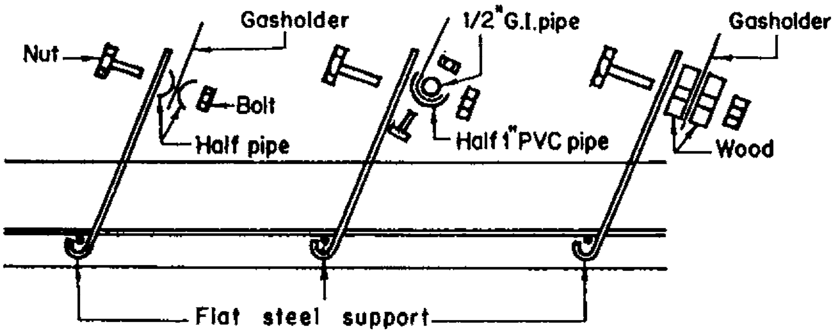
The plastic film has to have holes reinforced by steel rings. A rope is put through the holes and around the hooks. This method is common to fix canvas to trucks. The disadvantage is that the film receives point loads.

Fig. 4 Methods to fix the gasholder at the ring canal (Water Jacket)

4.



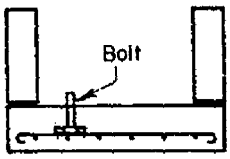
Fix flat steel supports in the basement of the ring canal at certain distances



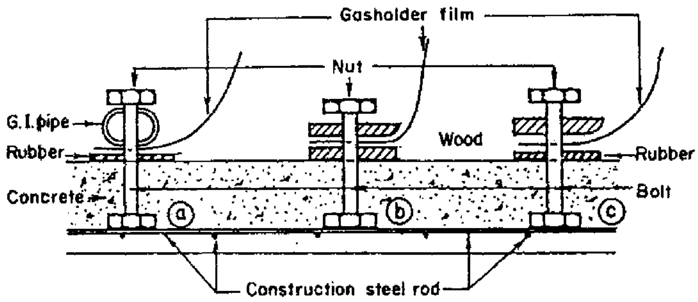
The film can be sandwiched in between two halves of a 1" G.I. pipe, of bamboo, etc (a), or two pipes of different diameter and of different materials like 1/2" G.I. pipe inside and half PVC pipe outside (b) or two wooden planks (c) and fixed to the flat steel supports.

Fig. 4 Methods to fix the gasholder at the ring canal (Water Jacket) (continued)

5.

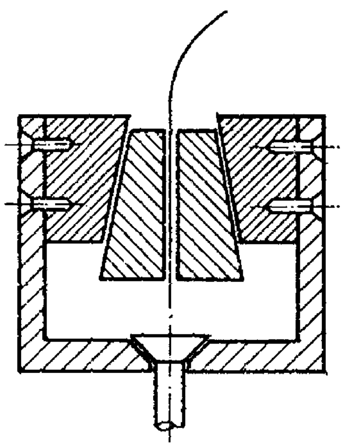


Fix bolts in the basement of the ring canal at certain distances. The bolts may be replaced by pieces of a 1/2" G.I. pipe with a thread at the end.



The film can be sandwiched between rubber and G.I. pipe or bamboo (a), between two planks of wood (b) or between rubber and one plank of wood (c).

6.



This is a more sophisticated support which tightens the stronger the higher the film is pulling i.e. the higher the gas pressure is.

Fig. 4 Methods to fix the gasholder at the ring canal (Water Jacket) (continued)

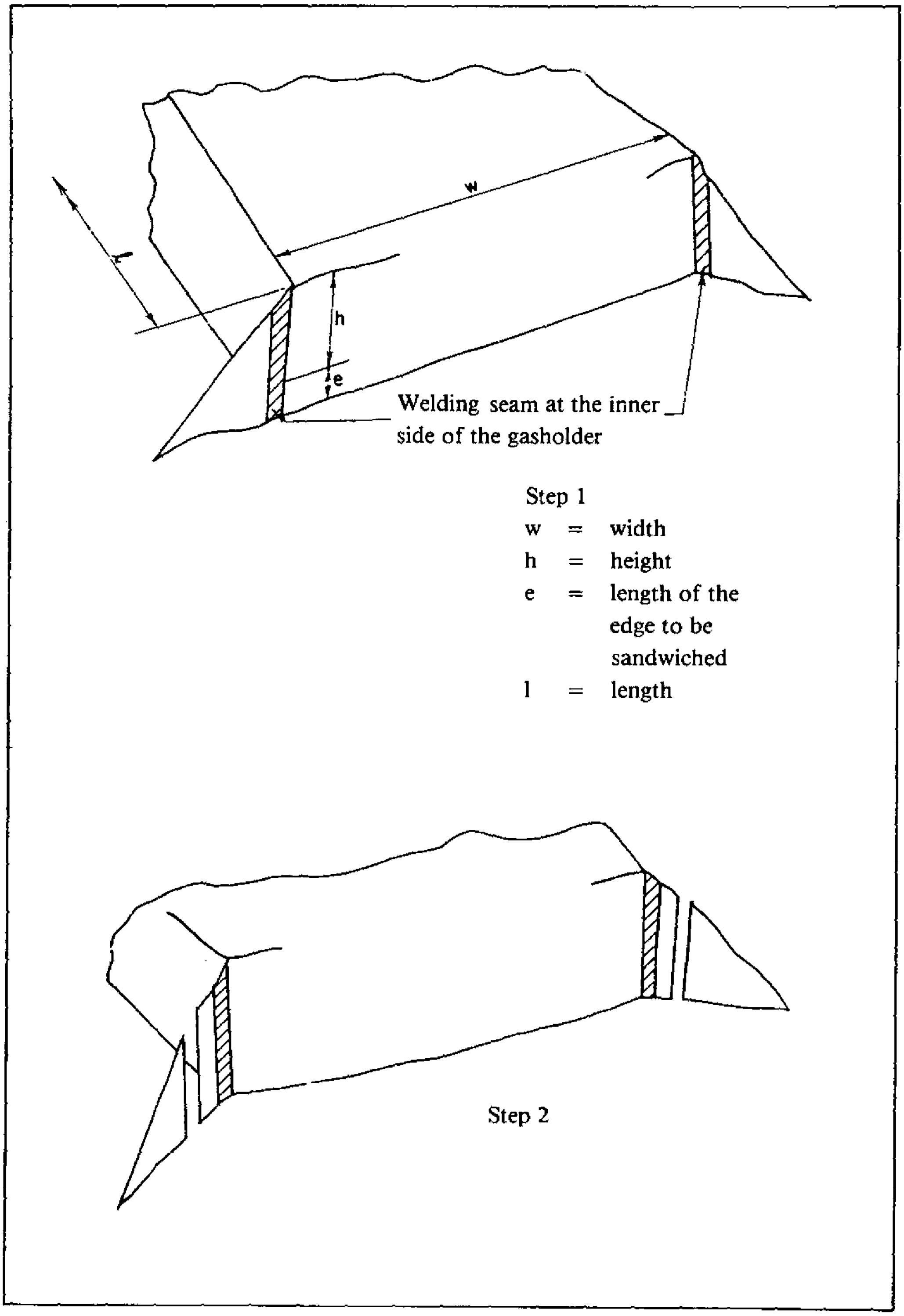


Fig. 5 Processing of the four corners of rectangular gasholders

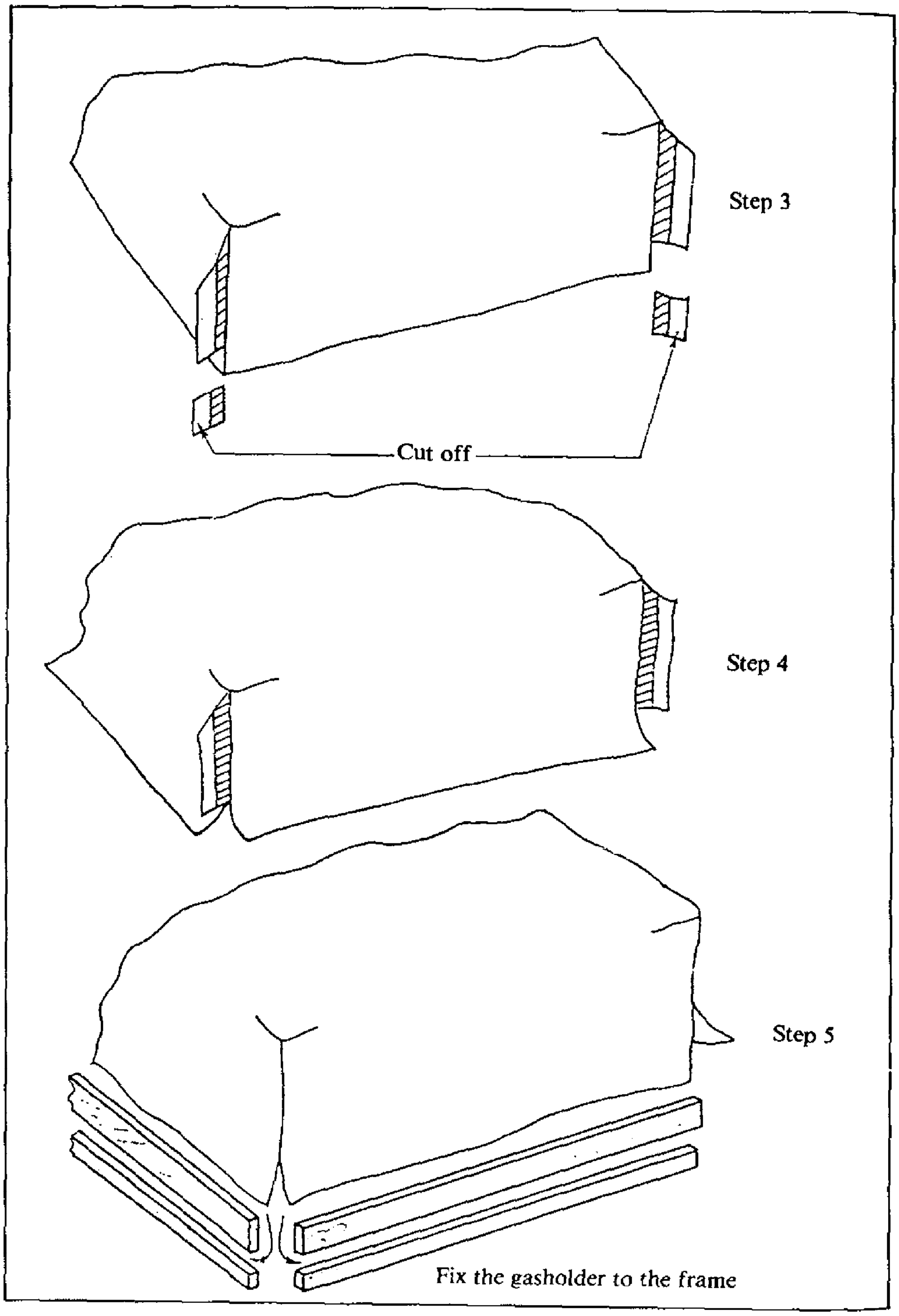


Fig. 5 Processing of the four corners of rectangular gasholders (continued)

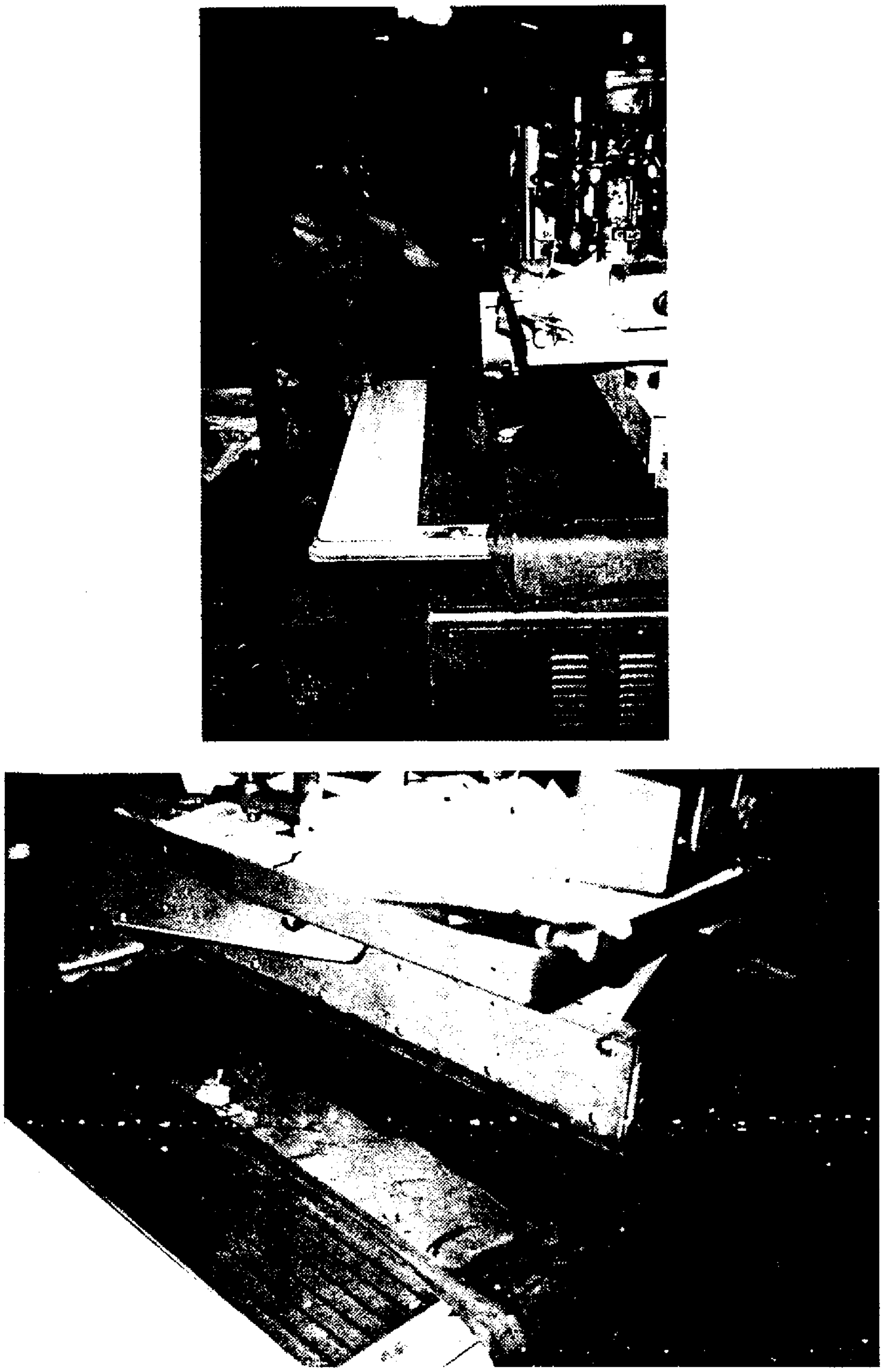


Fig. 6 Joining RMP Sheets with high frequency welder

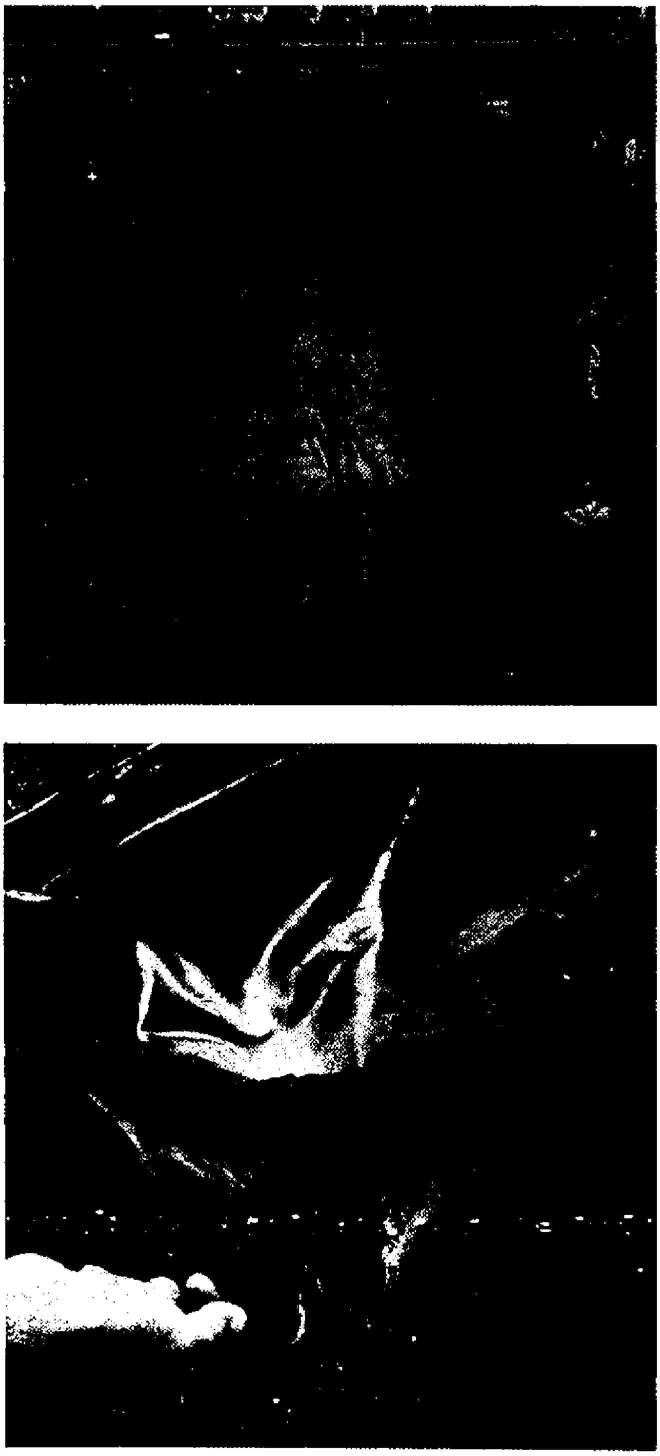


Fig. 7 Ready made RMP film with loop around

In China, about 20,000 batch digesters with volumes of 4-9 m^3 operate about 8 months a year. They are loaded once or twice a year with agricultural residues such as rice straw or corn stalks, mixed with manure. This is shown in Figure 9. The digester is normally cast in place according to Figure 2.3. The gas production is about 1 m^3 per day.[4]

2 Full-Scale Digester

A plug-flow digester of 170 m^3 volume was constructed at "Tabkwang Research Station" in Saraburi Province, a pig research station with about 1,000 pigs, belonging to Kasetsart University Research and Development Institute (KURDI). This station is conducting training courses for students and giving demonstrations to farmers on all aspects of pig raising and is also developing into a national demonstration site for biogas.

The full-scale prototype digester was constructed as in Figure 1 step one (clay soil), and has a ring canal as in Figure 2.1 and Figure 4.2. The trench was dug by backhoe, two meters deep into a clay layer and two meters further down into lateritic soil. A ferro-cement rather than plaster retaining wall was constructed inside because the 80° slope of the wall did not prove stable on a long-term basis. In 15 days hydraulic retention time (HRT), the manure of about 800 pigs and all flushing water can be digested.

This digester is the first pilot plant of this type being tested under field conditions in Thailand. This is also true for the RMP film, on which the contractor has given a 10 year guarantee.

Figure 10 shows the whole set up, consisting of the flushing canal and the manure collection tank in the front, the plug flow digester in the middle, the effluent tank in the background and the power shed on the left.

The ferro-cement wall is 3.5 cm thick and made of 6 mm (horizontal) and 9 mm construction steel rod (vertical), with one layer of chicken wire inside and another outside (see Figure 11). This was done on the advice of the Structural Engineering and Construction Division of AIT. The bottom is reinforced with a 15 cm thick concrete layer. The finished digester is shown in Figure 12.

The effluent holding tank is 4 m deep but with a slope of 63° instead of 80° as in the digester, a long term stable slope. The cavity is lined with a PVC film of 0.25 mm thickness, as shown in Figure 13.

An engine-generator set is installed, designed to cover 30 to 50% of the pig farm's electricity demand. The farm has peak demands of 30 to 50 KW, whereas the generator output is 10 KW. The balance is purchased from the main grid. There are two more digesters of the fixed-dome type, each of 65 m^3 digester volume. These were constructed 3 years earlier by Kasetsart University and together produce about 20 m^3 gas per day. Part of this gas is piped 320 m to a kitchen where it is used for cooking.

Technical data on the digester and engine-generator set are given in Tables 1 and 2.

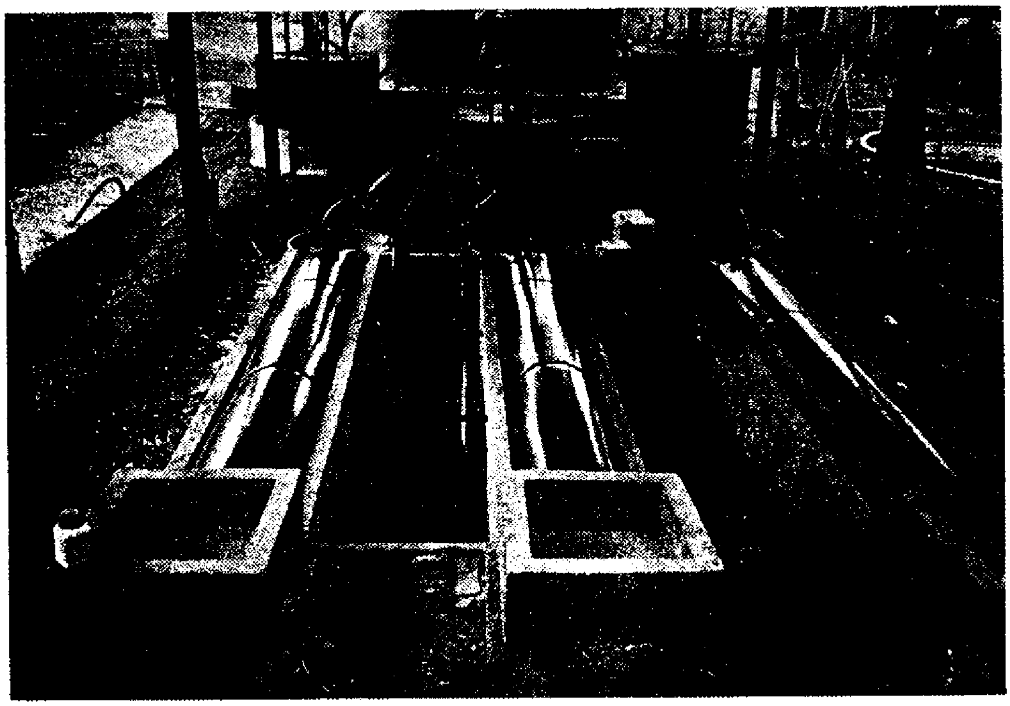


Fig. 8 Family scale digesters at Tabkwang Research Center, Saraburi

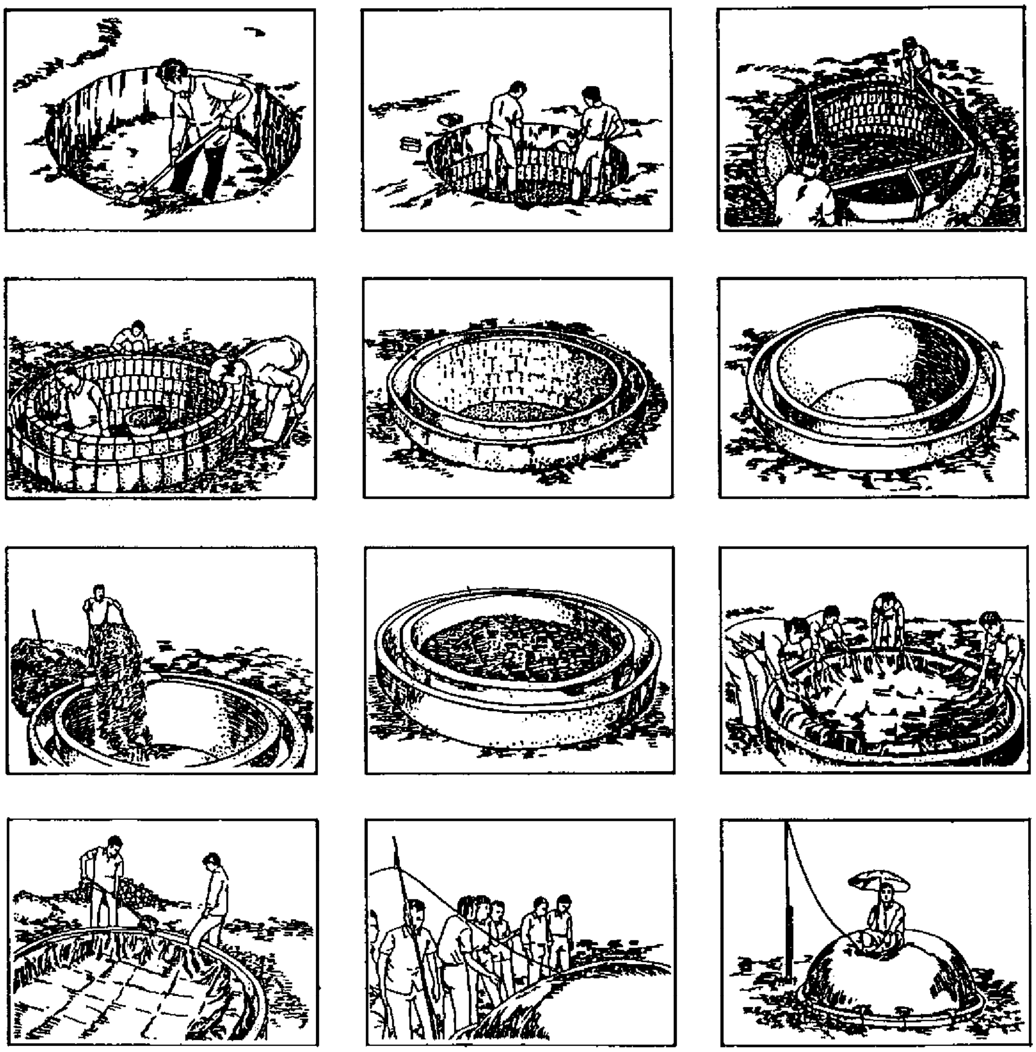


Fig. 9 Batch digester with RMP gasholder in China, Liaoning Province

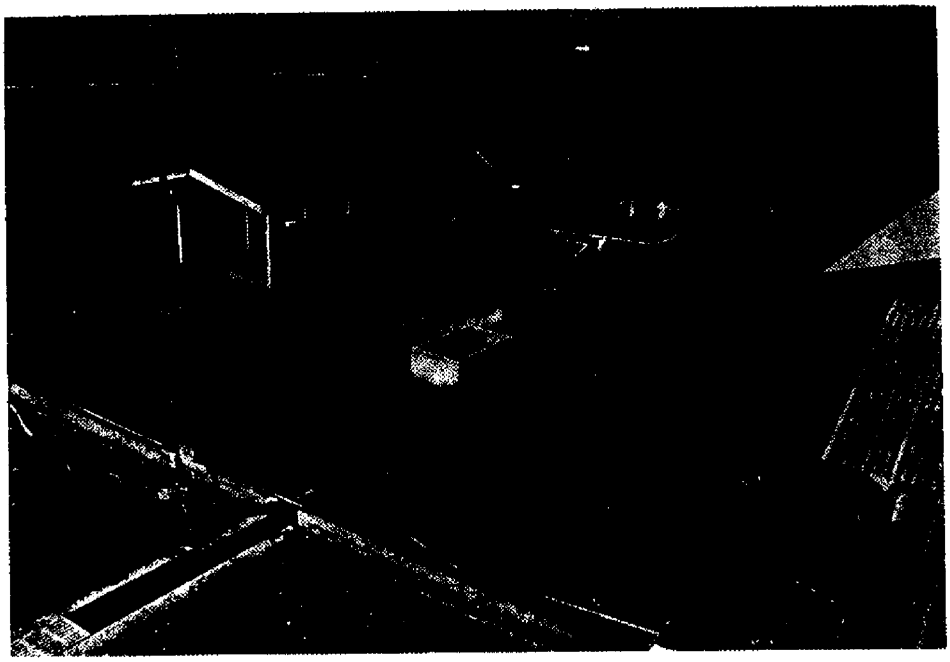


Fig. 10 Set up of full-scale digester at Tabkwang Research Station, Saraburi

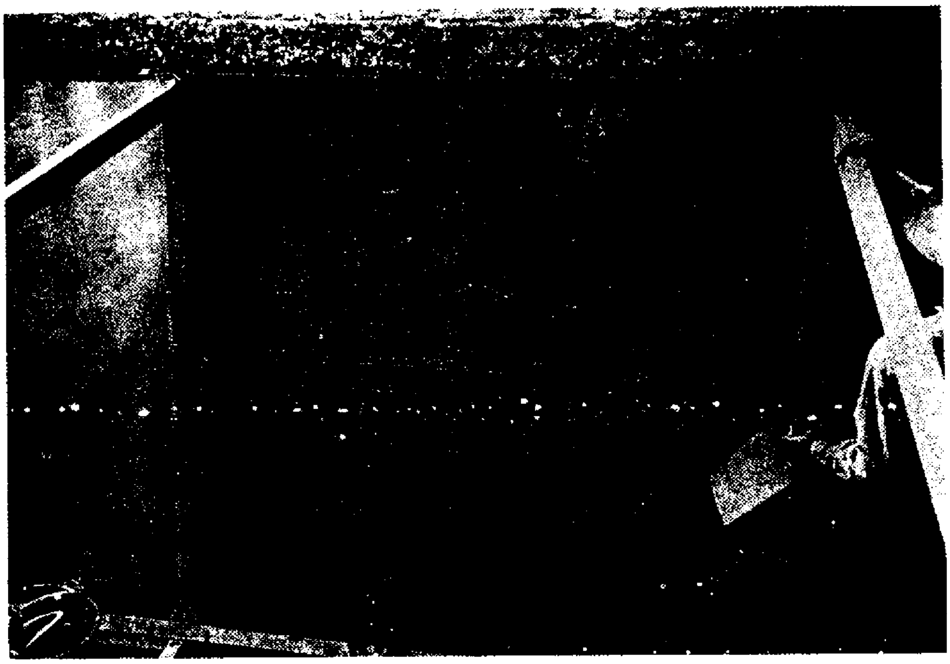
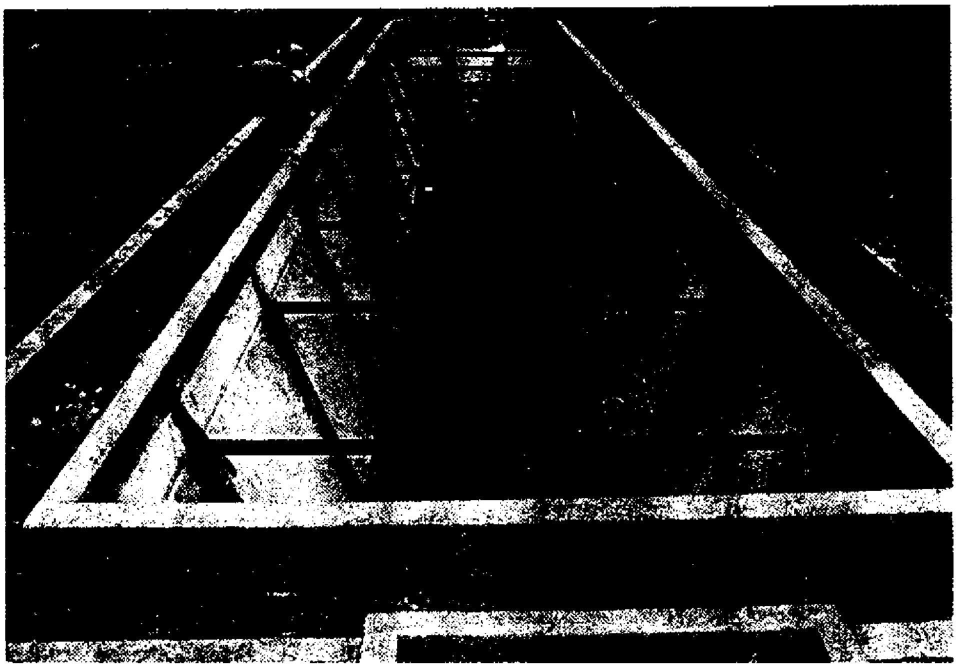


Fig. 11 Section of the ferro-cement wall



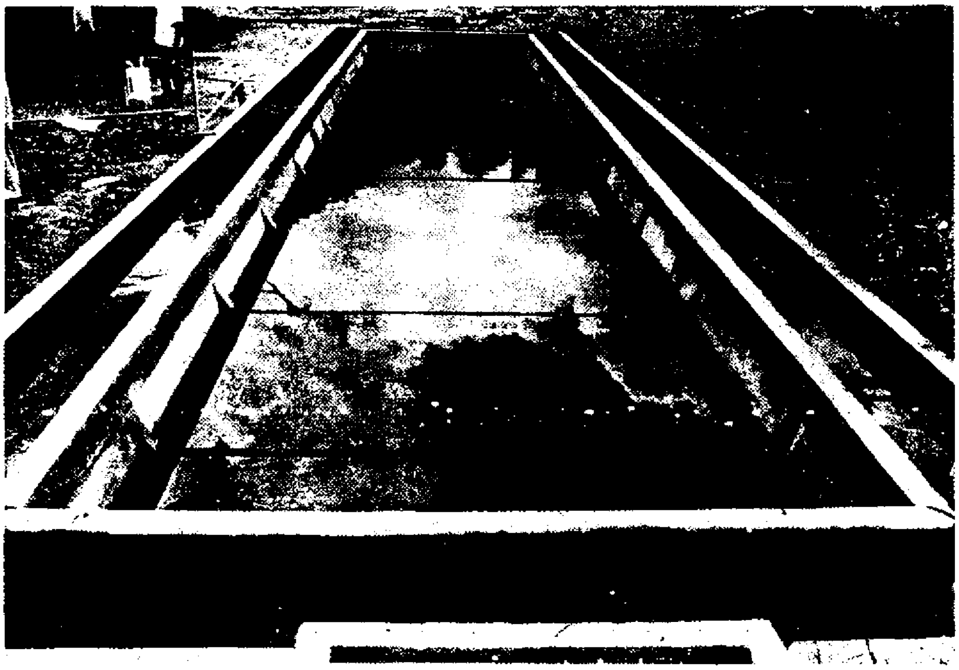


Fig. 12 Finished full-scale plug-flow digester

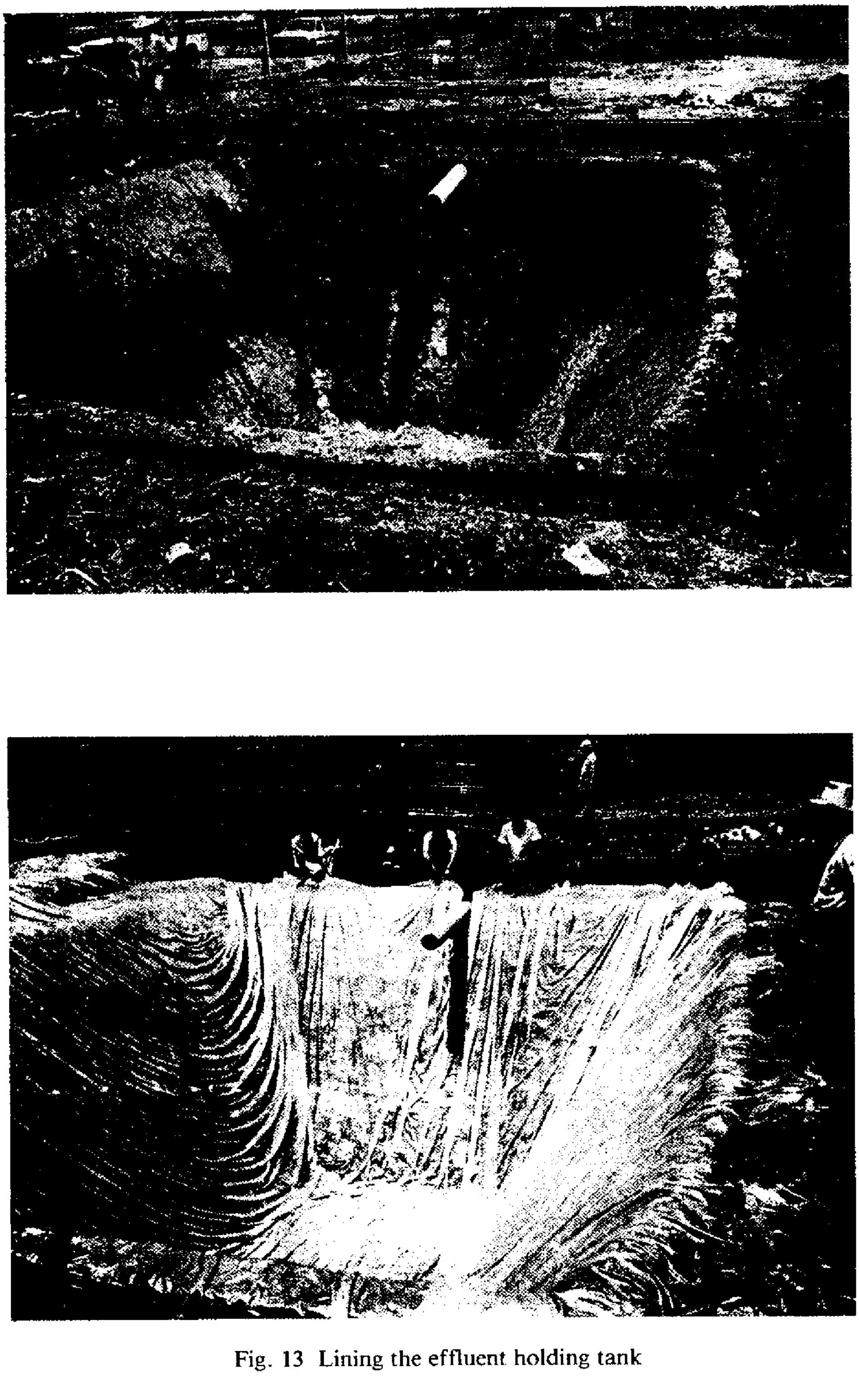


Fig. 13 Lining the effluent holding tank

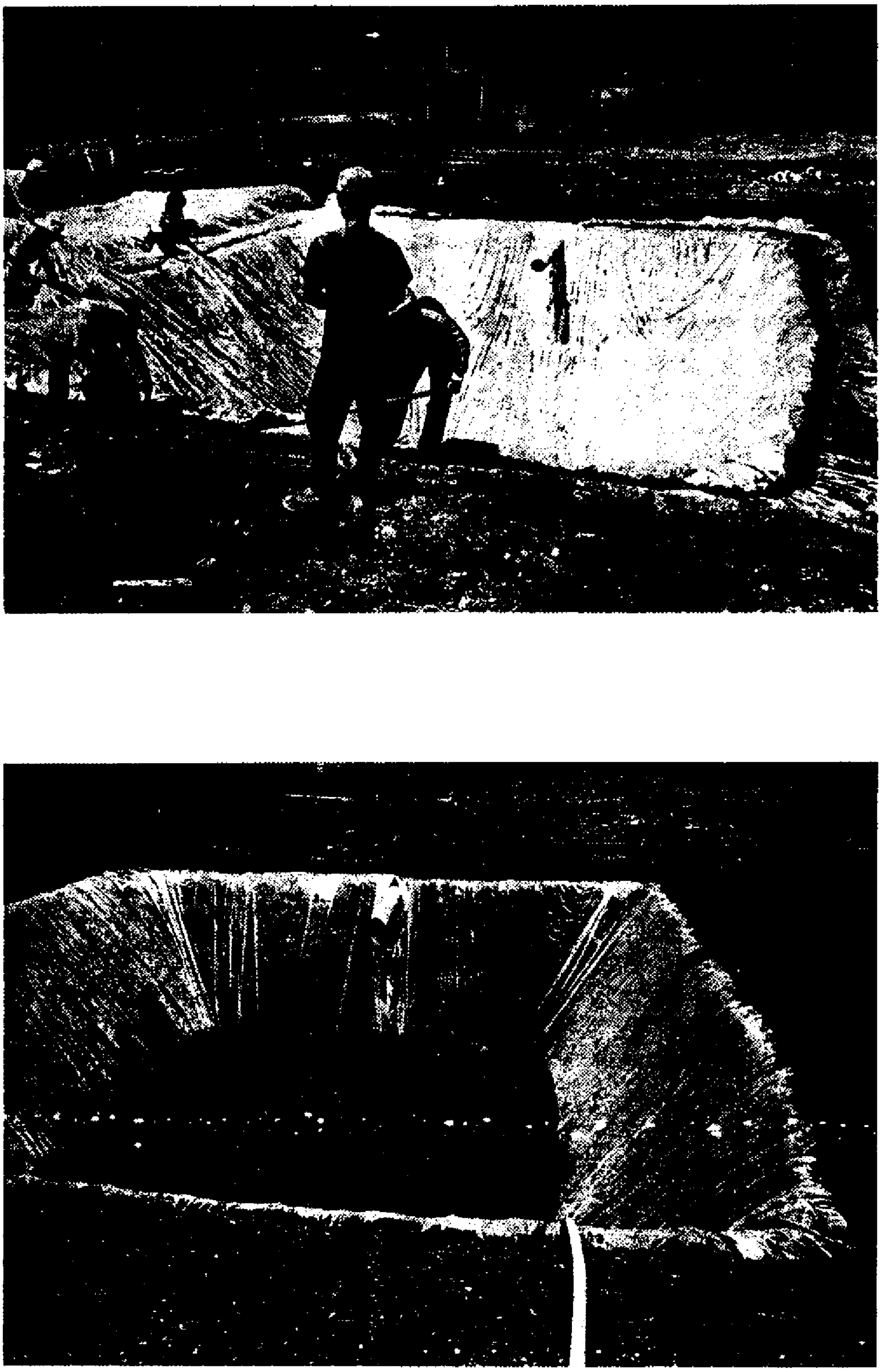


Fig. 13 Lining the effluent holding tank (continued)

TABLE 1 TECHNICAL DATA ON THE FULL-SCALE BIOGAS PLANT

DIGESTER	
Volume	170 cu.m.
Type	Plug-flow (trapezoidal shape)
Dimensions	Bottom length : 16 m, bottom width : 1.8 m; top length : 18 m, top width : 3.6 m; depth : 4 m; slope : 80 degrees
Retaining Wall	Ferrocement (steel rods with 2 layers of hexagonal chicken wire), 3.5 cm. plaster thickness
Inlet and Outlet Pipe	Dia. 20 cm, 45 degrees inclination
Ring Canal	Cast steel reinforced concrete bottom, 15 cm thickness and 1.12 m width; stainless steel hooks every 75 cm; brick wall
Gasholder	Material : Red Mud Plastic (RMP) film, 1.8 mm thickness; total length: 20 m; total width : 5 m; maximum height : 1.1 m (not expanded)
MANURE COLLECTION TANK	
Volume	3.1 cu.m.
EFFLUENT HOLDING TANK	
Volume	100 cu.m.
Depth	4 m
Lining	PVC film, 0.25 mm thickness
Slope	63 degrees

TABLE 2 TECHNICAL DATA ON THE ENGINE-GENERATOR SET

ENGINE	
Model	Nissan 784 H 20, 4 cylinder gasoline engine
Total displacement	1982 cu.cm. (Bore = 87.2 mm, stroke = 83 mm)
Designed Compression Ratio	8.2 : 1
Power Output	91 HP at 4,800 rpm
Max. Torque	160 Nm at 3,200 rpm
Weight	157 kg
Cooling System	New truck radiator
Engine Protection Devices	Max. temperature, min. oil pressure (new)
GENERATOR	
Type	Inductive synchronous generator (new)
Rated Max. Output	15 kW; 3-phase, 380 V, 30 Amp.
CONTROL PANEL	
Model of operation	Manual and automatic control operations
Measuring instruments	Amp., Volt, and Hour meters
Equipment protection Devices	for short circuit, overload current, reverse current, unbalanced phase and over and under voltage.

3 Recommendations on Construction Procedures for Large Digesters

1. Take soil samples for analysis of shear stress and cohesion.
2. Carry out penetrometer tests or Dutch Cone tests to analyse soil profile.
3. Determine the angle of the wall and the possible depth of the cavity.
4. Dig digester cavity with earth-moving machines without disturbing the digester edges (shoulders). Use man-power to smoothen the walls. This should be done as quickly as possible.
5. Insert inlet and outlet pipe and plaster the walls as soon as possible. Do not allow the soil to dry out and develop cracks.
6. If the gasholder is processed locally, order as soon as the final dimensions are available. In the meantime, the digester plaster is allowed to cure.
7. After one to two weeks of curing, fill the digester with slurry.
8. In parallel to the operation under 7, construct the ring canal. Take care that the basement of the ring canal is cast in one day in one piece.

INVESTMENT COSTS

1. Investment costs of the original version of the 170 m^3 plug-flow digester with ring canal, given in Figure 10, are as follows:

	Baht	US$
Digging (including 100 m^3 effluent storage tank)	15,000	600
Ring Canal	20,000	800
First Ferrocement lining (Baht 40/m^2)	6,000	240
Second Ferrocement wall (Baht 800/m^2)	120,000	4,800
Painting with flint coat	500	20
RMP – film, 120 m^2	50,000	2,000
Labour	40,000	1,600
	251,500	10,060

The investment costs of one m^3 total digester volume of this prototype are about Baht 1,500 or US$ 60. It is outlined below that there is a good scope for further cost reductions.

Additional investment costs :

	Baht	US$
Biogas pipeline 320 m G.I. pipe (material only)	13,000	520
15 KW engine-generator set + control box	50,000	2,000
One spare engine	8,500	340
Power shed	10,000	400
Electrical connection	5,000	200
PVC film lining of 100 m^3 effluent storage tank	4,800	192
	90,800	3,632

Investment costs for an improved version could be reduced considerably. The slope is now 65° instead of 80° thus increasing the costs for the ring canal, RMP-film, and ferrocement lining, but avoiding the ferrocement wall :

	Baht	US$
Digging	15,000	600
Ring canal	25,000	1,000
Ferrocement lining	10,000	400
RMP-film	70,000	2,800
Labour	20,000	800
	140,000	5,600

The investment costs for one m^3 total digester volume amount now to Baht 820 or US$ 33.

It is obvious that the investment cost for the imported RMP-film is very high. In addition, no import tax was calculated yet. If welded locally, the cost could already be reduced remarkably. On the other hand, normal PVC film of 0.25 mm thickness would cost about Baht 8,000.00 including welding. In this case, the investment costs would be reduced to about Baht 500 or US$ 20 per m^3 total digester volume, which is acceptable when compared to fixed dome digesters. The next stage for cost reduction would be to fix the gasholder inside and avoid the ring canal. This measure would not effect the performance at all.

2. Investment cost of a 810 m^3 plug-flow digester with ring canal, constructed in the Ivory Coast, are as follows :[6]

Digging, ring canal, flushing canal (connection to feed lot), EPDM*-film	US$	31,150
The EPDM-film alone		5,000

The investment costs for one m^3 total digester volume are about US$ 38.

3. Investment costs of a 11 m^3 family scale vertical biogas plant (see Figure 3) without ring canal but with ferrocement lining (one layer of chicken wire), constructed in the Ivory Coast in stiff laterite soil, are as follows :[6]

Material	US$	264
Labour		118
Transport		44
	US$	426

The investment costs for one m^3 total digester volume are about Baht 1,000.00. This digester is about 4 to 5 times cheaper than a digester with a floating drum of mild steel.[4]

In Thailand, the investment cost of this biogas plant would amount to about Baht 2,800 or US$ 111.

	Baht	US$
Ferrocement lining, 28 m^2	1,120.00	45
1 pipe, ϕ 10 cm, 2.7 m long	300.00	12
Bricks	200.00	8
Wood	200.00	8
15 m^2 PVC film, 0.3 mm thickness	350.00	14
Labour, 10 man days	600.00	24
	2,770.00	111

The investment costs for one m^3 total digester volume are about Baht 250.00 or US$ 10. Hence, they are much cheaper than conventional fixed-dome designs.

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* Ethylene - Propylene - Terpolymer rubber

EXPERIENCE WITH PLASTIC FILMS

There is wide range of materials utilised in the production of sheets, films, and coated fabric, comprising thermoplasts (PVC, RMP, PE,* PB,** and others) and elastomers (EPDM, CR,*** IIR**** and others).

Only a few have been tested so far for aging gas permeability, maintenance and repair. The availability of the expensive and long lasting films such as RMP and EPDM is limited in many countries of the third world so that cheap, locally made films such as PVC, PE or canvas are being used since some years. In China and Taiwan, RMP is in extensive use since about 10 years.

PVC, RMP and elastomers such as EPDM can easily be mended with special glues if available. The glue has to be kept properly sealed.

PE film cannot be glued. It has to be repaired with a hot air gun. A PE film of 0.15 mm thickness was tested for about 2 years in the Ivory Coast (see Figure 3 and chapter 3.1). No damages were recorded. The methane permeability was about 500 cm^3/m^2.d.atm. and did change slightly from new. The film had to be replaced after two years, but when used as a cover for greenhouses, it needs to be replaced every year. The biogas atmosphere seems to extend life time.

There is yet no recorded experience of the use of pure PVC film. But Red Mud Plastic (RMP), a mixture of PVC, red mud and ingredients such as discharged engine oil, has been tested extensively. It has good aging properties and should last about 3 to 5 years under outdoor conditions in China, if no unforeseen damages such as cutting, tearing etc. occur.[3] A manufacturer in Taiwan guarantees 10 years. Tensile strength is not reduced, but even increases with aging. Changes in methane permeability were not yet followed up. RMP films are available from Taiwan at thicknesses of 0.6, 1.2, and 1.8 mm and cost (f.o.b.) about US$2.3/kg (density is 1.25 g/cm^3). In China, RMP Film is of 0.2, 0.3, 0.4 and 0.6 mm thickness. The cost (f.o.b.) is US$1.10/kg but sometimes US$12/kg are being quoted for export. RMP film can be easily mended with glue. The Taiwanese manufacturer charges about 300% of material cost for processing (welding) into the desired shape. This expense could be greatly reduced if the film is processed locally. Another cost constraint would be the import tax, which is for Thailand about 70% of material cost. Thus, locally available films of 20 to 60 B per m^2 may be chosen, which may have to be replaced after one or two years. More intensive tests should be carried out with locally produced films.

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* Poly ethylene

** Polybutylene

*** Chloroprene rubber

**** Butyl rubber

To summarize, advantages are that the digester body can be easily constructed and the requirements for masonry skill are relatively low. The plastic film gasholder can be easily removed and the farmer has access to the digester at any time. The construction cost are relatively low if chicken wire and cement are cheap. Disadvantages are that the life time of the gasholder is low if conventional films are being used. Furthermore, the film may be damaged by rodents but this was reported only occasionally. Eventhough the film can be mended easily, the glue has to be kept sealed well and the glue must be available in village hardware shops.

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