

china: azolla propagation
and
small-scale biogas technology



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INTRODUCTION

This is a report on the fifth of a series of Study Tours organized under the FAO/UNDP programme, in cooperation with the People's Republic of China.

The Study Tour was financed by the UNDP as part of the Preparatory Assistance phase of the Inter-Country project "Improving Soil Fertility through Organic Recycling" RAS/75/004.

The tour took place from 21 May to 11 June 1978 and had the following objectives. To gain knowledge and experience in:

- the multiplication of Azolla as a source of biological nitrogen, particular attention being paid to propagation of Azolla and its protection from disease, insect damage and adverse climatic conditions;
- harvesting and agricultural use of Azolla;
- construction of small-scale biogas units;
- management of biogas units and efficient use of the gas by farming communities and of the effluents for improving soil fertility.

The study group consisted of eighteen participants, fifteen from countries in Asia and three from FAO; in all, twelve different nationalities were represented. A list of participants is given as Annex 1.

The group entered China by train from Hong Kong and travelled extensively in the provinces of Guangdong, Zhejiang, Shanghai-Shi, Jiangsu, Sichuan and Beijing Shi. (See Figure 1 and Programme in Annex 2). In all, fifteen People's Communes were visited where practices of biogas and Azolla production were active and in which these practices differed in nature. Thus it was possible to study many kinds of biogas unit and to learn of different techniques in Azolla propagation. The group was the first such body to visit Sichuan Province and this was by special request as the province is a leading one in biogas technology.

This report is devoted exclusively to the subject matter of the tour, Azolla and biogas. Related matters of organic recycling were also seen but these have been adequately described in the report of the Study Tour on recycling of organic wastes (FAO Soils Bulletin No. 40, 1977). Similarly, matters of more general consideration such as the structure of People's Communes, relevant history and agricultural background, have been fully described in previous reports and are not repeated here. A chapter is added however in which possible follow-up activities are discussed so that the knowledge gained can be applied in other countries.

As in previous reports, internationally accepted units of measurement are used with the Chinese equivalents in parenthesis; Chinese units are explained in Table 1.

With great sorrow is recorded the death from heart-failure of one of the participants, Mr. Paitoon Nagalakshana from Thailand, which occurred towards the end of the tour while the group was visiting the Tumen People's Commune in Sichuan Province.

P.R. Hesse
Team Leader

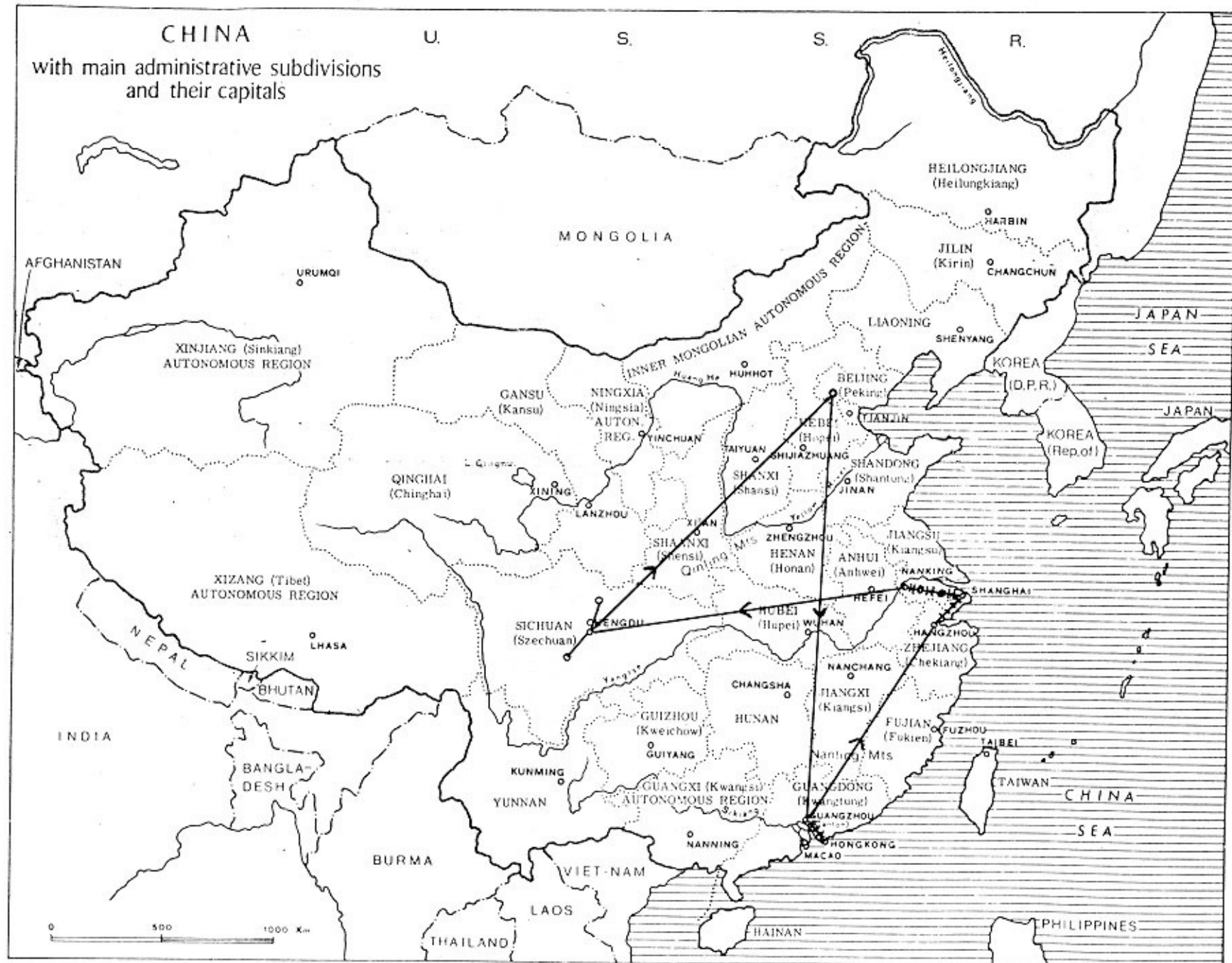


Figure 1 ROUTE TAKEN BY STUDY TOUR ON AZOLLA AND BIOGAS.

Table 1. Relevant Chinese Units of Measurement

1	mu	=	660	m ²	(0.066 hectare) *
1	jin	=	0.550	kg	
1	yuan	=	0.60	US\$	(as of October 1978)

* Note: In Sichuan Province the unit mu is equal to 1.3 times that in other provinces, thus 1 mu = 858 m² or 0.086 hectare.

ACKNOWLEDGEMENTS

The members of the FAO/UNDP Study Tour to China on Azolla and Biogas, which took place from 21 May to 11 June 1978, wish to express their appreciation to the Government of the People's Republic of China, to the Food and Agriculture Organization of the United Nations and to the United Nations Development Programme for the opportunity to participate in the tour.

The group members gained much technical knowledge which will be of immense value in their own countries for establishing or improving practices concerned with Azolla and biogas production. They also are very grateful to their Chinese hosts at all the many places visited for the friendly hospitality and excellent organization of arrangements.

Special thanks are due to those responsible in the Ministry of Agriculture and Forestry for the overall tour arrangements: Mr. Li Yung-kai, Director of the Bureau of Foreign Affairs, Mr. Chang Shi-chan, Head of the International Division, Dr. Yang Ching-jao, Head of the Soil and Fertilizer Office and to those who acted as interpreters throughout the tour, Mrs. Tsui Li-chuan, Mr. Yang Yung-hsing and Mr. Yin Pao-hsiang.

Several members of the group have contributed to the report but special credit must be given to Mr. D. Joshy* for the detailed reporting on biogas technology.

The figures have been drawn by Mrs. S. Hansen-Ascheri (FAO) and Mr. A. Backmann (SATA, Kathmandu), mostly from originals provided in China.

Photographs have been contributed by Kho Boon Lian, Chob Kanareugsa, D. Joshy, H. Matsuo and P.R. Hesse.

* Soil Scientist, Department of Agriculture, Nepal.

1.1 General

Azolla has been used in parts of China for many years as a means of improving the fertility of rice soils and as an animal feedstuff; practices for its cultivation and use have thus been developed to a stage where they can act as a guide for other countries in the same region.

1.1.1 Biology of Azolla

Azolla is a genus of the Azollaceae family of cryptogamic, free-floating ferns. The name is derived from the two Greek words Azo (to dry) and Ollya (to kill) thus reflecting that the fern is killed by drought and so can hardly be considered as descriptively specific.

The genus has six known species: A. pinnata which is the most prevalent species in Asia, A. nilotica (north Africa), A. filiculoides (southern South America to western North America), A. caroliniana (eastern North America and Caribbean), A. mexicana (northern South America to western North America) and A. microphylla (tropical and subtropical America).

Azolla floats on the water surface with the fronds lying horizontally (Plate 1). The fronds vary greatly in size between species, those of A. pinnata for example, being 1-2 cm in diameter and those of A. nilotica having a diameter of about 15 cm. The colour varies from green to purplish-red (see section 1.1.2).

Adventitious roots hang vertically down into the water and can penetrate mud; their length varies with species, being 1-2 cm for A. pinnata.

Azolla has a sporophytic cycle (Figure 2) and for A. pinnata sporocarp development is associated with the cooler, winter months, whereas for A. filiculoides in temperate regions, development is associated with the summer months. As yet no method of inducing the sporophytic cycle has been found.

1.1.2 Fixation of nitrogen

The importance of cultivating Azolla lies in the fact that it lives in association with a blue-green algal symbiont which fixes enough atmospheric nitrogen for rapid growth of the plant. The blue-green algal species is Anabaena azolla and it lives in cavities of the fern's upper lobes (Figure 3). Thus the Azolla-Anabaena complex offers a source of organic nitrogen fertilizer and may be considered as an aquatic green manure and so, of particular interest in rice cultivation.

The Azolla-Anabaena symbiosis can produce 10^3 kg (1 ton) of green manure per 10^4 m² (hectare) per day, containing 3 kg of fixed nitrogen which is equivalent to 15 kg of ammonium sulphate or 7 kg urea. It has been estimated that the developing world, by means of Azolla cultivation could produce one and a half million tons of nitrogen per rice crop.

Experiments have shown that Azolla can double its weight in a nitrogen-free substrate within three to five days and vigorously growing Azolla contains between 0.1% and 0.2% nitrogen, or from 3-5% N on a dry-weight basis.

The relationship, if any, between nitrogen-fixing ability and colour of Azolla has not been satisfactorily settled. At one Commune it was said that young Azolla remains reddish in colour until commencement of nitrogen assimilation causes the colour to change to green. In another Commune (see section 1.2.3), if the Azolla is red, it is sprayed with a solution containing urea and superphosphate. However, it has

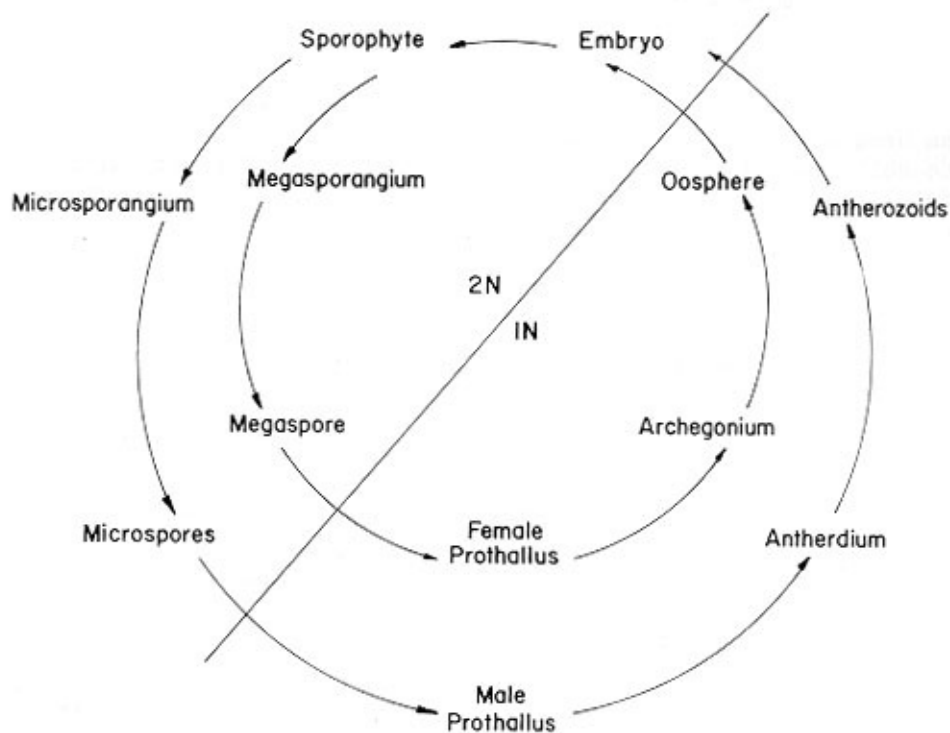


Figure 2. Life cycle of *Azolla*

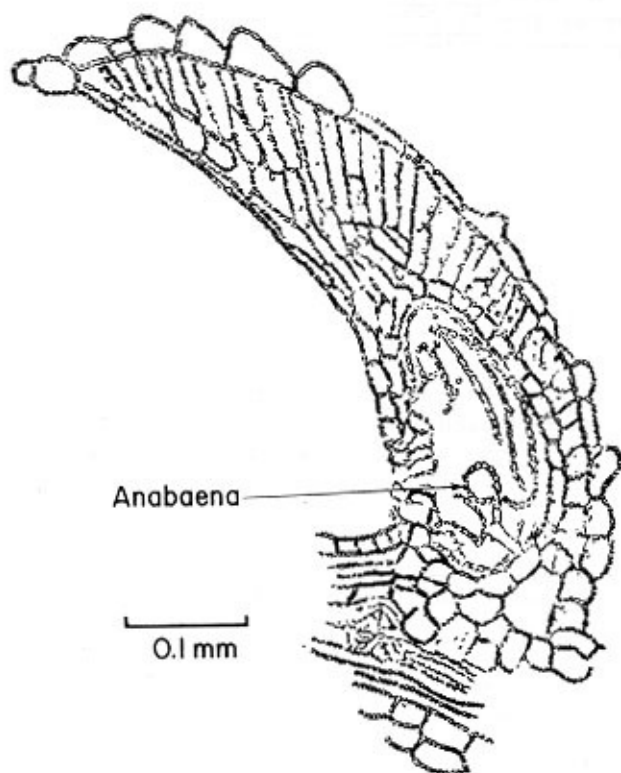


Figure 3. Section through the dorsal lobe of *Azolla* showing *Anabaena* filaments (after Strasburger 1873).

been shown that red Azolla contains just as much nitrogen as green Azolla and mature plants can be of either colour. Research at the International Rice Research Institute* has shown that the red colour of Azolla is associated with phosphorus and with calcium deficiency as well as with temperature and this was borne out during discussions with several Chinese experts. In Guangdong Province, the red colour was associated with high summer temperature and in the Changzhou district it was stated that red colour is due to a too dense cover of Azolla. Whether or not there is a relationship between denseness of growth and/or high temperature and availability of phosphorus or calcium has yet to be demonstrated. For practical purposes the colour of Azolla does not seem to affect nitrogen fixation or growth; in most parts of China red and green Azolla were seen in mixed stands. In Vietnam, green, red and purple Azolla are distinguished as three morpho-physiological types or strains; the red Azolla is said to be resistant to high levels of salinity, the purple is resistant to acidity and the green to high temperature.

1.2 Propagation of Azolla

1.2.1 Extent of Azolla cultivation in China

The species of Azolla grown in China is A. pinnata and in Guangdong Province at least, the variety is Imbricata. The plant is known locally as "luping" or "hang ping".

There are records of Azolla cultivation in Zhejiang and Fujian provinces during the Ming dynasty nearly 400 years ago and in Guangdong Province, Azolla has been cultivated for improving rice soils for more than one hundred years and as an animal fodder for even longer. The province normally has about 750 thousand hectare of land devoted to Azolla production.

In Zhejiang Province during modern times, Azolla cultivation has been practised only since 1974 as a consequence of fertilizer and fodder shortage. For example, the Anshi People's Commune has increased the land area used for Azolla ten times (from 40 to 400 ha) since 1974.

Similarly, in Sichuan Province, Azolla has been seriously cultivated only since 1972 and its importance has been emphasized by the creation of special Production Brigades for its propagation (e.g. at the Tumen People's Commune).

Again, in Jiangsu Province, Azolla has been introduced relatively recently but now near Changzhou more than 70% of the rice fields are fertilized with Azolla and in the Hua Shi People's Commune over 10 000 kg/ha (1 500 jin/mu) of Azolla are grown for each rice crop.

It is estimated that over 6.5 million hectare are now cultivated for Azolla production in the country. However, not all China is yet convinced of the need to grow Azolla. At Wuxi, Jiangsu Province, Azolla was introduced in 1965 but since then its use has declined due to shortage of land for other crops. In the Shu Ching People's Commune near Shanghai, Azolla is not cultivated at all as a fertilizer, only on a very small scale in ditches as chicken and pig feed.

1.2.2 Methods of Azolla cultivation

Until such time as a procedure is evolved for initiating the sporophytic cycle, Azolla must be reproduced vegetatively. Two main practices are followed: the plant is grown in small nurseries and then "sown" onto the rice fields for further reproduction or, it is grown over relatively large areas as a green manure crop in its own right.

* At Los Baños, the Philippines

In either case it is necessary to maintain a basic stock of viable material throughout the year and this is discussed in section 1.2.4.

Azolla nursery beds are small (3 x 4 m), shallow (10 cm) basins in groups of ten or twenty (Plate 2). Water is maintained to a depth of 3-6 cm and Azolla stock is put into the beds at approximately 1 kg m⁻². Rate of reproduction varies according to climatic conditions, especially temperature (see section 1.2.3) and so differs slightly from province to province. In Jiangsu Province only three days are necessary before the nursery beds are fully covered by Azolla ready for harvest. It was claimed that during the period 20 May to 10 July, 0.5 kg of Azolla ultimately produces 5 000 kg; another period of high growth rate is September-October.

The usual rate of multiplication of Azolla is about five-fold over a period of five weeks. Rice fields are "seeded" with Azolla stock at a rate of about 7 500 kg/ha (1 000 jin/mu).

In some parts of China a procedure is used known as 'double narrow rows'. In this procedure rice is grown in double rows about 10 cm apart; a space of about 60 cm is left between each pair of rice rows. Thus a bigger space is left for Azolla to grow and it can be cultivated for one month longer than usual. A record crop has been obtained of over 14 000 kg rice and 140 000 kg Azolla per hectare simultaneously. Every available space is utilized for growth of Azolla. For example during periods when compost pits are not in use as such, they provide small localized Azolla 'nurseries' (Plate 3)

An unusual practice was observed in Sichuan Province. At the Tumen People's Commune, growth of Azolla is encouraged by tapping it with bamboo brushes. Armed with a long-handled brush of bamboo, the farmer advances through the Azolla-covered rice field and gently beats the Azolla mat (Plate 4). This was said to sub-divide the plants and accelerate growth; it is done once a week.

1.2.3 Optimum conditions for cultivation of Azolla

i) Temperature: The optimum temperature range for growing Azolla pinnata in China is from 293 K to 298 K (20-25°C). According to information given by those concerned in the Anshi People's Commune near Hangzhou, Azolla will not grow at temperatures below 278 K (5°C) although it can survive at temperatures down to 270 K (-3°C). Above this temperature its growth rate increases over a period of five days, as indicated in Table 2.

Table 2. Effect of temperature on the growth rate of Azolla with reference to the rate at 278 K (5°C).

<u>Water temperature</u>	<u>Increased growth rate</u>
283 K (10°C)	20%
288 K (15°C)	60%
293 K (20°C)	110%
298 K (25°C)	223%
303 K (30°C)	180%
308 K (35°C)	120%
316 K (43°C)	stops growth
318 K (45°C)	90% dies

The Chinese experts were interested to hear of the work being done at the International Rice Research Institute on temperature effects. Experiments have indicated that A. mexicana may be able to resist higher temperatures than can A. pinnata and that A. filiculoides grows best at temperatures below 298 K (25°C). Apparently Malaysian strains of local Azolla are the most tolerant of high temperatures. Other experiments using what is thought to be A. pinnata showed no significant differences in yield or in



Plate 1. Azolla pinnata floating on water surface between rice plants.
(Anshi People's Commune, Zhejiang Province).

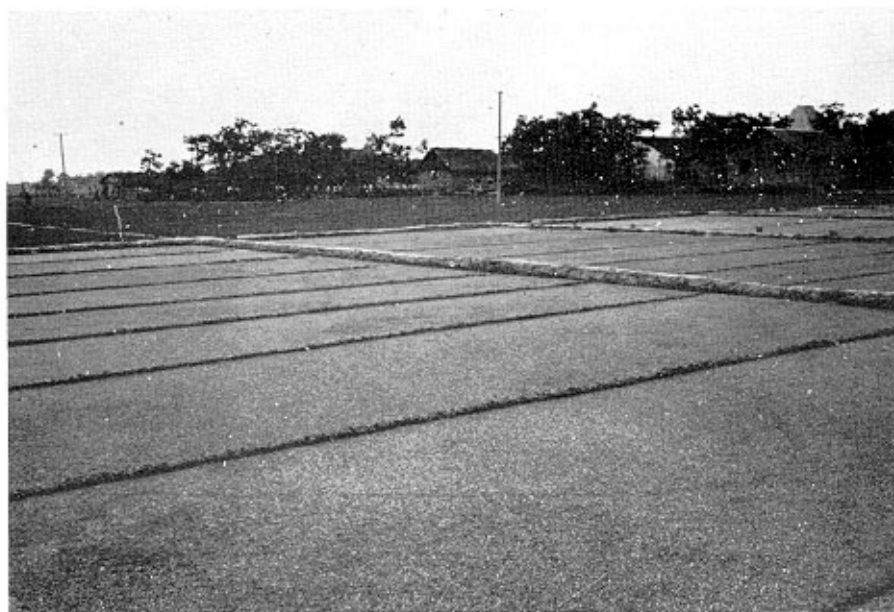


Plate 2. Nursery beds for Azolla pinnata at Anshi People's Commune,
Zhejiang Province



Plate 3. Azolla pinnata covering the surface of a compost pit
(Anshi People's Commune, Zhejiang Province).



Plate 4. Tapping Azolla beds with bamboo brushes to stimulate growth
(Tumen People's Commune, Sichuan Province).

nitrogen accumulation over the average (i.e. of day and night) temperature range of 295-304 K (22-31 °C). When the temperature exceeded 295 K (22 °C) however, reddish-brown discoloration was apparent in the fronds (see also section 1.1.2).

ii) Light: It was said that the optimum solar energy for growth of Azolla is from 20 000 to 50 000 lux (20-50 kcd sr m⁻²) and that the permissible range is from 5 000 to 100 000 lux (5-100 kcd sr m⁻²); during the rainy season sunlight was sometimes a limiting factor for growth when Azolla and rice were grown together.

iii) pH value: A neutral (pH 7) reaction has been given (FAO Soils Bulletin No.40, 1977) as the best for growth of Azolla. At the Pin Niu People's Commune near Changzhou, a pH range of 4 to 6 was said to be best and that Azolla is very sensitive to alkalinity. The soils of the Commune however had pH values of up to 8 and Azolla grew quite well on the overlying water. Research made at the International Rice Research Institute has suggested that pH effects are connected with availability of iron and this confirms the acid range of pH 4-6 as being most suitable.

iv) Salinity: For good growth of Azolla, the salt content of the water should be less than 0.1%.

v) Humidity: The optimum relative humidity is 85-90%; at humidities below 60% or higher than 100%, Azolla does not grow.

vi) Nutrients: For optimum growth, Azolla needs fertilization with phosphorus and, in some instances, potassium. At the Anshi People's Commune near Hangzhou experiments on phosphorus fertilization were made during the period mid-April to early May. Phosphorus was added at a standard rate of about 5 kg P/ha (1 jin P₂O₅/mu) using three different forms. Superphosphate gave a 56% increase in weight of Azolla, rock phosphate a 45% increase and fused magnesium phosphate a 22% increase. The phosphorus was added in split applications every two days.

Research at the International Rice Research Institute has shown that phosphorus and calcium deficiencies restrict growth of Azolla and that phosphorus is best added at 2.5 kg/ha every two days, five times in all. As ATP-molecules are necessary for the process of nitrogen fixation, phosphorus is an important limiting factor for Azolla growth.

At the Anshi People's Commune potassium is also needed for Azolla during the winter months and this is sprayed on as a 1% solution of potassium sulphate at a rate of 800 kg K/ha (130 jin K₂O/mu).

Nitrogen fertilization is not usually necessary but at the Hsiachiao People's Commune in Guangdong Province, if the Azolla is reddish-coloured it is sprayed with a solution containing 1% urea and 1% superphosphate. It was not clear however whether or not the urea was necessary as development of green colour could well have been due to the phosphate (see section 1.1.2). At the Anshi People's Commune near Hangzhou, ammonium sulphate is applied at 15 kg/ha during March/April and at any time when rapid growth is required.

A common practice is to fertilize Azolla by means of compost. Compost is prepared from vegetative matter such as straw, mixed with river silt (Plate 5) and in due course is mixed into the Azolla nurseries (Plate 6).

The influence of external factors upon the growth of Azolla is diagrammatically presented in Figure 4.



Plate 5. Preparing compost from a mixture of straw and silt pumped from a river (Hsilang People's Commune, Jiangsu Province).



Plate 6. Compost being mixed into the Azolla beds (Hsilang People's Commune, Jiangsu Province).

1.2.4. Preservation of Azolla

As the plant is reproduced vegetatively, it is necessary to maintain viable stocks throughout the year and this presents problems during the very hot and very cold months. Procedures for solving the problems vary between Communes.

i) Preservation during summer (July/August)

At the Hsiachiao Commune in Guangdong Province, if the water temperature reaches 315 K (42 °C) it is drained off during the night and replaced with fresh cooler water. This is done every night until day temperatures drop to permissible levels.

At the Pin Niu People's Commune near Changzhou, Azolla is kept between widely spaced (1 m) rice plants which provide shade as shown in Plate 4. During this warm part of the year, pests are most active and so pesticides are used to help preserve the Azolla; the pesticide is an organo-phosphorus compound.

A similar procedure is followed in Sichuan by the Tumen People's Commune. An average of 850 m² (1 mu) of Azolla is preserved for future propagation and this is grown between widely spaced (1 m) rice on 15 cm of standing water. At noon each day the water is stirred to reduce the surface temperature; pesticides are also applied. If the Azolla layer becomes too dense, as indicated by a rippling or corrugating of the surface mat, it is manually thinned. Summer temperatures in Sichuan reach 308 K (35 °C).

ii) Preservation during winter (November-March)

At the Anshi People's Commune near Hangzhou, Azolla is heaped in pits dug in the rice fields; in very cold weather the pits are covered with plastic sheets.

At the Pin Niu People's Commune near Changzhou, winter temperatures can reach 270 K (-3 °C). Several methods are used to preserve Azolla; in one method, it is placed on 25 cm of water in a pit and covered with plastic to keep it air-tight: the water is changed frequently. In another method the Azolla is stored in thin layers at the bottom of 30 cm deep pits and covered with straw (Fig.5). Necessary humidity is provided by a shallow depth of water at the bottom and aeration is provided by means of bamboo pipes. It was said that Azolla can be kept alive in this manner for two months. During the winter months Azolla cannot be transported and should not be touched as movement causes it to die.

A third method used by the Commune was to pipe industrial waste hot water into the Azolla fields in order to raise the temperature.

At the Tumen People's Commune in Sichuan, Azolla is preserved in the open fields, but in selected spots exposed to sunshine and shielded from wind. For the purpose it is grown in exceptionally thick, dense layers and is fertilized with phosphorus and potassium to encourage growth. Five percent of the total paddy area is used and, again, it was emphasized that during this period the plant must not be physically disturbed. The average winter temperature is 300 K (7 °C) but can reach 271 K (-2 °C).

1.3 Agricultural Use of Azolla

1.3.1 As green manure

The principal use of Azolla is as a green manure for rice. In some parts of China the plant is used also as a green manure for other crops; at the Pin Niu People's Commune, Changzhou for instance, Azolla was being composted and used to fertilize wheat

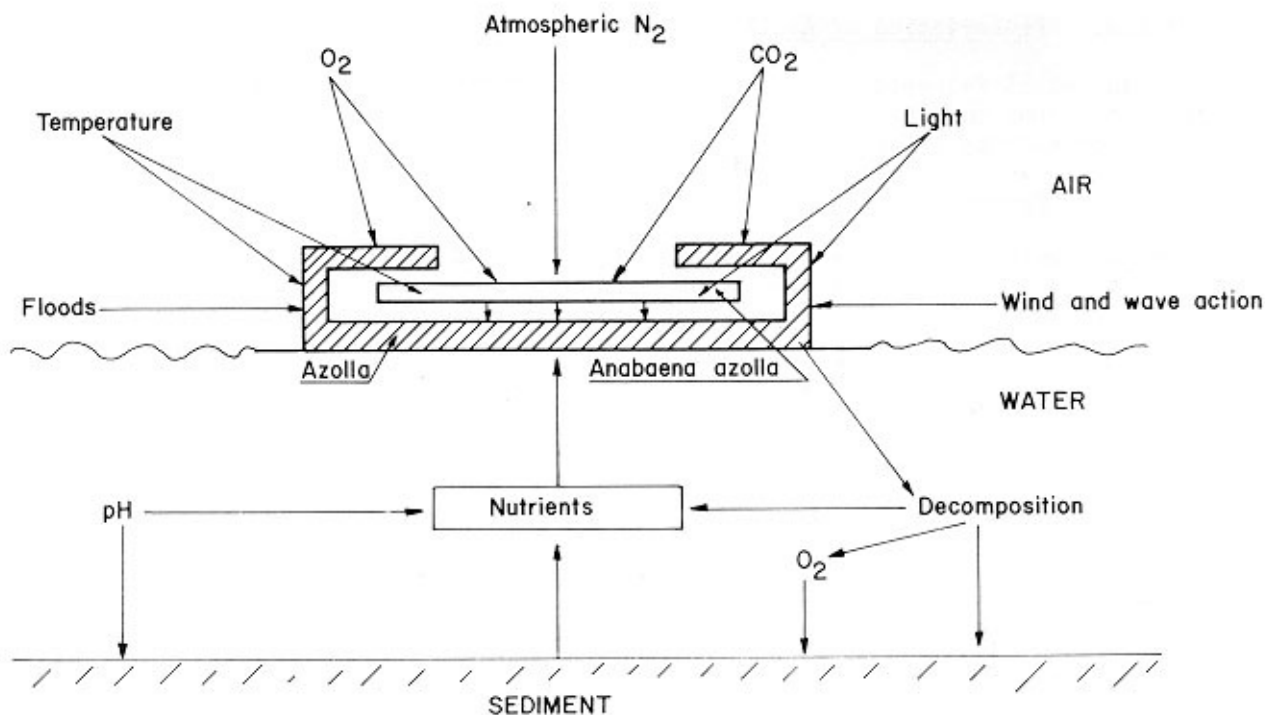


Figure 4. Diagrammatic representation of influence upon growth of *Azolla* of outside factors (after Ashton & Walmsey, 1976).

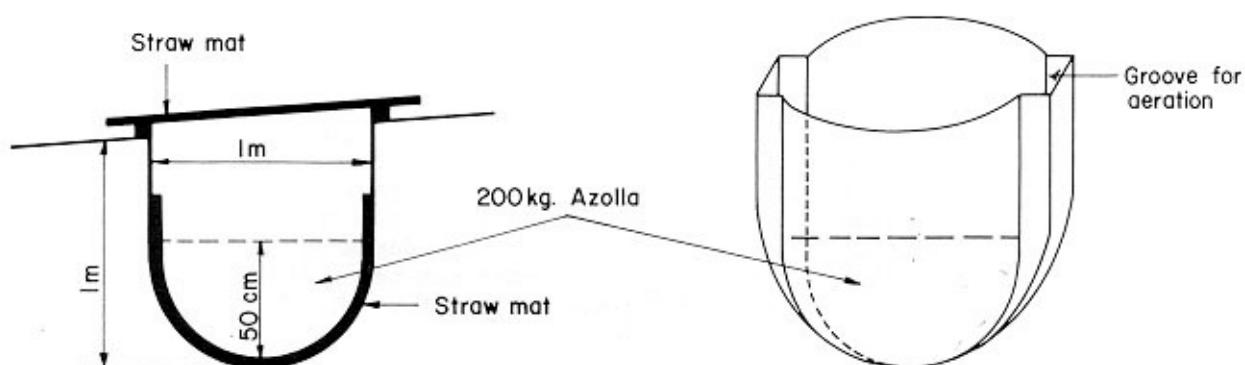


Figure 5. One method for keeping viable stocks of *Azolla* during cold winter months at Changzhou, Jiangsu Province (from FAO Soils Bulletin No.40, 1977).

and at the Tumen People's Commune in Sichuan Azolla is added at 30 000 kg/ha to wheat, maize and rape. Fertilizer trials have been made using Azolla in several provinces. Typical results of Azolla application are a yield increase of over 800 kg/ha for wheat, 710 kg/ha for broad beans and 945 kg/ha for maize.

In some Communes Azolla mixed with river silt is applied as fertilizer to upland crops.

The practices of using Azolla for rice fertilization vary between provinces and even between Communes. At the Anshi People's Commune Hangzhou, fields are flooded to a shallow depth, about 3-4 cm, and 'seeded' with Azolla at a rate of 7 500 kg/ha of fresh Azolla harvested from the nursery beds; the Azolla is thus 'seeded' into muddy water. When the field is covered with a mat of Azolla (about 20 ton/ha) and which usually takes about ten to fifteen days, the water is drained off and the Azolla ploughed into the soil. Rice is transplanted 2-3 days later. A second and third crop of Azolla may or may not be similarly grown and incorporated before rice is transplanted into the field.

The other technique for cultivation is to sow the plant in the field after transplanting rice seedlings. For example, at the Tumen People's Commune, Sichuan Azolla is added to and multiplied in, the fields after transplanting the first rice crop seedlings. Phosphorus and potassium fertilizers are added and fields are carefully weeded before adding the Azolla at 7 500 kg/ha (Plate 7). When the water surface is covered with Azolla (Plate 8) about 70% of the plant is dug in by hand, the remaining 30% being left to regenerate; no tools are used, the Azolla is buried in the mud with the hands (Plates 9 and 10) and this is usually done at about the end of May. After harvesting the first rice crop, the field is again flooded and in due course (about the end of June) the second crop of Azolla is dug or ploughed in before transplanting the second rice crop, and again about 30% is left to regenerate. A final digging in, this time completely, is done towards the end of July.

It was said that before the Commune started using Azolla paddy yields were only 3 000 to 3 600 kg/ha (500-600 jin/mu). In 1977 Azolla was used at the rate of 21 000 kg/ha (3 500 jin/mu) and paddy yields rose to 9 600 kg/ha (1 600 jin/mu).

After being incorporated into soil, Azolla decomposes within about two weeks; as green Azolla has a C/N ratio of about 10, it decomposes easily. According to one Commune (Anshi) 1 000 kg of Azolla is equivalent to 15 kg of ammonium sulphate and shows residual fertilizing effects. Experiments made at the International Rice Research Institute have shown that no nitrogen is available from Azolla until the plant has decomposed and that after a period of two weeks only 40% of the nitrogen is available to rice plants; it takes eight weeks to liberate 75% of the nitrogen and so residual effects are to be expected. In this connection the variety of rice is important and a variety having a long growing period will benefit most from Azolla applications.

When harvesting Azolla from the nursery beds it is first swept into piles by horizontally pushing a bamboo stick across the water surface; the plant is then gathered into baskets for transport (Plate 11). From 7-10 cm of standing water is necessary during harvesting in order to obtain a clean, mud-free crop of Azolla.

Experiments made at the Anshi People's Commune showed that incorporation of Azolla into the soil reduced the bulk density from 1.28 to 1.15 g cm⁻³, increased pore space by 3.7% and increased humus content by 0.05%.

In provinces south of the Yangtze river the cultural pattern is wheat, rice, rice occupying 420 days including nursery propagations. Thus firstly wheat is grown and this is followed by the first rice crop planted at the end of May and harvested in August. The second rice crop is raised in the nursery during June, transplanted in August and harvested in September. This is often followed by a green manure crop. This intensive



Plate 7. Weeding a rice field by treading the weeds into the mud before seeding with *Azolla* (Tumen People's Commune, Sichuan Province).



Plate 8. Water surface of rice field completely covered with *Azolla pinnata* just prior to burying the *Azolla* (Anshi People's Commune, Zhejiang Province).



Plate 9. Burying the Azolla by hand in the mud of a rice field at the Anshi People's Commune.



Plate 10. Detail of Plate 9, showing the burying procedure.

agriculture is made possible largely by the use of Azolla on a large scale.

1.3.2 As animal feed

Records going back to 540 B.C. indicate the use of Azolla as an animal feedstuff in China. In most communities Azolla is used to supplement animal (pigs, ducks and fish) feedstuff, usually after drying; it was said to contain 16% protein and 2% fat on a dry-weight basis. Azolla has been used up to 50% in the diet of pigs and one hectare of green Azolla will provide enough roughage for about two hundred pigs. At Pin Niu People's Commune in Jiangsu Province dried Azolla was mixed with sludge from biogas plants as an additive to pig feed (Plate 12).

1.4 Problems of Azolla propagation

The problems to be faced when growing Azolla can be summarized as:

- i) breeding of varieties that can resist high and low temperatures;
- ii) conservation of viable material during hot and cold months;
- iii) pest and disease control;
- iv) only one method of propagation, i.e. vegetative;
- and v) transport of material.

The first two problems relating to temperature resistance and preservation of Azolla, have been discussed in section 1.2.3 and the best possible solution is to develop or adapt other species or strains of Azolla for the temperature ranges concerned; research on this is under way.

Damage, or even total destruction, of Azolla by pests is a very serious problem particularly during the summer months. The principal insect pests of Azolla are the larvae of Lepidopterous and Dipterous species, Pyralis, Microgaster, Nymphula and Chironomus, which eat Azolla leaves during May-August. These pests are controlled by using a 2% emulsion of DDT or with 20% 'Phosment'. During the periods April-May and August-October, larvae feed on Azolla roots and are combated with a 1:800 mixture of 50% 'Fenthion' and water or by spraying with 'Parathion'* or 'Toxaphene'. Snails are another pest, attaching themselves to the roots and young leaves; they are controlled with the same insecticides as for larvae.

Some common pests of Azolla are shown in Plates 13 - 16.

At the Tumen People's Commune in Sichuan, it is the practice to use ducks for destroying harmful insects and snails in Azolla beds (Plate 17).

During periods of high temperature Azolla is attacked by the fungus Rhizoglyphus; control is attempted by spraying with diluted 'Defusit' or 'Dipterex' mixed with 'Malathion'.

The fourth problem, of vegetative propagation, is not being examined yet in China but at the International Rice Research Institute work has been commenced on the sporophytic cycle and, if successful, will enable Azolla to be propagated by spores as well as enabling research to go ahead on the breeding of new strains and species having desired characteristics.

* Note that use of Parathion is restricted in many countries and use of DDT is restricted in some countries.



Plate 11.

Harvesting Azolla in baskets from nursery beds at
Pin Niu People's Commune, Jiangsu Province.

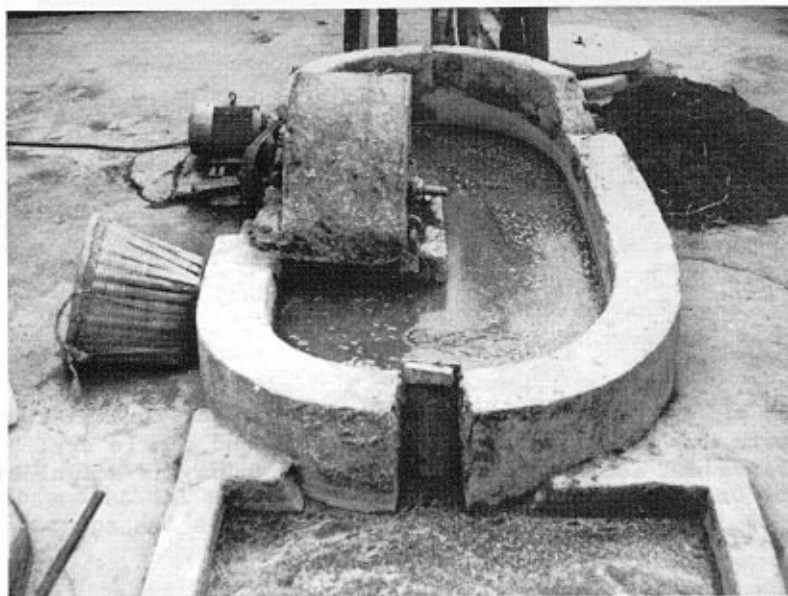


Plate 12.

Azolla being mechanically mixed with sludge from a
biogas unit to provide a pig feed additive (Pin Niu
People's Commune, Jiangsu Province.

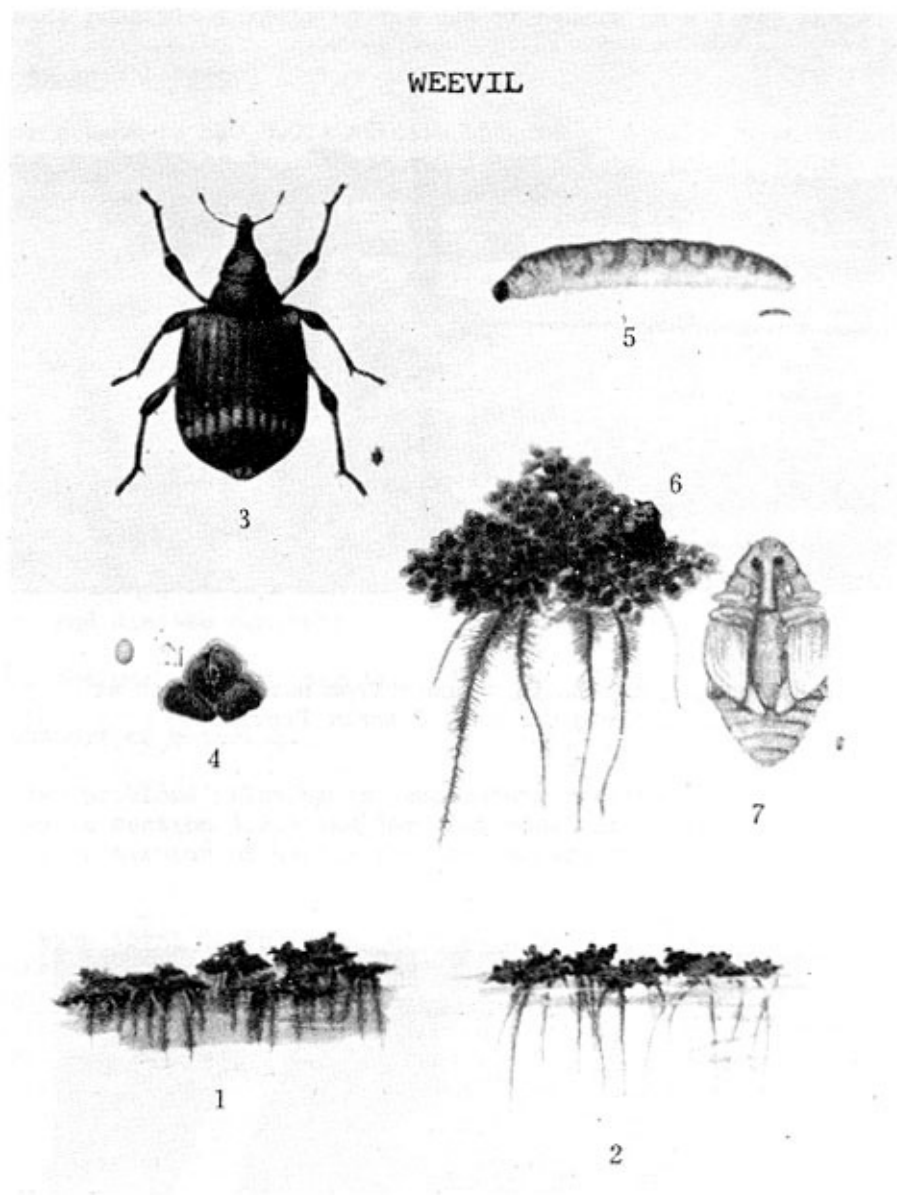


Plate 13.

Pests of Azolla (Weevil): 1. Unaffected Azolla; 2. attacked Azolla; 3. moth and actual size; 4. egg deposit and single egg; 5. larva and actual size; 6. cocoon; 7. pupa and actual size.

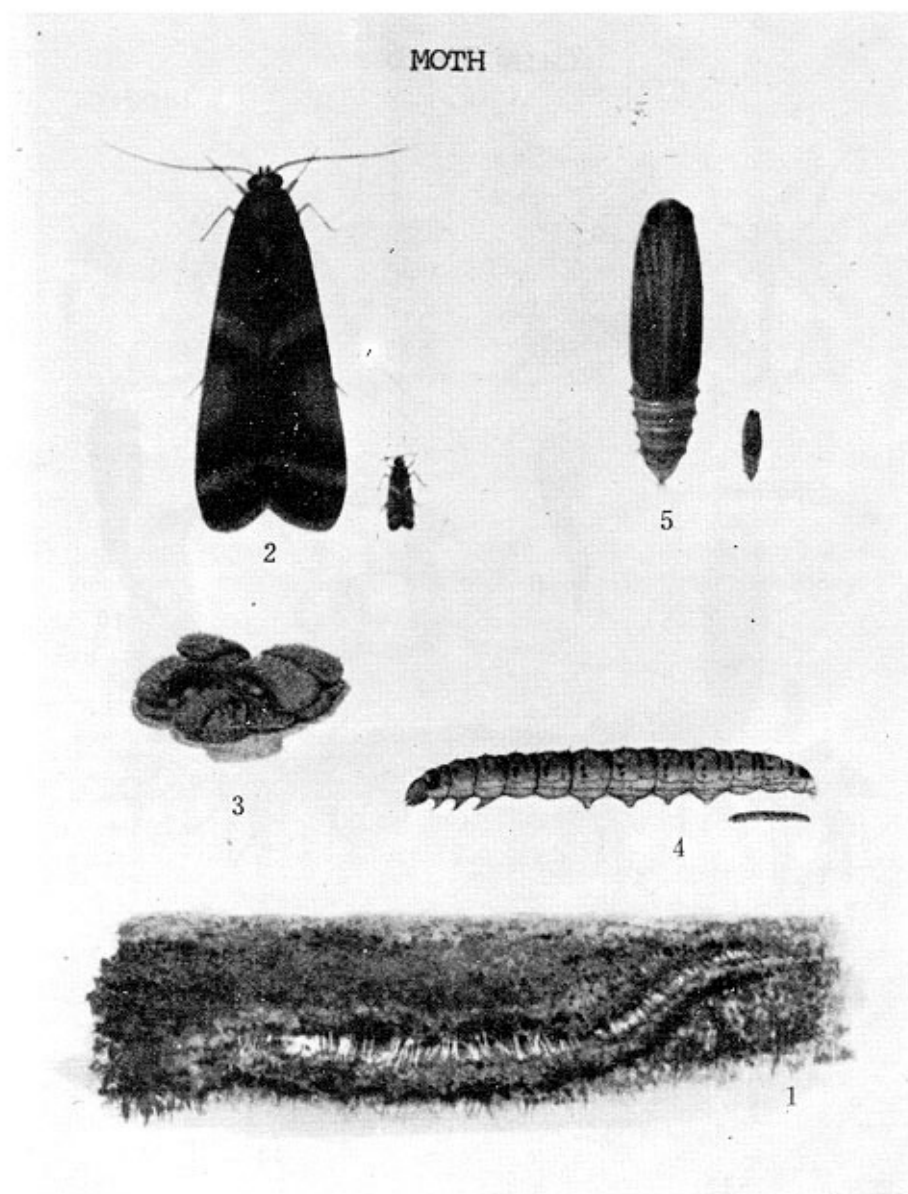


Plate 14. Pests of Azolla (Moth): 1. Tunnel dug by moth in Azolla; 2. moth and actual size; 3. eggs on Azolla; 4. larva and actual size; 5. pupa and actual size.

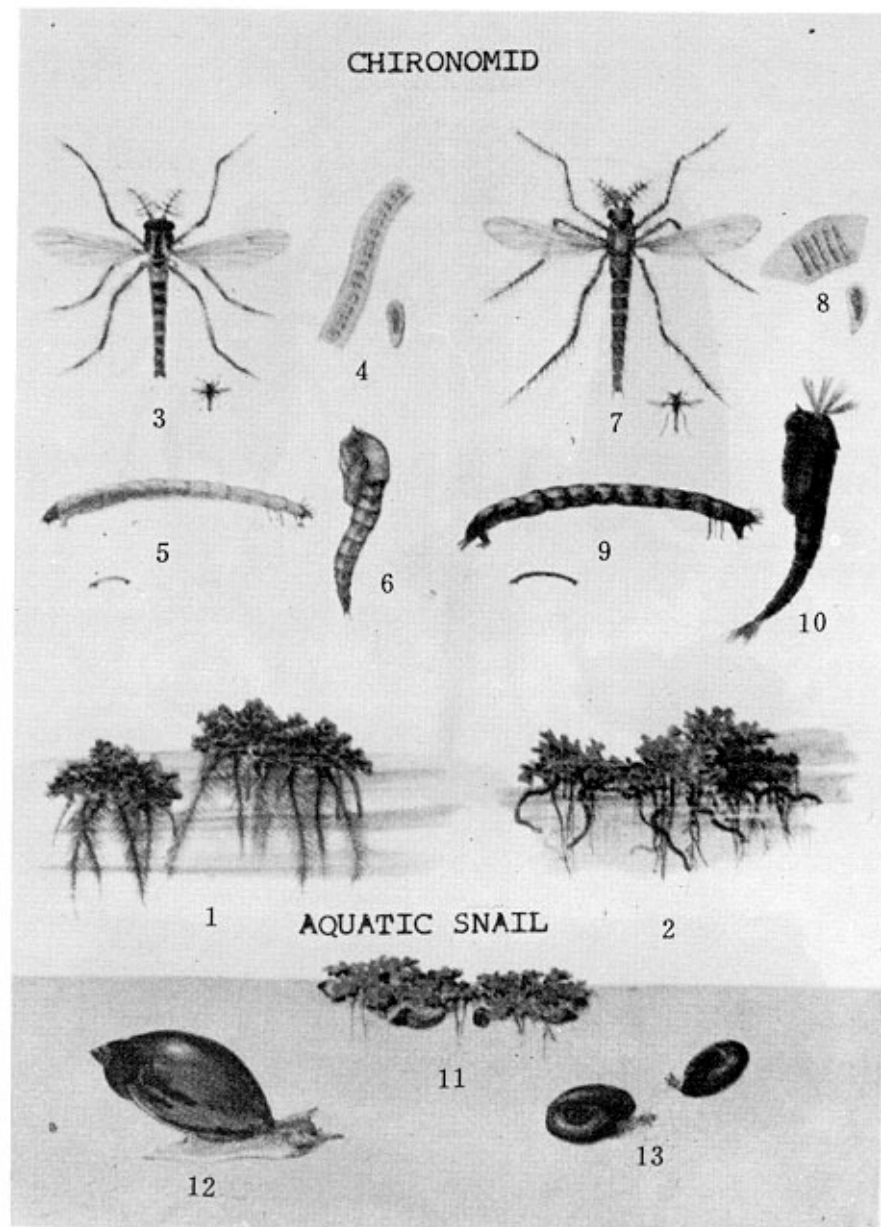


Plate 15. Pests of Azolla (Chironomid): 1. Unaffected Azolla; 2. attacked Azolla; 3. moth (white silk worm) and actual size; 4. egg mass and egg; 5. larva and actual size; 6. pupa; 7. moth (red silk worm) and actual size; 8. egg mass and egg; 9. larva and actual size; 10. pupa; 11. Azolla attacked by aquatic snail; 12 and 13 aquatic snails.

NYMPHULA

PYRALID

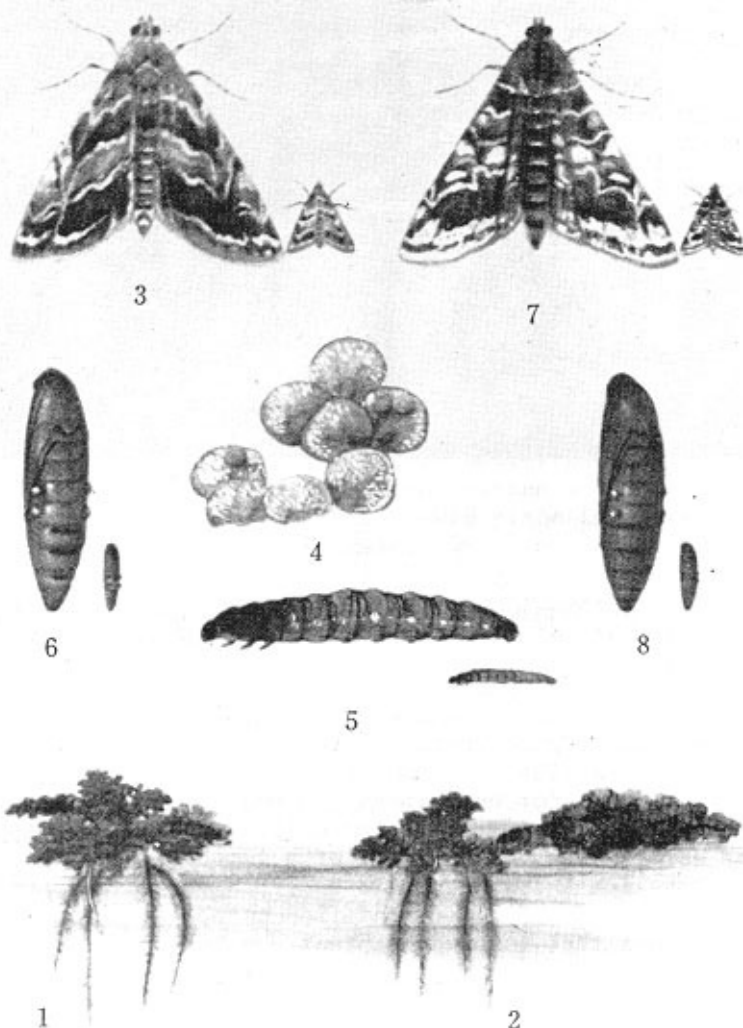


Plate 16. Pests of Azolla (Nymphula and Pyralid): 1. Azolla affected by young larva; 2. Azolla affected by adult larva; 3. moth and actual size; 4. eggs on surface of Azolla; 5. larva and actual size; 6. pupa and actual size; 7. Pyralid moth and actual size; 8. Pyralid pupa and actual size.

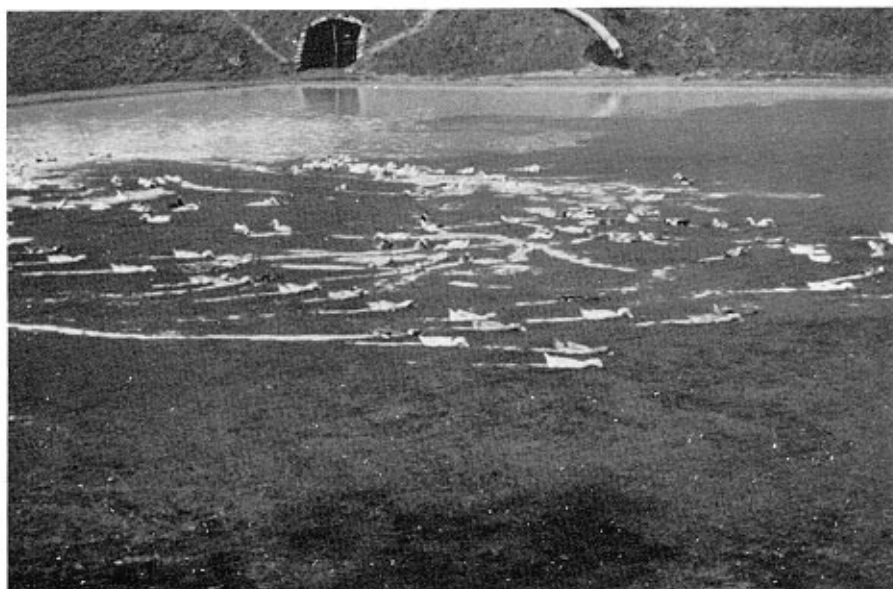


Plate 17: Ducks eating snails and harmful insects on a bed of Azolla at the Tumen People's Commune, Sichuan Province.

The fifth problem, that of transport, is not of much consequence in China today, but if more suitable kinds of Azolla are found elsewhere in the world, they would have to be transported - even if only for experimental purposes. Once Azolla can be propagated through spores, the transport problem will be solved automatically but meanwhile, the Chinese were interested to learn of a temporary technique developed at the International Rice Research Institute. In order to obtain and send Azolla specimens from various countries for experimentation purposes, a small quantity is 'seeded' onto agar-jelly in a test-tube; the plant can be kept alive in this manner for over one week.

Usually in a biogas digestion unit all three phases are occurring simultaneously and if any one phase gets out of hand, production of methane is adversely affected. This is especially so for the acid-forming phase as too great an acidity will prevent the methane-producing bacteria from functioning. The theoretical optimum acidity is from pH 6.8 to 7.2.

The highly specific methane-producing bacteria* are also sensitive to temperature; optimum temperature is 308 K (35 °C) and the bacteria cease to function if the temperature drops below 283 K (10 °C). The methane bacteria are also very sensitive to oxygen and are slow to reproduce. The acid-forming bacteria are not very sensitive to the environment and tend to reproduce rapidly.

As the methane-producing bacteria cannot use nitrogen or carbon from sources such as carbohydrates and protein, the acid-forming phase is essential and thus it is important to obtain and maintain the correct balance between the two bacterial populations. This depends not only upon the temperature and degree of acidity, but also on the nature of the original organic material.

As bacteria use carbon atoms at a rate approximately thirty times faster than they need nitrogen, the best ratio of carbon to nitrogen in the organic material is 30 : 1. If too much carbon is present digestion will decrease as soon as all nitrogen is used; similarly if too much nitrogen is present digestion stops when the carbon is exhausted and excess nitrogen is lost as ammonia. A proper nutrient balance is also important and especially phosphorus availability; thus it is often beneficial to add night soil to the source organic material.

During the acid phase the pH value will drop to below 6 over a period of two weeks. After a further two weeks as digestion continues and ammonia is formed, the pH will again rise and with methane formation will reach a value of 7 and will continue to rise to 8.2. At this stage the mixture is fairly well buffered and new material can be added without disturbing effects.

The bacteria are most efficient when they have intimate contact with their food source and thus methane production can often be increased by gently stirring the mixture during digestion. This is sometimes done mechanically but in China is usually achieved by the effect of adding fresh material at the bottom of the digester.

2.1.2 Benefits of Biogas Production

The benefits to be derived from small-scale biogas units can be considered from two aspects, the immediate primary benefits of the outputs - gas and manure, and secondary benefits related to the inputs - human, animal and crop wastes.

The gas produced, being largely methane with up to 30% carbon dioxide, is a 'clean' and convenient fuel. Its combustion does not pollute the atmosphere and its calorific value is higher than that of many traditionally used fuels (Table 3); the group were told in one Commune that cooking times have been more than halved since biogas has replaced wood.

* There are four morphological groups of methane bacteria:

Rod-shaped cells, Sporulating	e.g. <u>Methanobacillus</u>
Rod-shaped cells, Non-sporulating	e.g. <u>Methanobacterium</u>
Spherical cells in sarcina arrangement	e.g. <u>Methanosarcina</u>
Spherical cells not in sarcina arrangement	e.g. <u>Methanococcus</u>

Table 3. The effective calorific value of biogas compared with some other fuels.

1m ³ of biogas will generate approximately 23 x 10 ⁶ J (5500 kcal) of heat energy.	
<u>Fuel</u>	<u>Calorific value</u>
Biogas	15 600 kJ kg ⁻¹
Wood	2 400 kJ kg ⁻¹
Charcoal	7 000 kJ kg ⁻¹
Kerosene	18 000 kJ kg ⁻¹

Use of the gas as fuel saves other fuels such as kerosene and coal and eliminates the need to burn other valuable natural resources. Thus by using biogas instead of firewood, deforestation and hence soil erosion is reduced.

The gas provides a convenient and cheap source of power not only for cooking, but for lighting, heating and running farm machinery, irrigation pumps and so on. If larger biogas units are employed, or if the gas from several small units is combined, generators can be run to produce electricity.

The effluent and sludge remaining after digestion has taken place, is a rich and effective manure. All objectionable odour is removed and most harmful organisms are killed. At the Liang Chu People's Commune for example, it was said that 86% of the pathogens in the source material are destroyed during digestion (see Section 2.3.7).

Due to the removal of carbon during digestion, the organic material remaining is richer in nitrogen and phosphorus than the original material and is thus a superior fertilizer to normal compost. Although the solid sludge residue has to be manually applied to the fields, the liquid effluent, which is also a valuable fertilizer, can be pumped out and sprayed as required (Plates 27 and 28). Use of the residues as manure saves mineral fertilizers and their expense.

The less obvious benefits relate principally to control of environmental pollution. The process turns offensive waste materials from humans and animals into useful products and is an ideal method of waste disposal. Similarly crop residues and other vegetable waste matter are converted to fuel and manure instead of being burnt or left to rot.

2.1.3 Extent of Biogas Production in China

Production of biogas on a small, haphazard scale has been known in China for many years but its deliberate organization and development form part of the social reconstruction programme started with the "Great Leap Forward". The response has been positive but variable. Thus, for example, whereas in Sichuan Province there are special Biogas Promotion offices and over one million small biogas units, in Guangdong Province biogas has developed to a relatively small extent and in Shanghai Shi, at the Shu Ching People's Commune (for example) small-scale biogas has not been introduced at all.

In Zhejiang Province there is a special administrative office for popularizing biogas and in one commune (Liang Chu) fortyseven percent of the households have biogas, amounting to over two thousand units; however distribution is very erratic and some Production Brigades of the Commune have no units whatsoever; it seems as if the influence and interest of individual Production Brigade and Team Leaders is very important.

In the same province (Zhejiang) the Chang Ching Production Brigade of the Evergreen People's Commune commenced biogas production only in 1977, whereas in Wuxi county twenty three thousand units are operating. In Jiangsu Province the Pin Niu People's Commune has a biogas research and demonstration centre and by 1975 eighty percent of the households had individual units and the Commune was building a large unit for producing electricity.

In general, biogas technology having started to develop in China in 1958 waned during the late sixties when it was claimed that the process was uneconomic; its use again became popular in 1970. It is difficult, if not impossible, to estimate the total number of small biogas units now in China, but there must be at least several million.

2.2 Construction of Biogas Units

2.2.1 General

A biogas unit consists of two basic parts: a fermentation tank where the organic material is digested and, a storage tank where the produced biogas is collected. In most other countries where biogas is produced these two components are constructed as separate parts of the unit. An inverted metal drum is placed on the fermentation tank to serve as a gas holder and this floats on the slurry moving up and down according to the volume of gas. Such gas holders need skilled artisans and equipped workshops to fabricate them and are thus expensive. Furthermore, metal gas holders require regular painting to prevent damage and hence leaks, due to rusting; all countries using the floating drum design of unit are experiencing this problem.

The unique feature of biogas units of Chinese design is that the two basic components of digestion tank and gas holder are combined into one. Thus the metal gas holder is replaced by an upward extension of the digester into a dome-shaped structure. The design is variously referred to as 'fixed-dome' or 'drumless'. A second distinguishing feature of the Chinese biogas unit is that it is completely underground thus saving land space and improving temperature conditions for fermentation. The third important feature is that locally available materials are used to construct the units; this leads to variations in details of construction in different locations and also to low building costs.

The fixed-dome type of biogas unit is a development from earlier designs having a rectangular shape and which suffered from defects due to leakage of gas (see section 2.2.4).

2.2.2 Size of biogas units

A biogas unit can be designed either to process a given amount of organic material or to produce a given amount of gas. The size of household biogas plants in China is determined by the amount of gas required for daily use. Under normal conditions it is assumed that 1.5 m³ to 2.0 m³ of gas per person would be sufficient for family cooking and lighting.

Each cubic metre of raw material will yield from 0.15 to 0.30 m³ of gas per day, depending upon climatic condition and kind of material used. Based on these assumptions the size of the digester is calculated according to family needs. Usually the size of a

Chinese household biogas plant is from 6 m³ to 8 m³ but sizes up to 12 m³ were occasionally encountered.

Sizes of 50 m³ and above are suitable for community purposes and some examples of these are discussed in section 2.7.

2.2.3 Placement of biogas units

Household biogas units are sited in upland where the groundwater table is low. A unit should not be far from the house where the gas is to be utilized but at the same time should not be near to a source of drinking water. Two main kinds of site were observed; one near to the house but in the open where sunlight (and hence warmth) is not restricted and the other inside the house underneath the kitchen or under the animal stalls. The latter arrangement gives the best protection from low temperature during winter months and is also a neater and more compact arrangement than having the unit outside; however potential danger from gas leaks is greater.

The prevalent arrangement for siting of household biogas units is referred to locally as the 'three-in-one' whereby the unit is connected with a pig-sty and the house latrine (Figures 6 and 7, and Plates 18 and 19). In other places a 'two-in-one' arrangement is common with either the latrine or the animal pen being attached to the digester.

Community biogas units are sited for convenience of loading, cleaning and gas utilization. Where animal wastes are the main input the unit is usually placed near to the animal sheds on a farm whereas if human wastes are used to any extent, the unit adjoins the latrines outside a school, factory, hospital and so on.

In all cases, as the biogas unit is entirely underground (with the necessary exception of inlets and outlets), no space is wasted and the land above the unit can be used for other purposes. Thus vegetable gardens, animal compounds and even pathways were seen on top of biogas plants.

Sometimes topography has to be taken into consideration. At the State Orchard Tehyang County, Sichuan Province it was not possible to build a sufficiently large unit, or set of units, adjacent to the cattle sheds on a hilltop. The units were accordingly built on a relatively level site further down the slope. Cattle dung, made into a slurry with water, was conveyed to the digesters down a cement trough which crossed the road by means of a small 'aqueduct' (Plate 20).

2.2.4 Design of biogas units

As mentioned in section 2.2.1, there are several variations in design of biogas units in China, this being due mainly to kind of available building material and also to differences in soil and level of water table. However, all variations are of the same basic, batch-feed type of unit and all are below ground level.

Modification and improvement of design is a continuing exercise in China and this is the responsibility of special organizations, committees or departments set up at Commune or even County, level. Furthermore, individual Production Brigades and Production Teams have their own small groups of technicians for investigating the design and operation of units which results in continual modification to existing designs.

The early design of biogas unit in China was rectangular in shape, with flat base and top and having a liquid pressure tank for controlling gas pressure (Figure 8). This design of unit tended to leak gas from joints and corners and has now been discarded.

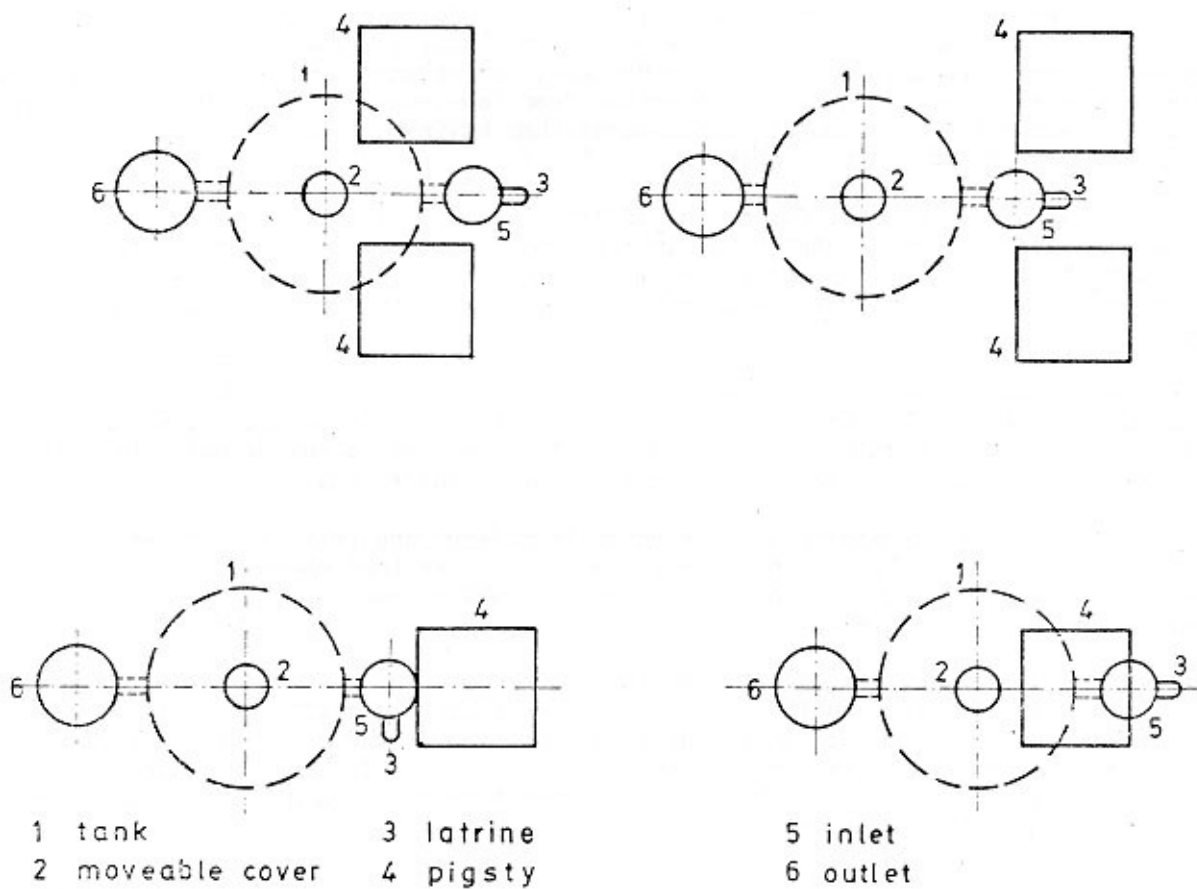


Figure 6. Layouts for the 'three-in-one' placement of biogas units.

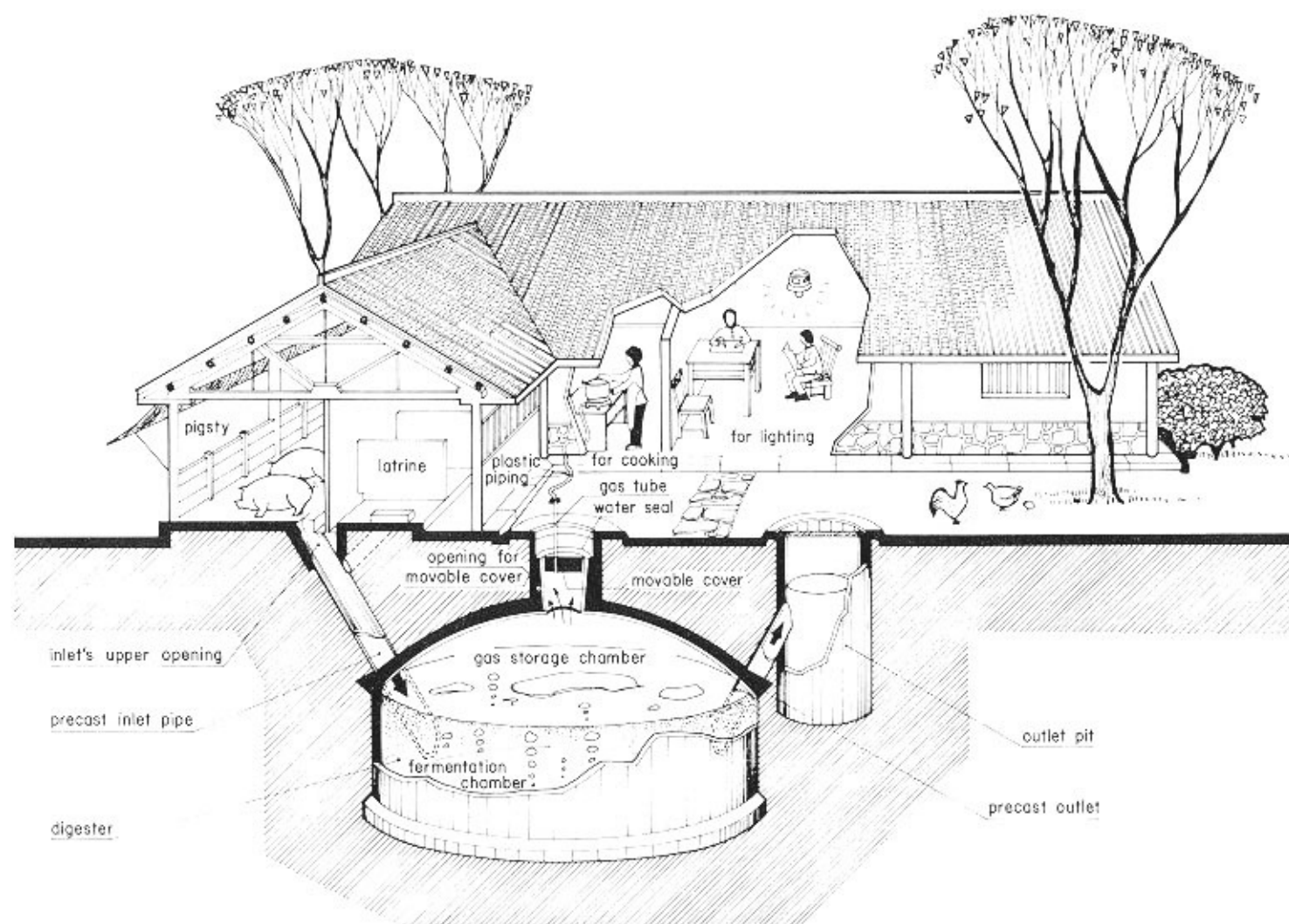


Figure 7. The placement of a typical 'three-in-one' biogas unit in a Chinese household.



Plate 18. Inside a pigsty at Liang Chu People's Commune (Zhejiang Province) showing the household latrine situated in the same building. The latrine and pig pen connect directly to a biogas unit beneath the floor.



Plate 19. Outside the pigsty of Plate 18, showing an inlet in the wall for adding household waste to the biogas unit and, at ground level, the biogas unit outlet.

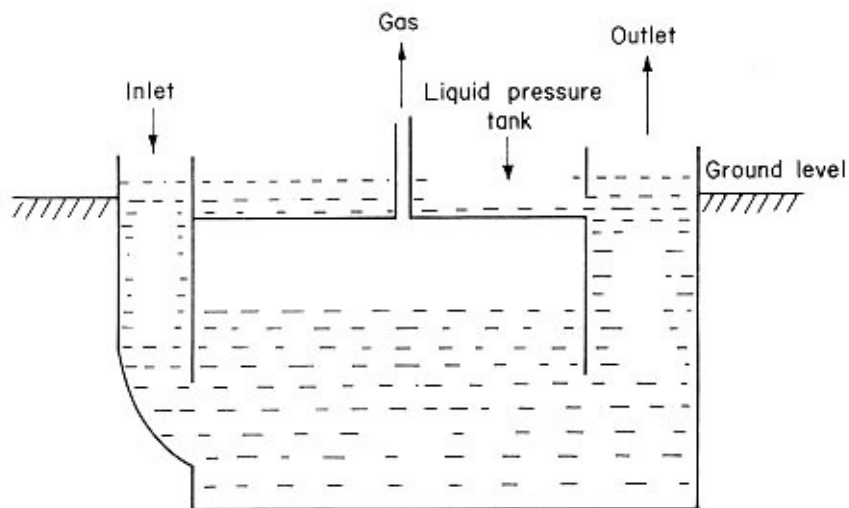


Figure 8. General arrangement of rectangular biogas plant having a liquid pressure tank on the top.

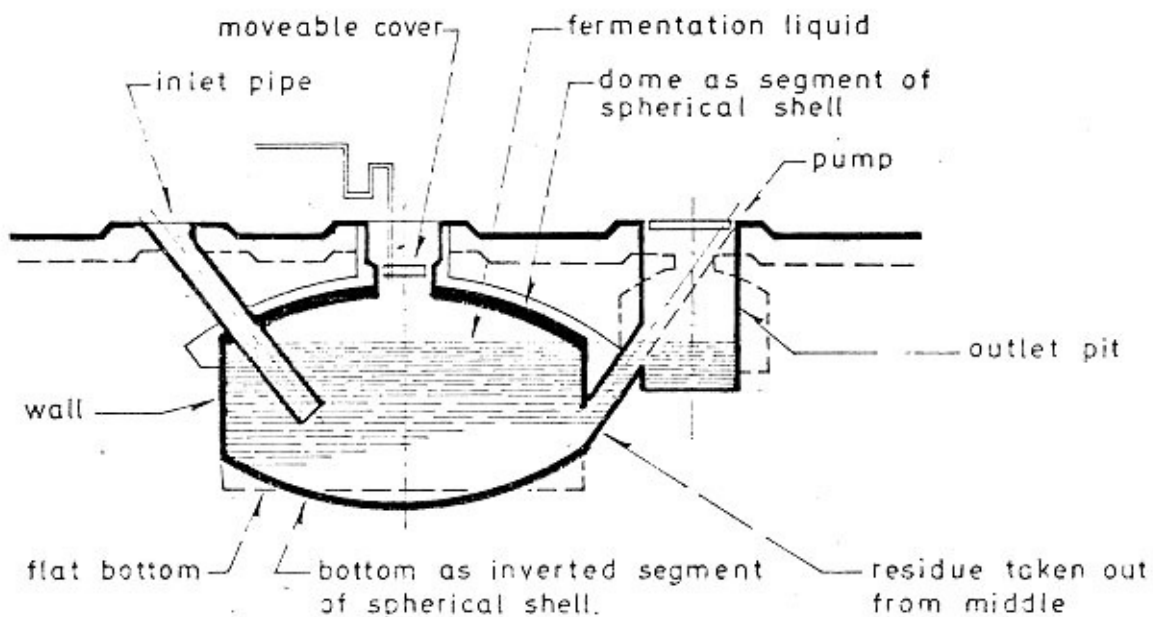


Figure 9. Basic design of a Chinese biogas unit.

The basic design of modern Chinese household biogas units is shown in Figure 9. It is circular, small and shallow. A circular unit is relatively easy to construct and is economical in building materials. The bottom of the unit is saucer-shaped resulting in proper stressing; the saucer-shape also increases the diameter and reduces the depth of the digester. The increased diameter gives a larger surface of fermentation liquid and thus more gas production. In earlier designs, depth of digestion tanks varied from 3 m to 4 m but in present designs it is not more than 2 m; this also helps to reduce costs of construction. In the floating drum (vertical) type of digester common in other countries the depth is from 3.5 m to 4 m.

The tank is designed without consideration of bending movement and so wall and dome should be independent of each other; the wall and bottom are considered as being hinged together. The load of the dome is transmitted directly to the soil through the springing of the dome to lessen the wall load.

The basic design of biogas plant includes a manhole fitted at the top and having a removable cover. This facilitates maintenance and permits removal of sludge when cleaning out the digester as well as providing a means of exhausting gas prior to cleaning; it also serves as a safety device in case the outlet pipe becomes clogged.

The inlet pipe enters the unit about halfway down and thus feeds the raw materials at middle height; its present straight, narrow shape is an improvement upon earlier designs which had a wide mouth and were bell-shaped at the bottom. Materials are easily fed in and the pipe is convenient for stirring the fermenting liquid.

The outlet pipe also is situated with its lower opening at middle height of the digester. This position results in parasite eggs settling in the deeper part of the tank and not being expelled with the effluent as a health hazard (see section 2.3.7). The wide-mouthed outlet must be covered as a safety precaution and to improve sanitation.

Due to the fixed dome design, gas pressure inside the digester becomes very high, up to about 10 kN m^{-2} (1000 mm of water) for example, compared to that in the floating tank design which rarely exceeds 0.7 kN m^{-2} . The pressure varies however according to gas production and use. When the pressure in the tank exceeds atmospheric (about 100 kN m^{-2}) slurry in the digester is forced into the outlet chamber and when the pressure in the gas storage space decreases again slurry from the outlet chamber flows back into the digester. Thus pressure in the tank is automatically controlled and the system is followed in all family size biogas plants; it is an improvement upon the liquid pressure tank situated on top of the old, rectangular designs (Figure 8). Pressure is further controlled by use of small (approx. 1 cm) diameter polyethylene tubing at the gas outlet. At one household of Chang Ching Production Brigade (Evergreen People's Commune, Zhejiang Province) gas pressure was measured and found to be less than 0.5 kN m^{-2} (5 cm of water) at delivery point to the gas burner.

As previously mentioned, details of design for household biogas plants vary according to type of soil, water table and building material. However in Sichuan Province three types of structure are most common; these are:

- Tank cast-in-place (Figure 10)
- Tank cut-in-place (Figures 11 and 19)
- Masonry tank (Figure 12)

For tanks cast-in-place, suitable concrete mixtures are poured to cast the walls, dome and base, whereas cut-in-place tanks are dug out directly from suitable (hard, clayey) soils with the minimum of structural work. Sometimes the two systems are combined by a cast dome being fixed onto a cut-in-place tank. For masonry tanks, bricks, stones, pre-cast cement structures and so on, are used.

The group was shown plans of all the above designs, each of which has its own variations depending upon the capacity or size of unit to be built. Thus each design of biogas unit shown in Figures 10 - 12 can be used to build units having a capacity of 6, 8, 10 and 12 m³, certain details varying according to materials used. The same designs can be used for units having capacities of 50 m³ and 100 m³ providing certain specified modifications are made. Full details of all these modifications were given and it is intended by FAO to incorporate them in a comprehensive handbook.

2.2.5 Materials for construction of biogas units

In fixed-dome designs of biogas unit the main problem to overcome is gas leakage, which occurs if the dome and joints are not properly made or plastered; the possibility of leakage is enhanced by the high gas pressures formed.

The materials used for tank construction in China are:

- i) Lime-clay. This is a traditional building material in China, and which with the correct proportion of water, compaction and curing becomes hard and durable. The mixture contains lime and clay in the proportion 1 : 2 - 19 by weight and varies in moisture content from 21% to 24%; curing takes a long time.
- ii) Lime-concrete. This mixture is also traditional and contains lime, sand and gravel in a proportion of 1 : 3 : 6 by volume. After adding water the ingredients are thoroughly mixed and prior to use any visible lumps of lime are removed. This prevents 'flowering' of lime in the walls of the tank and which damages the structure. When using the mixture it is poured in successive layers, each layer being tamped repeatedly for compaction.
- iii) Low-strength concrete This is a mixture of concrete having a compressive strength of 30 kg cm⁻² (# 30) and a paste made from lime and clay. Usually this mixture is employed for the body of the tank while for the joints and any corners # 150 cement is used.
- iv) Concrete. This is made using portland cement and has a strength of # 400.
- v) Other. Apart from the materials listed in (i) - (iv) above, bricks, stones, rocks, slate and so on, are used for construction of biogas digesters, their selection being determined by local availability. In such cases the binding material is a mortar of # 10 to # 15 made with cement, sand and lime.

The quantity of material to build a biogas unit of from 6 m³ to 8 m³ depends upon the kind of material used. As an example we can consider the construction of a household biogas unit by Chang Ching Production Brigade (Evergreen People's Commune, Hangzhou):-

Cement	500 kg
Gravel	1200 kg
Sand	1200 kg
Lime	25 kg
Bricks	50

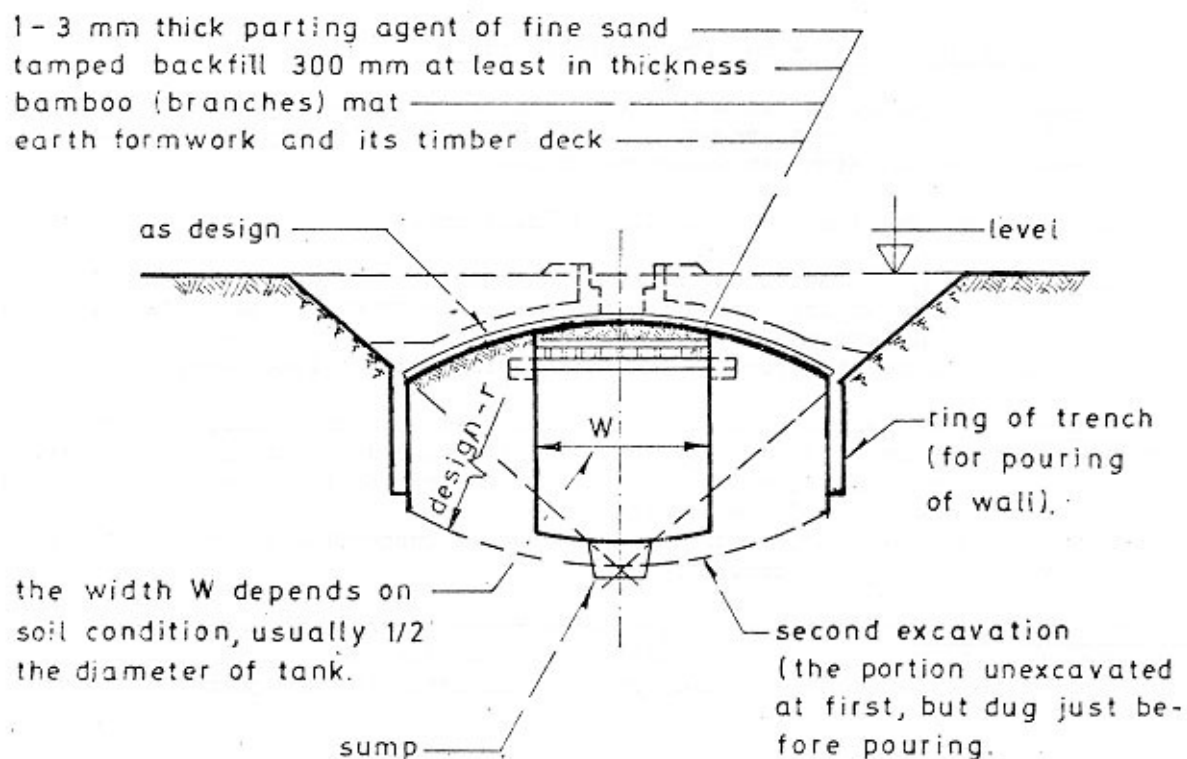
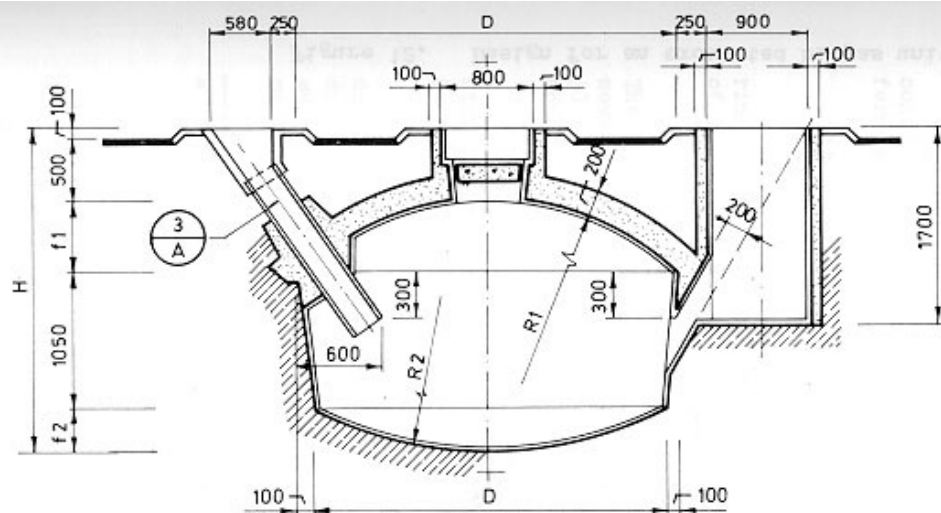
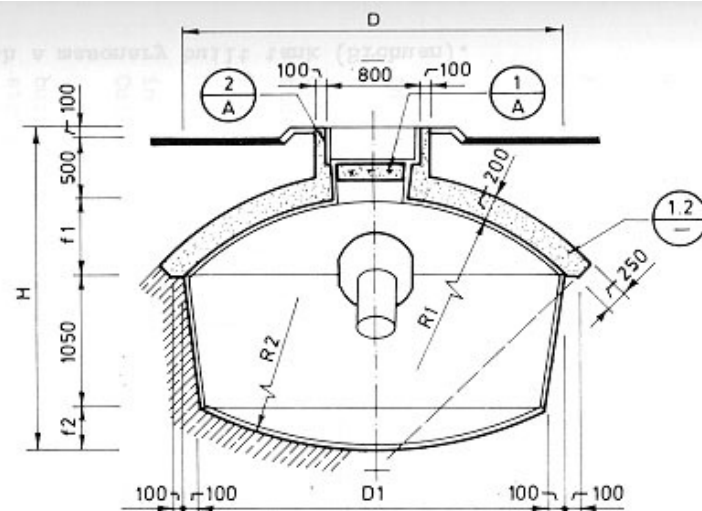


Figure 10. Design for a 'cast-in-place' biogas unit (Sichuan).

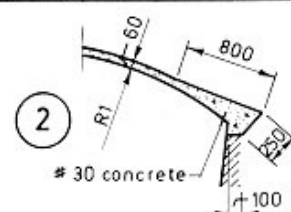
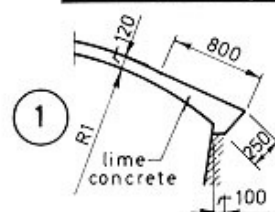
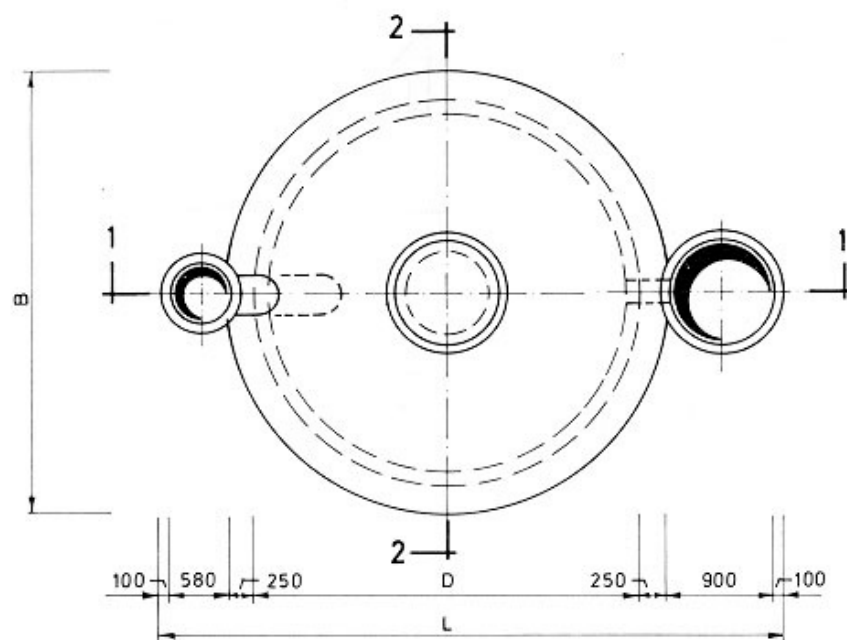


1-1 section



2-2 section

m ³	L	B	H	D	R ₁	f ₁	R ₂	f ₂	D ₁
6	4580	2960	2410	2400	1140	480	2340	280	2200
8	4880	3260	2500	2700	1960	540	2650	310	2500
10	5180	3560	2600	3000	2180	600	2980	350	2800
12	5380	3760	2660	3200	2320	640	3180	370	3000



note: the lower portion of tank is cut-in place in primitive soil and the remainder is of lime-clay.
When dome is of other materials, see details 1,2

measurements in mm
copied: 8, 9.78

Figure 11. Design for a 'cut-in-place' biogas unit with a cast concrete dome (Sichuan).
Note. Certain symbols appearing on biogas designs are not explained in this text but full details will be given in the forthcoming manual on Chinese-type biogas units.

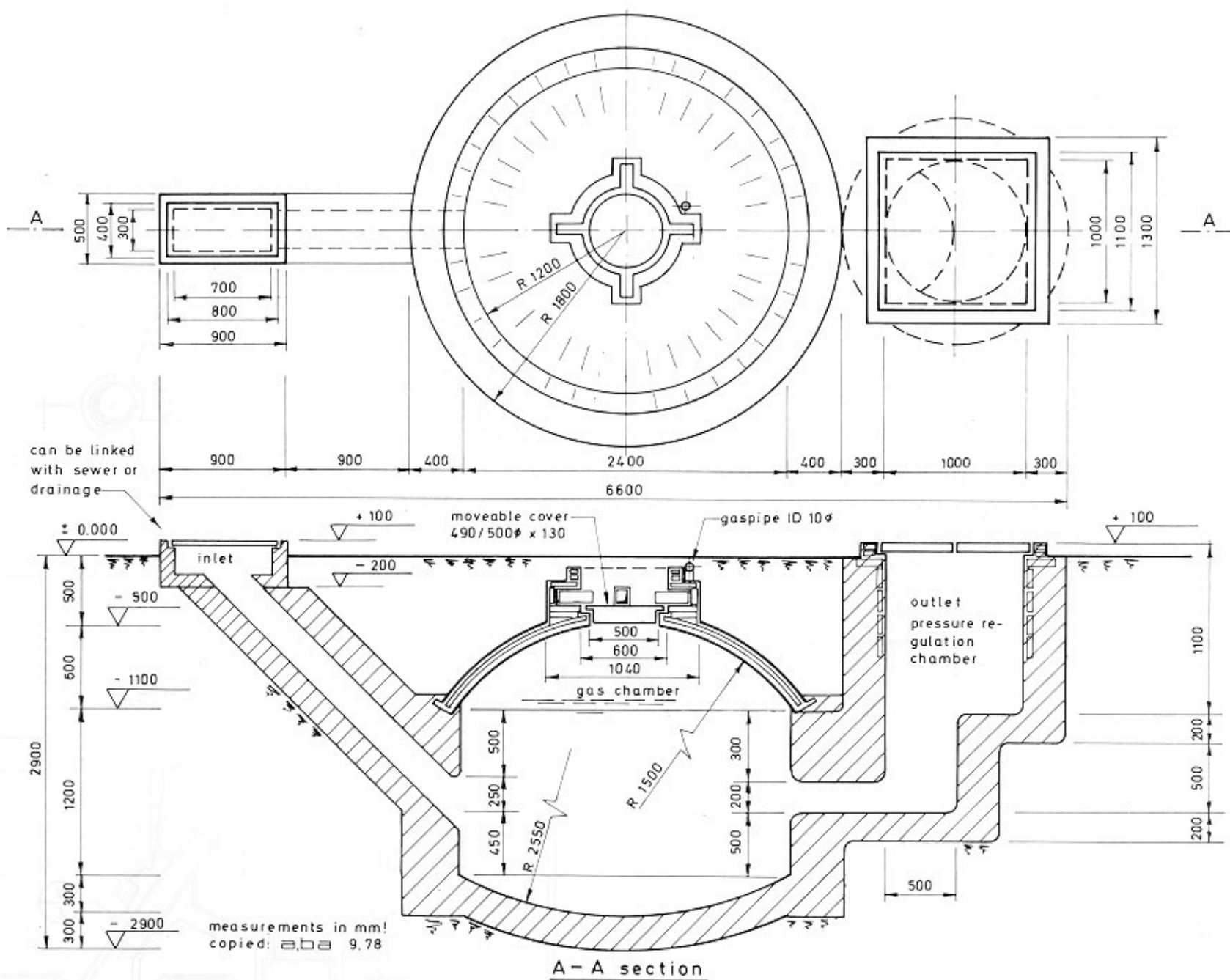


Figure 12. Design for an excavated biogas unit with a masonry built tank (Sichuan).

This Production Brigade obtained poor results by using bricks and since 1977 have used concrete, as reflected in the above figures.

At the Chen Hsiang Production Brigade (Pin Niu People's Commune, Wu Cheng County) a mixture of 5% lime and 95% clay was being used to construct the digester while bricks and cement were used for the dome. This procedure required for each unit:

cement	200 kg
lime	300 kg
bricks	500

and could be completed in two days by six men.

Costs of construction for small biogas units up to a capacity of 10 m³ varies between 30 to 60 Yuan (\$18 - 36)*. As the units are communally built, these costs take no account of labour.

2.2.6 Methods of construction

All units are built in the ground above groundwater level for preference but in no case should the groundwater level exceed half the height of the digester wall. Cut-in-place tanks are exclusively above ground water level for obvious reasons.

Two major approaches to construction are followed; in one method the tank is built with minimum displacement of soil which is dug out afterwards from the finished structure and in the other method all soil is first removed by digging a pit and the unit constructed in that pit.

Cut-in-place biogas units are a variation of the second approach and instead of constructing a tank inside the excavation the soil itself is shaped to form the fermentation tank. Construction of cut-in-place units is limited by the kind of soil.

Method 1 - Cast-in-place

Firstly a shallow, circular pit is excavated in hard soil and in its base a ring trench is dug. Concrete is then poured into the trench to form the outside wall of the digester - this in effect is now a concrete cylinder in the soil.

The untouched soil within the ring now serves as a base for casting the dome. The soil is shaped into the required dome-shape with the help of a wooden deck; this is covered with a mat of bamboo branches on which is tamped an earthen backfill at least 30 cm thick. Finally a thin layer of sand is spread as a parting agent for casting the concrete dome (Figure 10).

The dome is cast not only layer by layer to the required thickness but strip by strip as illustrated in Figure 13. After curing, when the dome becomes hard, the earth beneath is excavated through the manhole at the top and as shown in Figure 10.

For casting the bottom of the unit, it is divided into strips and digging is done in numerical order of strips as indicated in Figure 14. While digging under the digester wall bricks are placed at several points on the circumference as a temporary support for the wall. When excavation is complete, the floor is poured with concrete mixture.

* Exchange rate in October 1978.

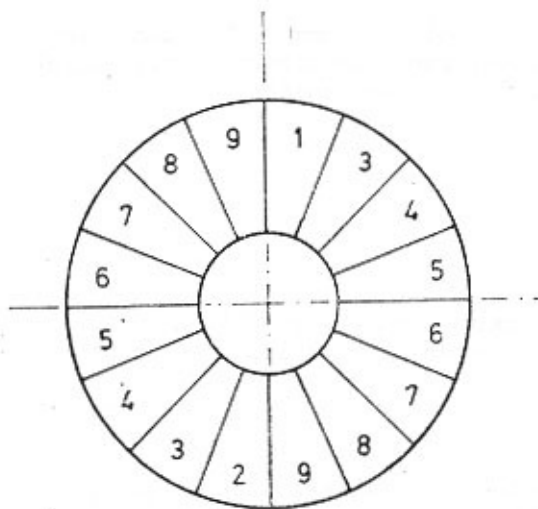
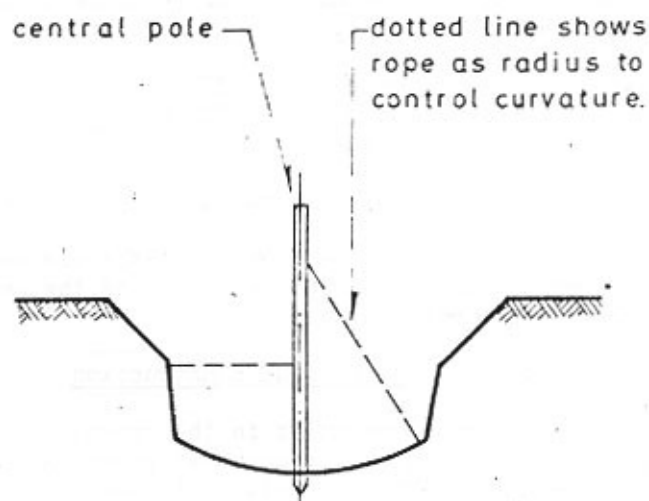


Figure 13. Casting of dome according to numbered segments.



top

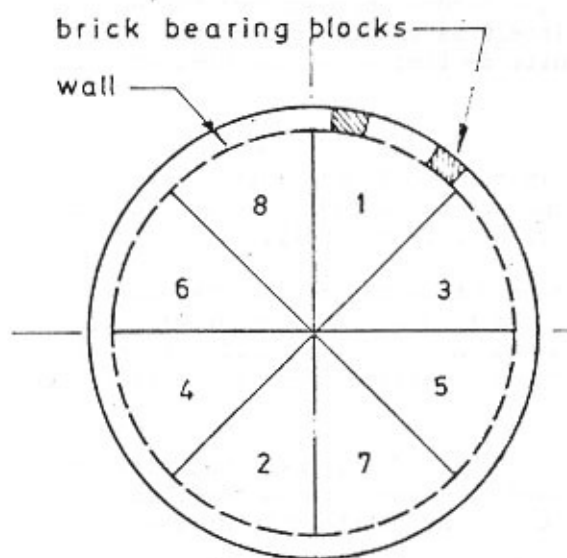


Figure 14. Excavating of bottom according to numbered segments.

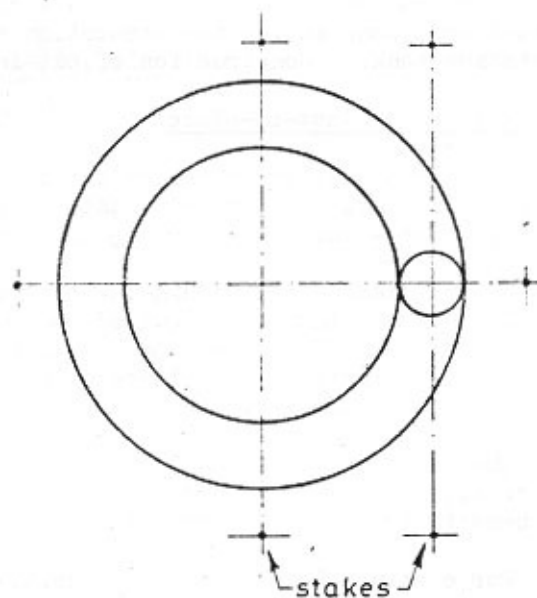


Figure 15. Use of centre pole with rope for initial laying out of biogas unit excavation.

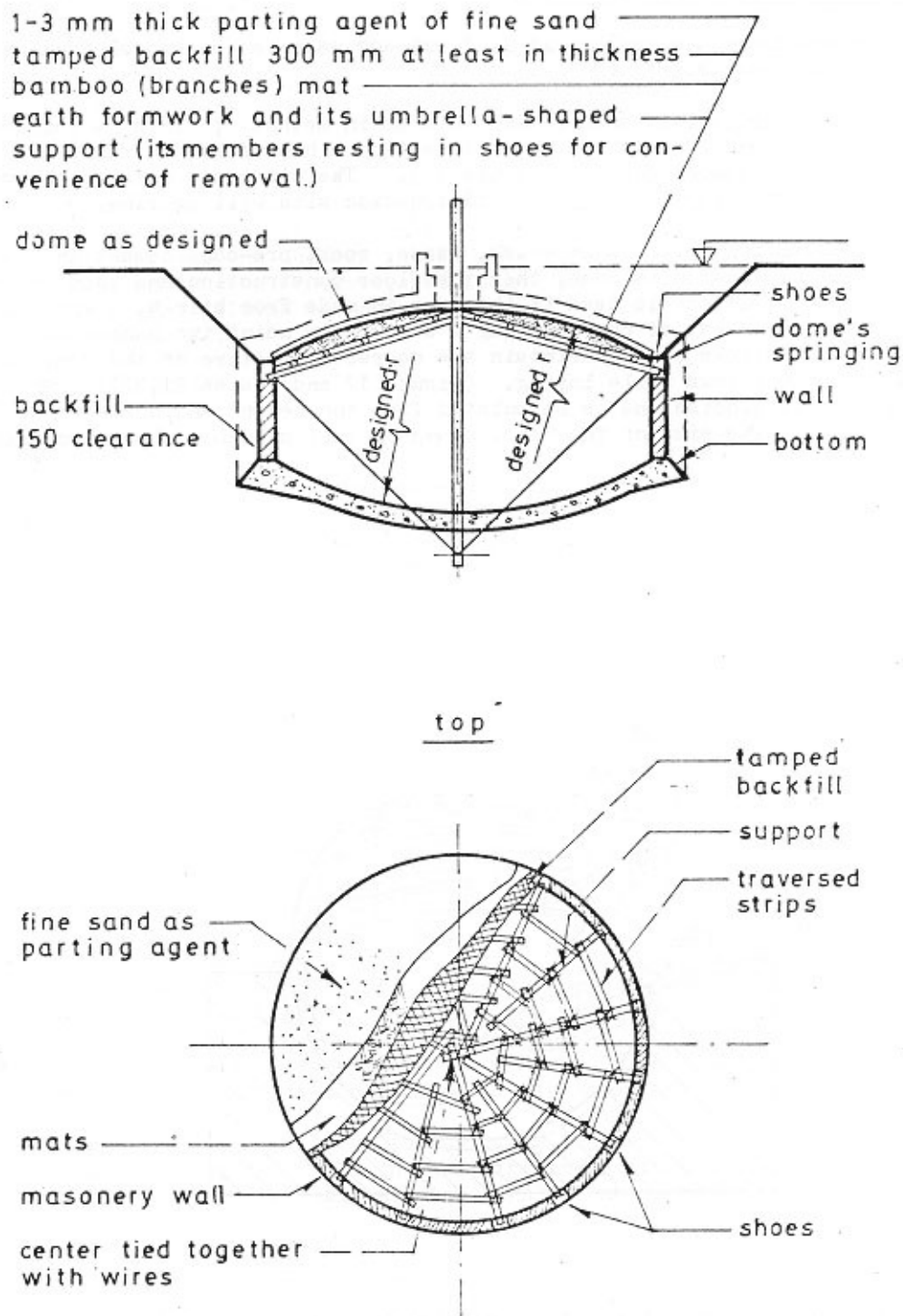


Figure 16. Overall excavation with cast dome on a bamboo support.

Method 2 - Preliminary excavation

In this procedure a circular pit is first dug using a centre pole and piece of rope for controlling the radius (Figure 15).

Next, the floor is laid down in segments as in method 1; this is followed by erection of the wall and finally the dome is cast on a back-filled earth frame resting on an umbrella-shaped bamboo support (Figure 16). The clearance outside the wall is back-filled with earth, layer by layer in alternation with wall pouring.

When the building material is brick, stone, rock, pre-cast cement and so on, first the overall excavation is done, then the floor construction and then the masonry. No umbrella-shaped structure is used if the dome is made from bricks. The Chinese have developed a very simple way of constructing a brick dome using two bamboo sticks and a metal clamp. The sticks are to maintain the correct curvature of the dome and the clamp is to hold the bricks while laying. (Figure 17 and Plates 21,22). The length of the bamboo sticks is precise and is calculated from the height and diameter of the fermentation tank. The size of the metal clamp is just enough to hold two bricks breadthwise.

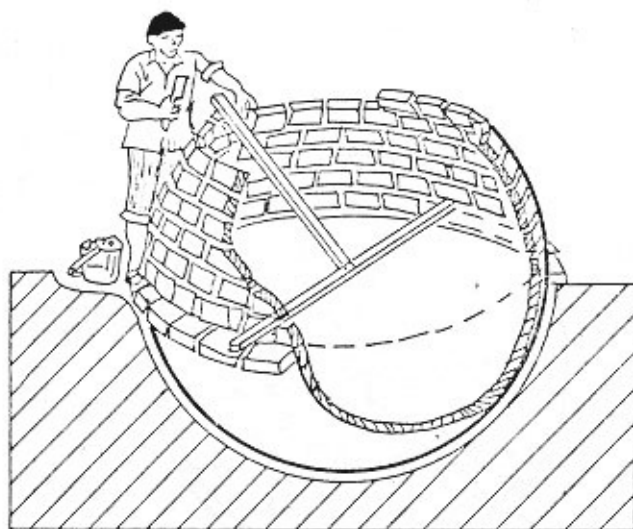


Figure 17. Method of building dome with bricks and using a pole for maintaining shape and angle. (see section 2.2.6 and Plates 21/22).

Cut-in-place biogas units

Two variations of cut-in-place fermentation tanks were seen in Sichuan Province, one simply cut in primitive soil (Figure 18) and the other having a cast dome (Figure 11). After shaping and tamping the fermentation tank, plaster is applied directly onto the soil.

In all cases, inlet and outlet pipes are made in concrete and fitted after completion of the digester tank. At the point where the inlet pipe passes through the dome's springing, the thickness of the concrete is increased. The moveable cover is also made from concrete and the opening in the dome is strengthened with a concrete ring or collar. At Wuxi in Jiangsu Province, provision was made in the cement collar for bricks to be inserted for holding the cover in place (Figure 12) and which are also evident in Plates 23 and 24.

Plastering

Efficient plastering of the walls and dome of the biogas unit is a very important part of construction. Gas and water leaks depend solely on how perfectly the plastering has been done. The Chinese advocate multilayer plastering with a final brushing of pure cement slurry or lime and sand mixture. Procedures differed slightly in different districts but that followed at the Evergreen People's Commune at Hangzhou is fairly typical. Three coats of plaster are applied.

- First coat of cement and sand (1 : 2.5), 8 mm thickness
- Second coat of cement and lime (1 : 1), 3 mm thickness
- Third coat of cement and lime (1 : 1), 3 mm thickness

Finally comes a brushing over with a slurry of pure cement or a very thin layer of plaster made from lime and sand (1 : 1).

Before applying the third coat of plaster, the whole inner surface of the tank is examined by tapping with a stick. If a hollow sound is given off at any place, that spot is dug out and replastered more solidly. The biogas unit being constructed as shown in Plates 21 and 22, appeared as in Plates 23 and 24 after plastering.

Gas outlet pipes are inserted through the dome at time of its construction and are made of metal, plastic or bamboo.

A special and possibly unique procedure was being practised at the Evergreen People's Commune, Hangzhou for building household biogas units.

In the first place the design of the unit was that of a sphere and had no straight-sided fermentation tank (Figure 19). The building procedure had developed as a result of the fact that the local water table was too high for usual practices.

The procedure is illustrated in Figure 20. Firstly the lower half of the sphere was cast in place in the upper and dry, layers of soil. Afterwards the upper half, or dome, of the sphere was built in brick and plastered: the biogas unit at this stage is partially above ground level.

A second excavation is made immediately to the side of the sphere and filled or allowed to fill, with water. The sphere is then floated above the deeper hole and sunk into position by filling it with water. Once in position, the water is pumped out and the construction completed in the usual manner.

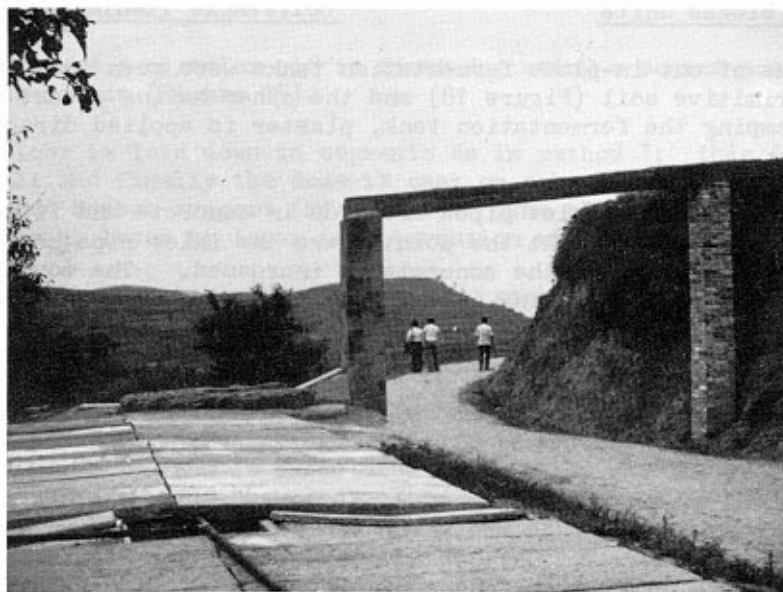


Plate 20. Concrete 'aquaduct' conveying cattle-dung slurry to large biogas digesters under concrete covers (State Orchard, Tehyang County, Sichuan Province).



Plate 21. Constructing the dome of a biogas unit from bricks and using bamboo sticks to maintain the correct shape and angle. Note the nail through the stick for supporting the brick while cementing and, at the upper right hand side, the wire clamps temporarily supporting recently laid bricks. The outlet of the unit is on the extreme right. (Evergreen People's Commune, Hangzhou).

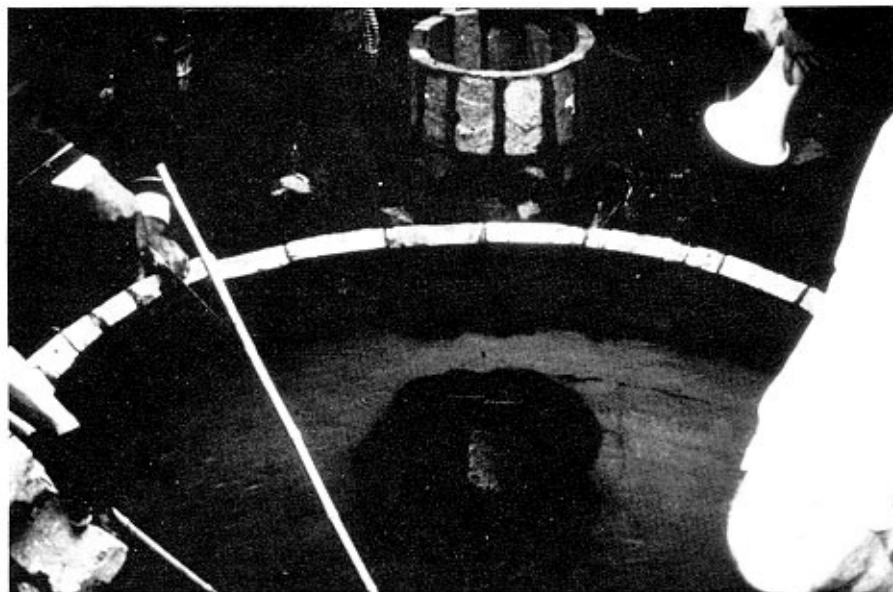


Plate 22. Showing how the brick being fixed is resting on the nail through the bamboo stick. Note also the inlet chamber connected to the interior of the tank.



Plate 23. The biogas unit shown under construction in Plates 21 and 22, after its initial plastering. The outlet is in the foreground and the inlet in the background.

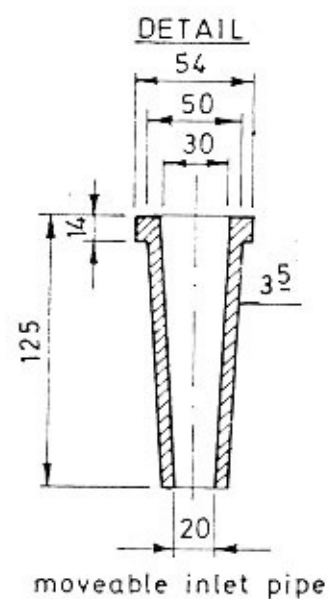
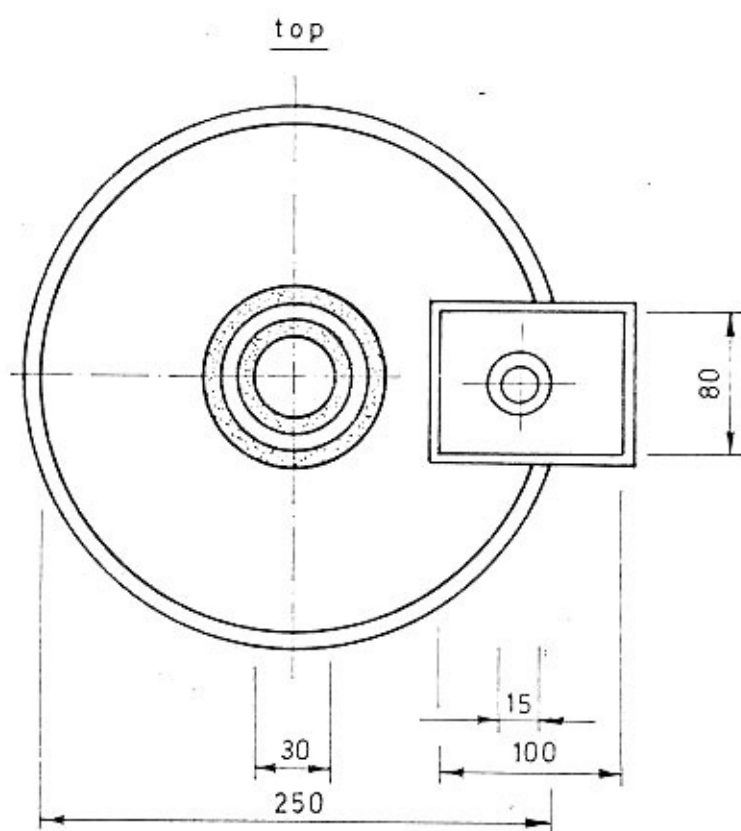
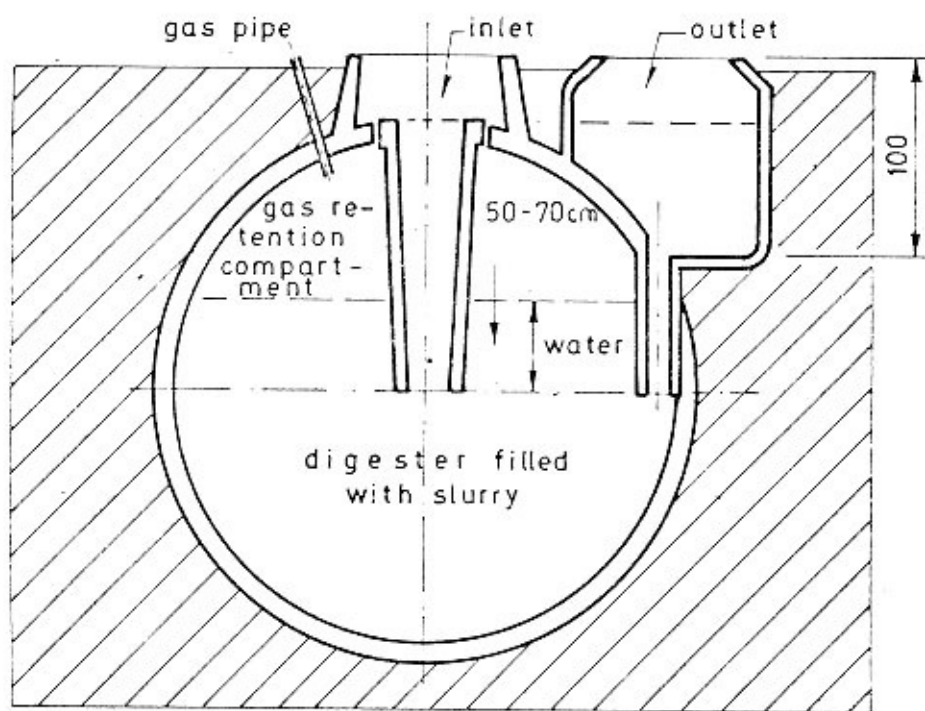


Figure 19. Design for spherical biogas unit (Evergreen People's Commune, Hangzhou).

2.3 Operation and maintenance of biogas units

2.3.1 Inputs

The amount of gas produced is in direct relationship to the raw material used for digestion. In China the raw materials used for household biogas production are of two kinds:

- (i) source of carbon - leaves, grass, agricultural waste
- (ii) source of nitrogen - human and animal wastes

For larger biogas units additional sources of material are sewage works and urban waste.

Depending upon availability, raw materials are used in different combinations. The most common mixture is 40-50% nightsoil and animal (mostly pig) excreta, 10-15% grass and crop residues and the remainder being water. This mixture sometimes has only 10% nightsoil with an excess of animal manure, but sometimes has 20% or even 30% of nightsoil. The carbon-nitrogen ratio varies between 1:15 and 1:25 and the ratio of solids to liquid is between 1:15 and 1:20. If water is added in greater amount, gas production decreases due to methane bacteria being restricted in nutrient uptake.

2.3.2 Loading

As previously mentioned (section 2.2.4), Chinese household-size biogas units are batch-feed type; that is, some if not all of the ingredients (inputs) are mixed and loaded in amounts sufficient to fill the unit all at one time. In most cases, it is the carbon-source material loaded in batches while the nitrogen-source materials are slowly added every day. However, sometimes the carbon-source material is bulk mixed with animal manure before loading, but even so, nightsoil and/or more animal manure is still added daily.

Frequency of bulk loading, depends upon circumstances but is usually two to four times a year. At Liang Chu People's Commune (Hangzhou, Zhejiang Province) 1300 kg of straw is put in the digester three times a year; at Pin Niu People's Commune (Changzhou) the digesters are loaded every four to six months.

The daily addition of nitrogen-source material is in the form of washings from latrines and animal pens. No special arrangements are necessary except to connect the sources to the inlet tube of the digester. In the three-in-one arrangement (section 2.2.3) for example, as each day a certain amount of excreta flows into the digester, so an equivalent amount of digested slurry flows into the outlet chamber. This renders feeding arrangements easy, prevents heat loss and improves sanitary conditions.

In some parts of China (for example 5th Production Team of the 7th Production Brigade of Yunghsing People's Commune, Mianyang County), raw carbon-source material such as grass and straw, are composted with biogas effluents before being loaded into the digester. The period of composting varies from ten days to several weeks and helps to produce biogas immediately after loading. In such cases, pH is often adjusted by mixing in lime or ashes.

In at least one Commune (Evergreen, Hangzhou) individual household biogas units were loaded with personally contributed carbon-source material and human wastes but with communally provided animal manure. This was because animals were not kept by each family and so pig dung was transported daily from the Commune's pig farm.



- 1 dig out half of the spheroid

lower half of sphere 1:2:4 cement, sand, gravel. gravel to be of 10-15 mm ϕ
concrete thickness 4 mm



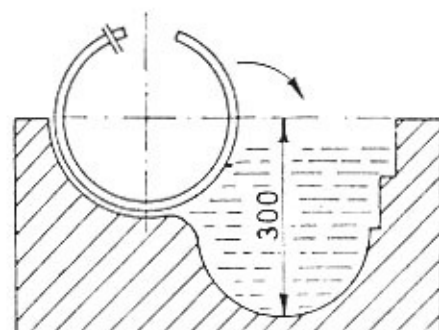
- 2 lay concrete

top of sphere is brick work, with a coat of cement and sand. (see Fig.17). If no bricks are used: 1:2.5 cement, sand plaster 8-10 mm thickness outside



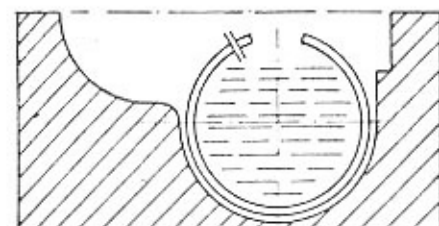
- 3 build top half of spheroid

inside
to coat three times:
1st. 1:2.5 cement+sand, 8 mm thick
2nd. 1:1 cement+lime, 3 mm thick
3rd coating 3 mm thick



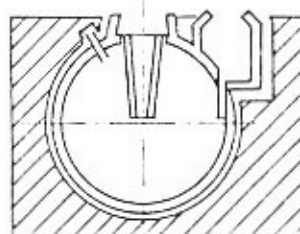
4.

dig out another deeper pit, fill this with water, and float the spheroid into right position.



5.

fill spheroid with water, when in its position empty both, spheroid and the pit.



6.

fit inlet pipe and outlet chamber.

Figure 20. Procedure for building the spherical biogas digester in land having a high water table (Evergreen People's Commune, Hangzhou).

2.3.3 Internal mixing

The principle of stirring the fermenting organic materials in a biogas unit is to break up the scum which forms on the surface and to agitate the sludge settled at the bottom. This stimulates bacterial activity (section 2.1.1) and results in higher gas production. The study group saw no evidence of any household unit being fitted with a means for stirring the contents. It was agreed that stirring improves gas production but the Chinese maintain that in such small units, daily addition of raw materials itself, provides the necessary agitation. At the State pig breeding farm near Hangzhou, an opportunity was given to see a manually operated stirring mechanism incorporated as an experiment into a large (50m³) biogas unit (Plate 25).

2.3.4 Emptying

The daily addition of washings from the latrine and animal pens results in an outflow of decomposed effluent into the outlet chamber. This effluent is removed manually in wooden buckets for agricultural use, or sometimes led away by means of shallow troughs. On one occasion the group saw a home-made, simple pump for emptying the outlet chamber. The pump (Plate 26) was merely a polyethylene tube of about 6 cm diameter fitted with a leather plunger and an outlet tube of 3 cm diameter.

In large-scale biogas units, the outlet chamber is emptied by pumps driven either by electricity or by the biogas (Plate 27), and the discharged effluent is sprayed directly onto the fields (Plate 28).

The digestion chamber of a biogas unit is emptied of sludge before each periodic loading with fresh raw material. This is done manually and the frequency of emptying is two or three times a year as dictated by the loading procedure. In actual fact, the digestion chamber is not completely emptied as from twenty to twenty five percent of the sludge is left to bacterially activate the newly added material.

2.3.5 Maintenance

As the Chinese model of biogas digester is almost completely underground and has no moving parts, routine maintenance is negligible. Every time the unit is emptied prior to re-filling, checks are made on the plastering and on joints and, depending upon the material used, it may be necessary to re-new the gas outlet pipe.

2.3.6 Safety precautions

(i) Pressure

Irrespective of size of biogas unit a simple safety device is fitted in the form of a pressure gauge. This consists of two glass tubes each 1m in length and 1 cm diameter; the tubes are connected by a rubber pipe forming a U-shape and contain coloured water. One end of the gauge is connected to the gas supply using a T-joint and the other is either left open or fits into an inverted jar through a two-holed rubber stopper (Figure 21).

The gauge indicates whether or not there is any leakage of gas and the quantity of gas in the unit. It also serves to protect the structure from damage due to too high pressure. When gas pressure becomes very high water will be forced into the bottle through tube C and any extra gas will be released through tube D; pressure then drops in the tank automatically. When the pressure inside the tank is reduced, water in the bottle will flow back into the gauge.



Plate 24. The dome of the biogas unit shown in Plate 23 when completely finished and awaiting the manhole cover. Note the strengthening collar on the top, fitted with slots for bricks to hold the cover in place. The gas outlet tube can be seen just in front of the collar.

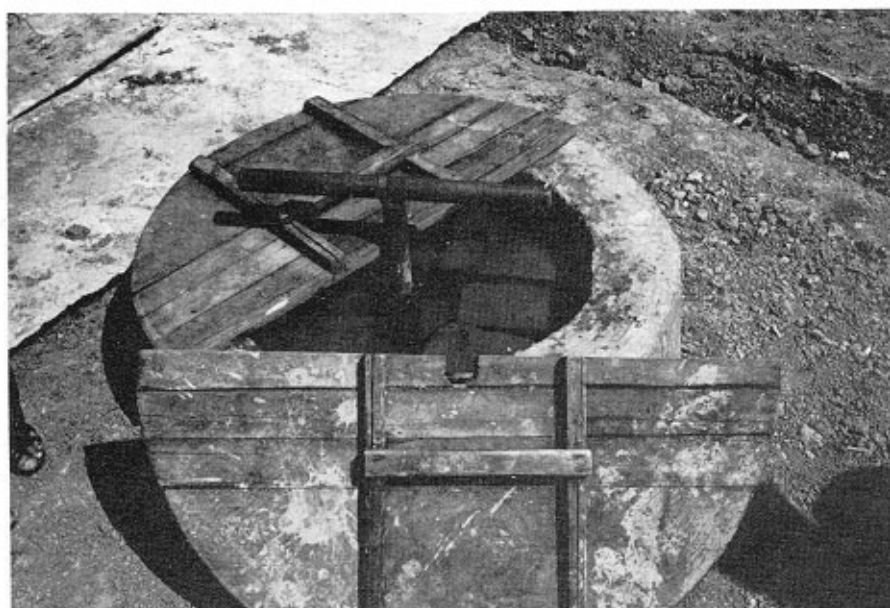


Plate 25. Handle of stirring mechanism through centre of a large biogas unit at the pig breeding farm near Hangzhou.



Plate 26. Home-made hand pump for emptying the outlet chamber of a biogas unit. The pumped effluent flows from the lower barrel-shaped junction into a trough which leads to a vegetable garden.



Plate 27. A biogas-driven pump removing effluent from a large biogas unit for direct field spraying. (Pin Niu People's Commune, Jiangsu Province).

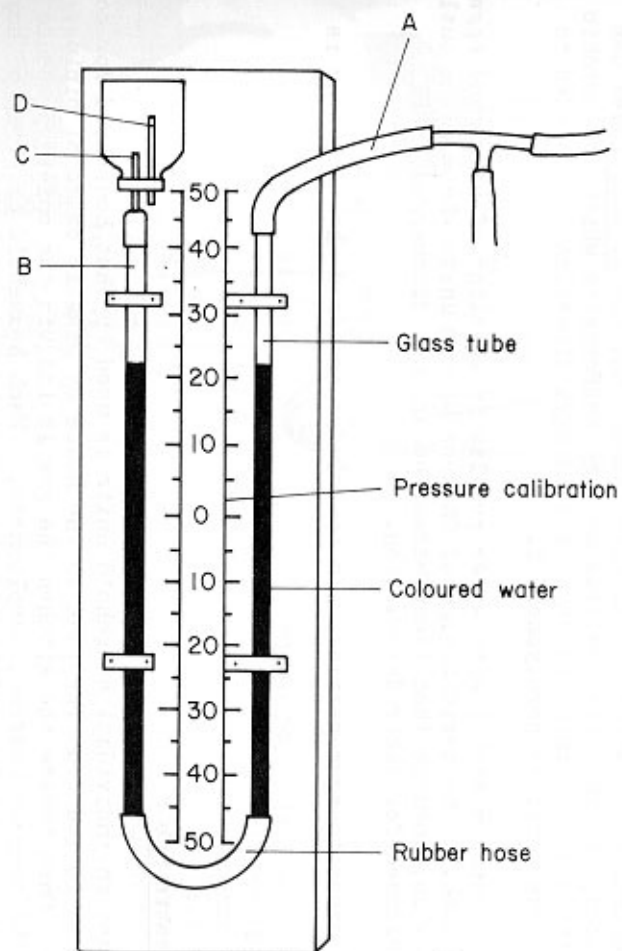


Figure 21. Safety pressure gauge for biogas.

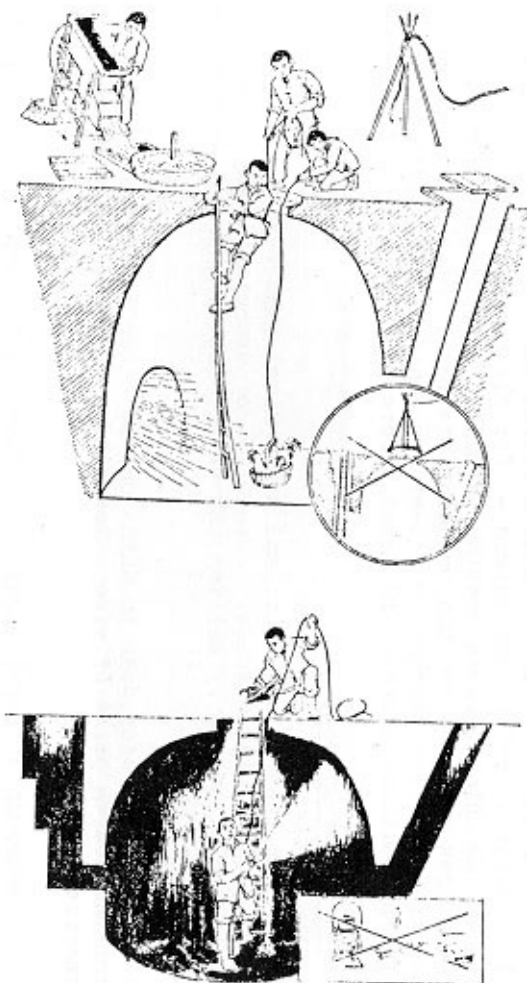


Figure 22. Some "do's and don'ts" when entering a biogas unit.

(ii) Toxicity and explosion

As biogas is combustible safety precautions should prevent any naked flame being introduced into the tank; furthermore methane is explosive if mixed with air in proportions ranging from 5% to 15% by volume. A 30% concentration of methane can anaesthetize a person while 70% concentration can asphyxiate. The tank therefore, must be well ventilated before one enters - for cleaning, maintenance and so on. One procedure used by the Chinese is to breathe through a hose hanging inside. Before entering the large biogas units at the pig breeding station at Hangzhou it is customary to lower a basket containing a live chicken as a test for non-toxicity in the atmosphere. Figure 22 shows the precautions observed in China before entering a biogas tank.

2.3.7 Control of disease

Application of raw sewage, nightsoil and even animal manure to agricultural soils, presents the problem of spreading disease. Digestion of excreta in the biogas tank greatly reduces this health hazard by killing the responsible pathogens, bacteria and so on.

Extensive research has been done in China on the effectiveness of the treatment in biogas plants from the health point of view. Some of the main findings of one year's research are summarized below:

- A comparison of fecal liquid introduced into biogas units with effluents showed that the total number of parasite eggs was reduced by 93.6%, the average number of hookworms was reduced by 99%, schistosome flukes disappeared and the number of dead ascarid eggs was high.
- Parasite eggs can survive in a biogas plant for 14 days in autumn and 37 days in winter.
- 90% of hookworm eggs died within 30 days in winter and 99% of filariasis parasites died during the same period in summer.
- experiments on bacteria viability showed that the E. coli index was reduced, the shigella bacillus and the spirochetes which are aerobic bacteria died within two days, but 44 days digestion were needed to kill the bacillus paratyphoid B.

Dilution of the input material with water results in settling of worms and eggs to the bottom of the tank. The basic design of Chinese biogas units wherein the outlet pipe commences halfway up, ensures that these parasites are not discharged until sufficient time has elapsed for their destruction.

Generally all parasite eggs settled with the sludge are dead when the tank is cleaned.

2.4 Use of biogas

2.4.1 Domestic use

The gas produced in individual household units is used by that household for cooking and lighting. The gas is led from the tank to the house by plastic or metal piping, usually underground. Once inside the kitchen the gas is led via the safety pressure gauge (2.3.6(i)) to the various household appliances. Each household or group of households, has its own contrivances for displaying the gas tubes and controlling the rate of flow. Some arrangements were relatively sophisticated using different coloured tubing



Plate 28. The effluent (see Plate 27) being sprayed as fertilizer onto the farmer's field.

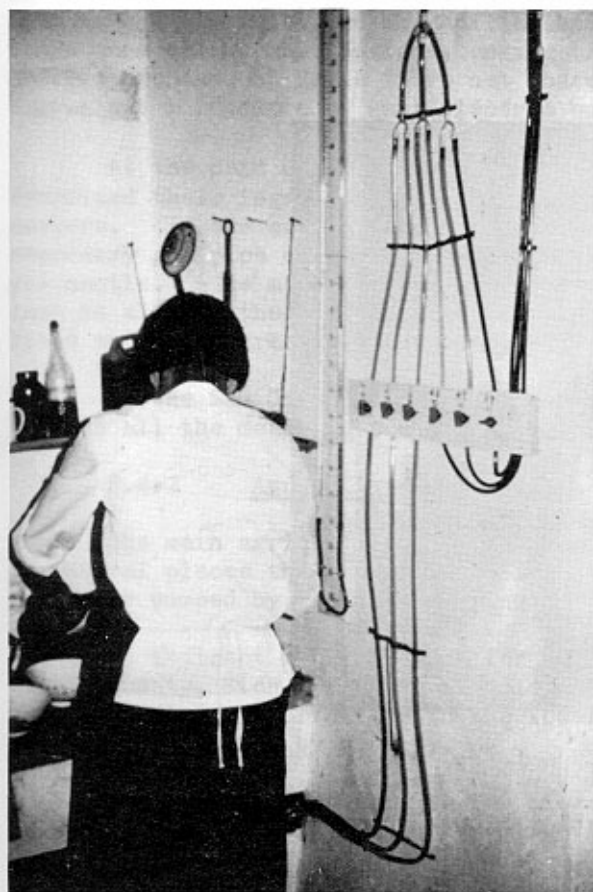


Plate 29. Inside a Chinese kitchen showing the orderly arrangement of gas tubes. Each tube is of a different colour according to the final use of the gas and all tubes are connected to the pressure gauge seen to the left. A series of plastic taps control gas flow. (Sichuan Province).



Plate 30. A locally made clay biogas burner (Anshi People's Commune, Zhejiang Province).



Plate 31. Showing the nozzle which fits into the clay biogas burner of Plate 30.

for different purposes and employing plastic or metal gas taps (Plate 29). At the other extreme, a single gas tube is led to burners and lamps using T-tubes and gas flow is controlled by means of a large clamp-type paper clip.

Cooking

The Chinese have designed a number of burners for use with biogas, all of which are simple and can be made locally. The burners are made from clay or occasionally metal, depending upon availability of materials (Figures 23 and 24 and Plate 30). Each Commune or even each Production Team, designs its own appliances and burners were seen of several different kinds and sizes. Designs are constantly being improved and distributed for the users' reaction before being locally manufactured in quantity.

The basic features of a burner are a nozzle, an air inlet and a mixing chamber. The nozzle is a hollow tube made of glass, metal, plastic or bamboo (Figure 23 and Plate 31). The size of the nozzle hole varied from 0.5 to 0.8 mm in diameter. By moving the nozzle in and out of the burner a proper mixture of air and gas is obtained in the mixing chamber before flowing on to the burning point. The appliances are made for a ratio of 1:8 to 1:10 gas/air mixture.

The burners are always placed inside a deep hearth to provide maximum heat (Plate 32). All burners seen in action by the group were working well as long as the cooking vessel remained in place; if a vessel was lifted however, the gas tended to go out.

Lighting

Again all the gas lamps seen were simple and locally made from available materials. As for the burners, the lamps have the basic features of nozzle, mixing chamber and air inlet and in addition have a clay ventury for attaching the mantle. Lamps were of two main designs, hanging (Figure 25) and standing (Figure 26) and the mantles are made of Ramie fibre net coated with thorium nitrate; biogas provides light equivalent to about a 60 watt electric bulb.

At the Hsin Chao People's Commune in Sichuan Province, the householders had exercised their ingenuity by fitting automatic lighting devices on burners and cookers. In the case of hanging lamps, a flint lighter was attached to a small, secondary gas pipe controlled by a tap (Figure 27) and situated immediately below the gas mantle. The mechanism of the lighter is worked by pulling a string and when the lamp is alight, the secondary gas supply is closed. For burners a flint lighter was fixed so as to directly light the appliance.

At the Shu Ching People's Commune, Shanghai a large biogas unit provided gas for cooking all the meals in a central communal kitchen.

2.4.2 Agricultural use

The main agricultural use of biogas in China is for running irrigation pumps. At several places the group saw fields being irrigated by sprinklers for which the water was pumped by a biogas-run engine (Plates 33 and 34).

An indirect use of biogas for irrigation purposes was seen at a State Orchard in Tehang County, Sichuan Province. Biogas engines pumped water up to a large reservoir on a hill-top. Sprinklers in the lower fields were then operated by the pressure of the water being fed by gravity.

Another agricultural use for biogas is for pumping out the effluents of the unit after digestion and spraying them directly as manure. (Plates 27 and 28).

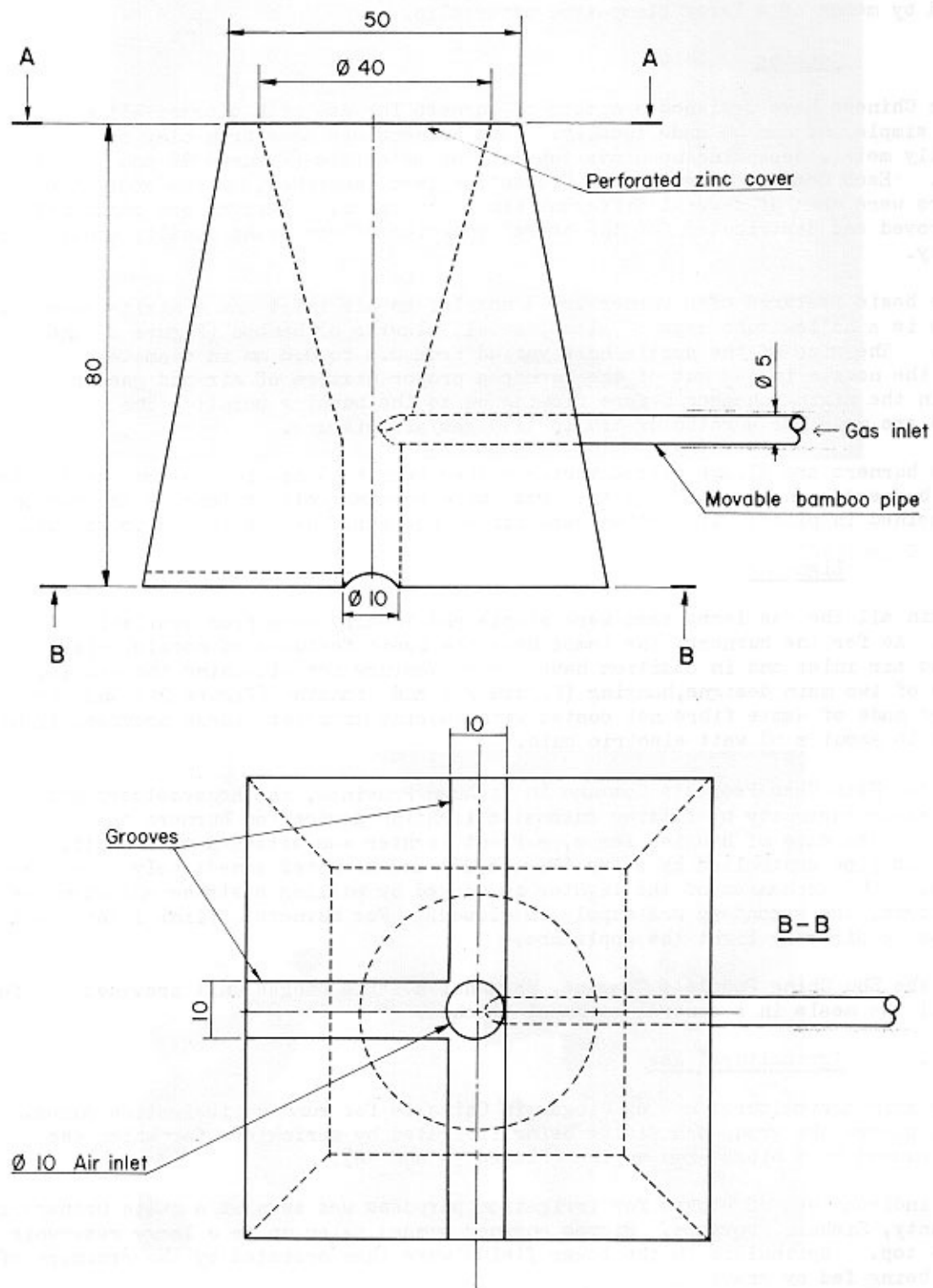
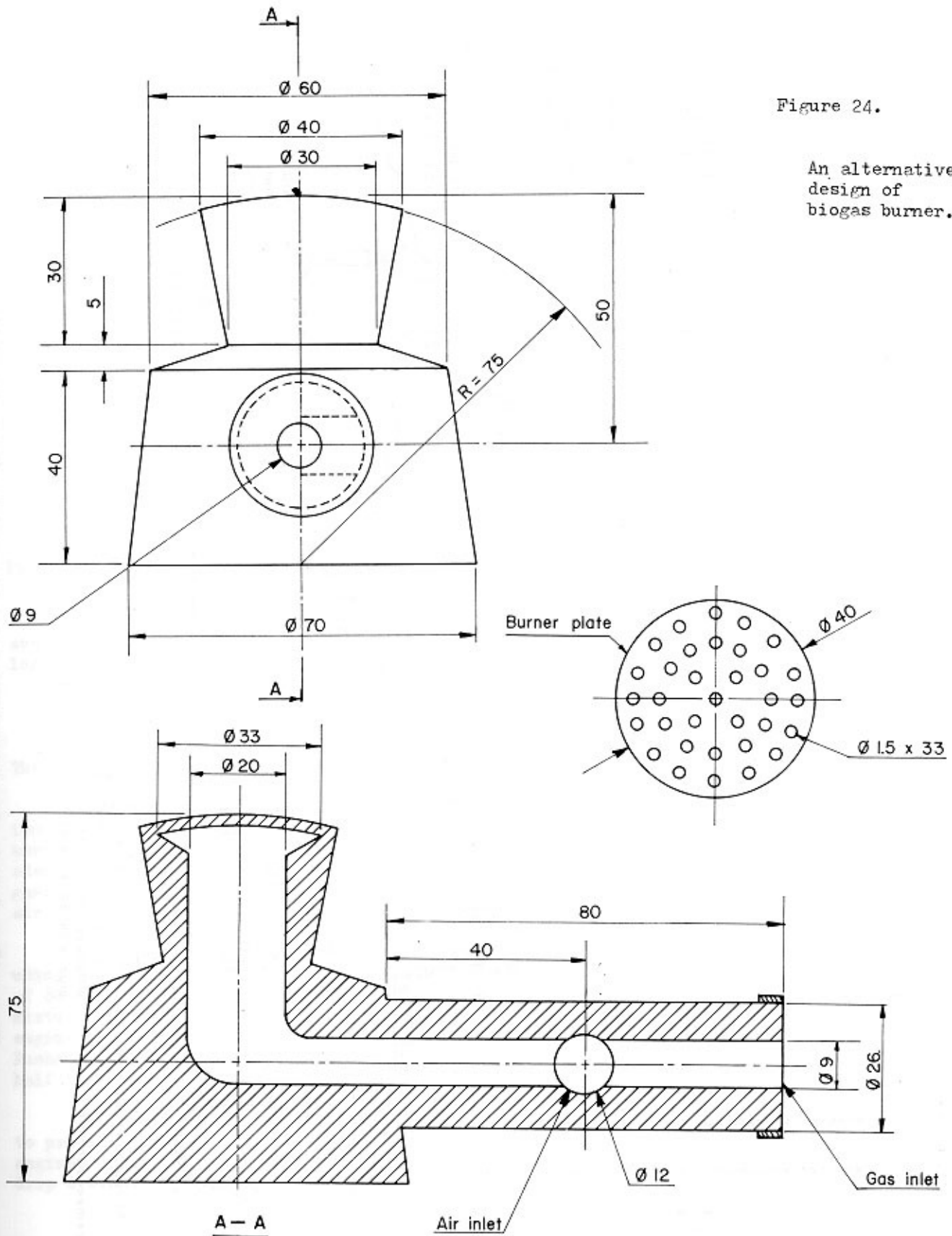


Figure 23.

Details of a simple, home-made biogas burner



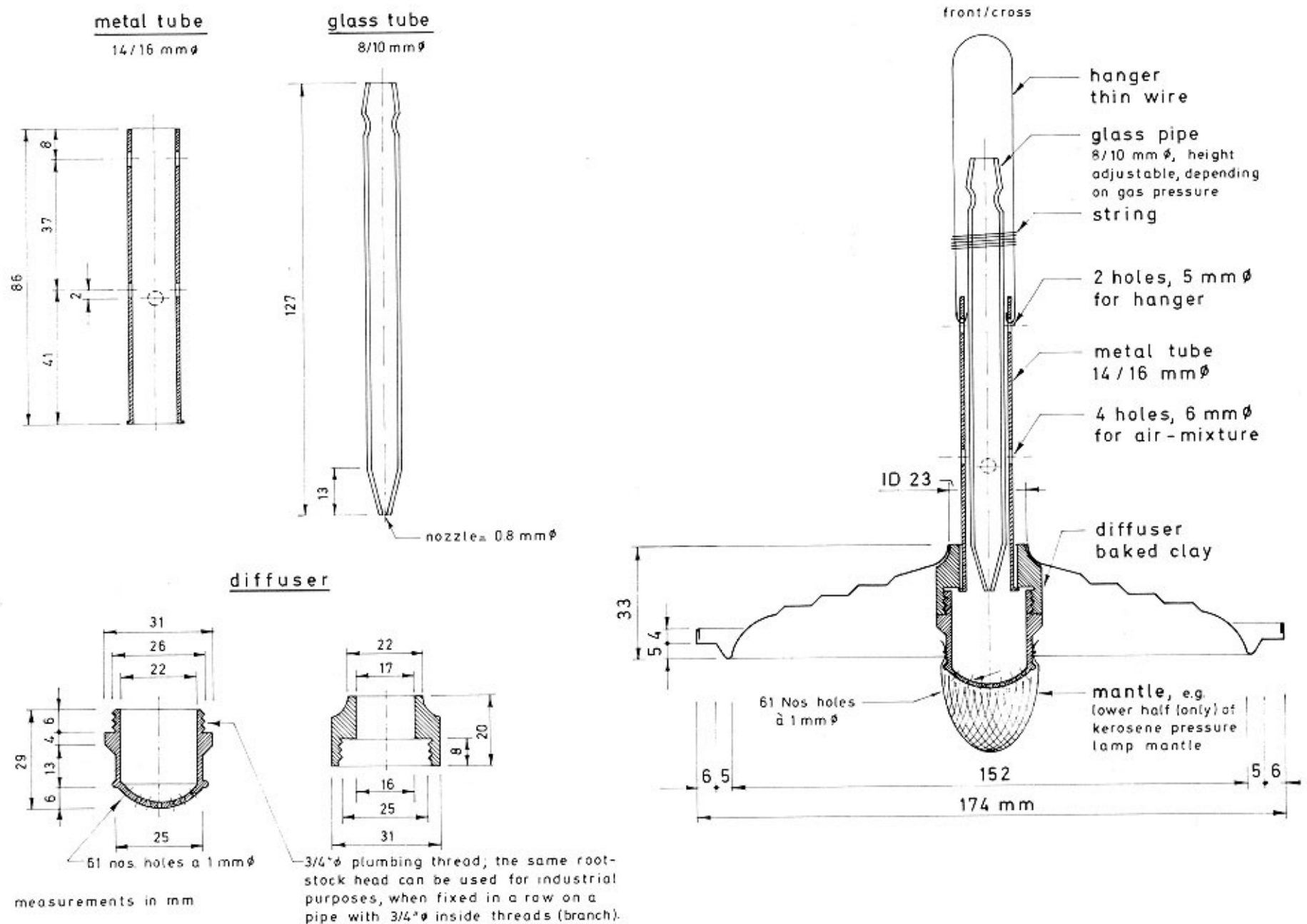


Figure 25. Details for construction of a biogas lamp (hanging model)

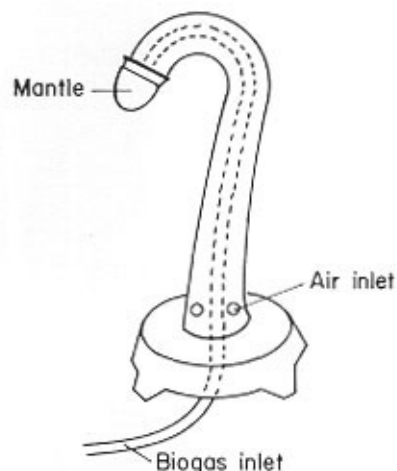


Figure 26.

A standing version of biogas lamp

The large quantities of gas necessary for running irrigation pumps are not available from the small household units and are produced on a communal basis by larger units.

2.4.3. Other uses for biogas

The most important and prevalent use of biogas is for the production of electricity. The electricity can then be used for domestic, agricultural and industrial purposes.

There is no biogas engine as such manufactured in China, but any internal combustion engine can be adapted to run on biogas. The group saw on several occasions, kerosene, diesel and petrol engines altered so as to run on biogas. The necessary adaptation involves replacement of the fuel injector by one designed to introduce the gas; in doing this care has to be taken for providing the correct mixture of gas and air.

At Fushan City, near Guangzhou, the municipality convert biogas to electricity using two engines. One is a 120 h.p. engine previously run on kerosene and the other of 80 h.p. was previously using diesel. These engines were adapted to use a biogas-air mixture of 1:7. Normally 1 m³ of biogas (which had 70% methane) is enough to run an engine for two hours or to generate 1 kW of electricity. Under summer conditions at Fushan enough gas is produced (from city sewage) to give 630 kW of electricity (only half this amount in winter) which is fed into the main electricity grid.

At the Hangzhou pig breeding station a 12 h.p. diesel engine had been adapted to produce 8 kW of electricity, enough for the uses of 100 people. The adapted engines do not always work entirely upon biogas; for example diesel is also fed by a drip system at 0.0004 kg s⁻¹ (1.6 kg per hour).

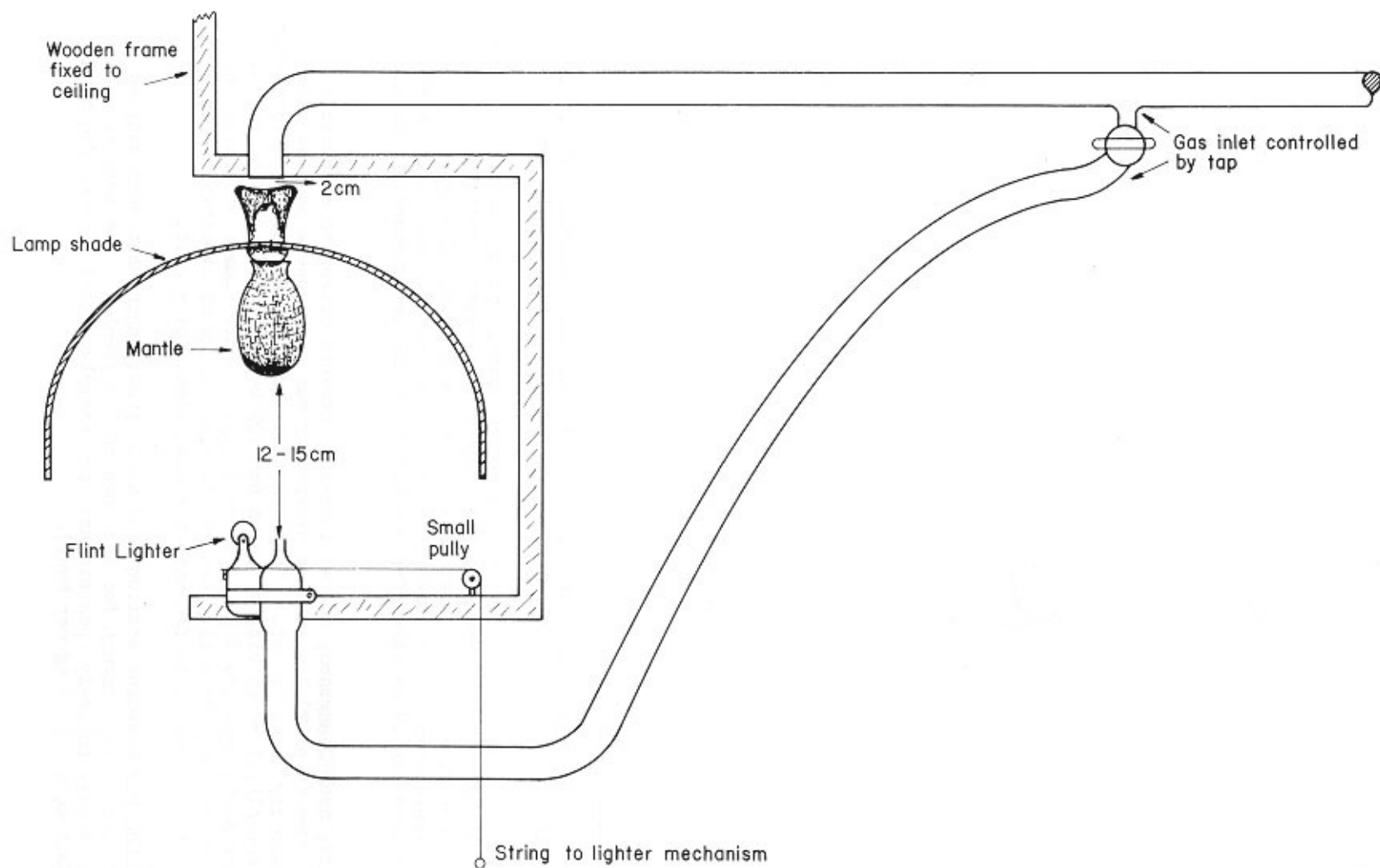


Figure 27. Use of a flint lighter for igniting biogas lamps (Hsin Chao People's Commune, Sichuan Province).



Plate 32. A Chinese kitchen showing how the biogas burners are placed inside a deep cover for maximum efficiency.



Plate 33. Biogas, stored in plastic bags is used to run irrigation pumps. (Mianyang, Sichuan Province).



Plate 34. Irrigation sprinklers operated by biogas as detailed in Plate 33.

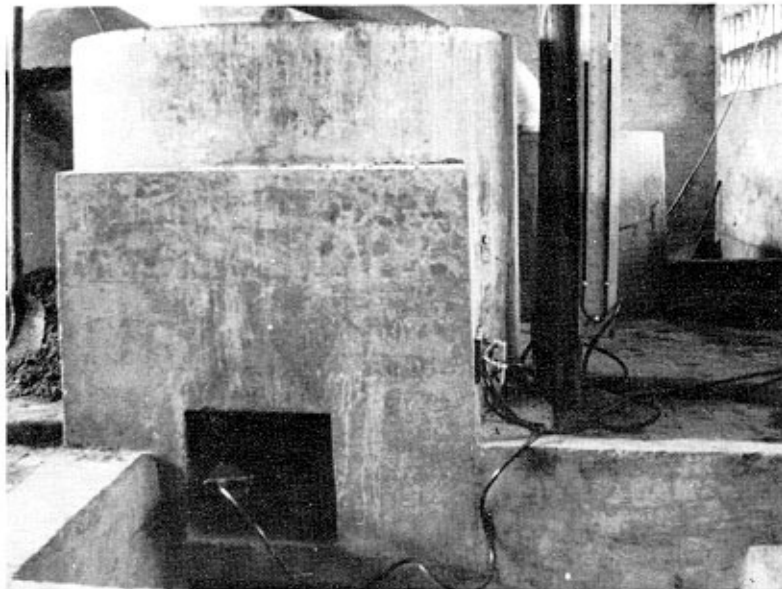


Plate 35. A large still being fired by biogas. Note the pressure gauge which accompanies all uses of biogas in China. (Pin Niu People's Commune, Jiangsu Province).

Other, direct uses of biogas seen were the running of small grain processing mills, noodles and tea processing factories, a nuts and bolts factory and a distillery. In the distillery (Plate 36) not only was the still itself fired by biogas but biogas-heated wire gauzes were heating the grain fermentation rooms.

2.5 Agricultural use of effluents

In most other countries a biogas plant is basically regarded as a source of energy for fuel, but in the Chinese concept it is more important as a source of organic manure. On more than one occasion biogas units were referred to as 'mini-manure factories'. It is suggested that this could be the reason why the Chinese do not place over-emphasis on the efficiency of gas-run appliances.

2.5.1 Manuring crops

The effluent from a biogas plant is of two kinds due to the nature of the raw materials used as input. One kind is a slurry which can be removed daily from the outlet chamber and the other is sludge which settles at the bottom and is available only when the tank is periodically emptied.

Both kinds of effluent are a good source of plant nutrients and also provide an excellent soil conditioner. The effluent is used as a basal or top-dressing for crops and it is applied manually or, in the case of slurry, as a direct spray (Plate 28).

The effluent is sometimes applied directly to the fields without further treatment, or it is first enriched with liquid ammonia and a phosphorus source or it is first composted in a pit with straw and silt.

Figures given (Mianyang City, Sichuan Province) for increases in nutrients in effluent compared with inputs were 14% for total nitrogen and 19.3% for total phosphorus. These results were obtained by comparing the results of biogas digestion with those of aerobic composting over a period of thirty days.

Regardless of method of application increased crop yields as a result of adding biogas unit effluents were said to be always obtained. The Liang Chu People's Commune (Yahang County) observed that a major factor in rice yield increase (10%) in 1977 was the application of effluent. At Mianyang city, the average increase in crop production in 1976 compared to 1975 was 13.2% and was said to be due entirely to application of effluent. Similar results were quoted in most communes visited.

The quantity of effluent obtained as organic fertilizer depends upon the size of the biogas unit and the amount of inputs. A plant of 7 m³ yields 20 000 kg of organic manure every year (Liangchu People's Commune). A farmer of the 10th Production Team of the 5th Production Brigade in Weicheng, People's Commune (Sichuan Province) kept records of inputs and output from his 9 m³ plant. He found that per year he obtained besides gas, 30 150 kg of slurry and 15 500 kg of sludge which he used on his rice and wheat crops.

2.5.2 Animal feed supplement

Use of biogas unit effluent (the sludge portion) as an animal feed supplement was observed only once by the group. This was at the Pin Niu People's Commune at Changzhou where sludge was mixed with dried Azolla as an additive to pig feed (Plate 12).

2.6 Problems of biogas technology

2.6.1 Operation during cold seasons

Although several million gas plants are operating successfully in China, they are not without problems. In all regions visited, a decrease in gas production during winter was reported. Whereas the gas produced during summer from a household unit is sufficient for cooking three or four meals a day and for light, in the winter, apart from light only two meals a day can be cooked.

Due to temperature limitations upon biogas production (section 2.1.1) the plants tend to be concentrated in the south-east of China and in Sichuan Province. In south China at Fushan City (Guangdong Province) gas production at 293 K (20 °C) during winter was half that during summer. In Sichuan Province, biogas plants operate for only eight to ten months of the year.

No account was given as to what is being done about this problem; however special reference was made to a biogas unit recently constructed at an altitude of 3 000 m somewhere on the Tibetan plateau from which no results are yet available.

2.6.2 Gas pressure

As described in section 2.2.4, gas pressure in the tank is high and subject to fluctuation according to the rate of gas formation. Fluctuating pressure does not lead to efficient running of biogas appliances which are designed to work at a fixed gas pressure.

Although this problem is not considered severe in China, if appliances and engines are to work with maximum efficiency, some form of pressure regulator is required.*

2.6.3 Other problems

Other problems associated with the Chinese design of biogas plant are:-

- no provision for breaking the scum build-up in the tank
- necessity for using manual labour or a pump for removing slurry from the outlet chamber
- need for periodic opening of the digester to remove sludge.

Problems in biogas technology still to be adequately solved but which are not peculiar to the design of unit, include purification of the gas to prevent gas meters, engines and so on from corrosion and improvement of measures to prevent health hazards. As discussed in 2.3.7, facultative bacteria such as paratyphoid B and E. coli can survive for long periods in the tank and further research is needed on this.

2.7 Large-scale biogas units

Although the Study Tour was essentially for examining small, household biogas units, the group had the opportunity to visit a number of large-scale units. The large units, run on a community basis are invariably used for production of electricity which is then used for domestic, agricultural and industrial purposes.

* As a result of the Study Tour, Nepal has recently developed a pressure regulator. This device is attached to the gas line and delivers gas at a constant pressure of about 1 kN m⁻² (8 cm of water).

The large biogas units are not necessarily circular in shape nor do they always have a dome-shaped gas tank. Some were rectangular with flat tops and some consist of several large tanks which are interconnected.

At Fushan City near Guangzhou, sewage was being converted to biogas for electricity production and for agricultural manure. Nightsoil is collected in carts and brought to the site where it is stored in special pits before being loaded into a series of thirty five digesters, each of 45 m^3 capacity. The material is digested for fifteen days, the gas being collected in plastic balloon-type holders; there are two such holders of 125 m^3 capacity each. In due course the effluents are loaded into boats and taken by river to farms. It was said that 60 m^3 per day of nightsoil gives 60 m^3 of sludge and 420 m^3 of biogas (in summer).

At the Pin Niu People's Commune, near Changzhou, the Cheng Hsiang Production Brigade had built two, interconnected units of 600 m^3 capacity each. (Figure 28). These units were fed with inputs of rice straw and the wastes of 40 cows and 200 pigs. The gas was used for operating a distillery and producing electricity and the effluent was pumped directly onto the fields.

Near Mianyang City, Sichuan Province, two round-shaped digesters were seen of 174 m^3 and 180 m^3 capacity respectively. The nitrogen-source input was the dung of 30 pigs and the gas was used for electricity to run small industries such as rice polishing and milling and noodle making.

A conventional round-shape biogas unit was visited in Sichuan Province and which had a capacity of 268 m^3 . This unit was still unfinished at the time and so it was possible to climb down inside. It had been constructed by the 10th Production Team of the 5th Production Brigade of the Weicheng People's Commune. A hillock had been partly flattened by removing 230 m^3 of earth for the construction and was to eventually have a milling and husking plant, accommodation for 100 pigs and houses for workmen.

At the time of visit the basic construction was complete, stone blocks having been used to make the tank which had a conventional, although large, dome top. The approximate dimensions are given in Figure 29. Of special interest was the design of the outlet; this was a long tunnel situated at the bottom of the tank and which led to a final opening through the hillside onto terrace land.

The outlet was fitted with a drop door which can be opened manually by going down the steps. On one side of each step was an extension in the form of a concave stone slab having a hole in it; each hole was plugged with a stone plug. The holes are connected vertically with the outlet tunnel with 5 cm diameter pipes.

During operation of the unit, a slurry of raw materials will fill the tank to a certain height and including the stairway. If one has occasion to descend the steps to open the drop door for emptying out the sludge, the stone plugs are removed from the steps and slurry is drained to the outlet tunnel.

It was intended to use rice straw, grasses and vegetable wastes as carbon material and pig dung as nitrogen-source material and to renew the raw input material once every six months.

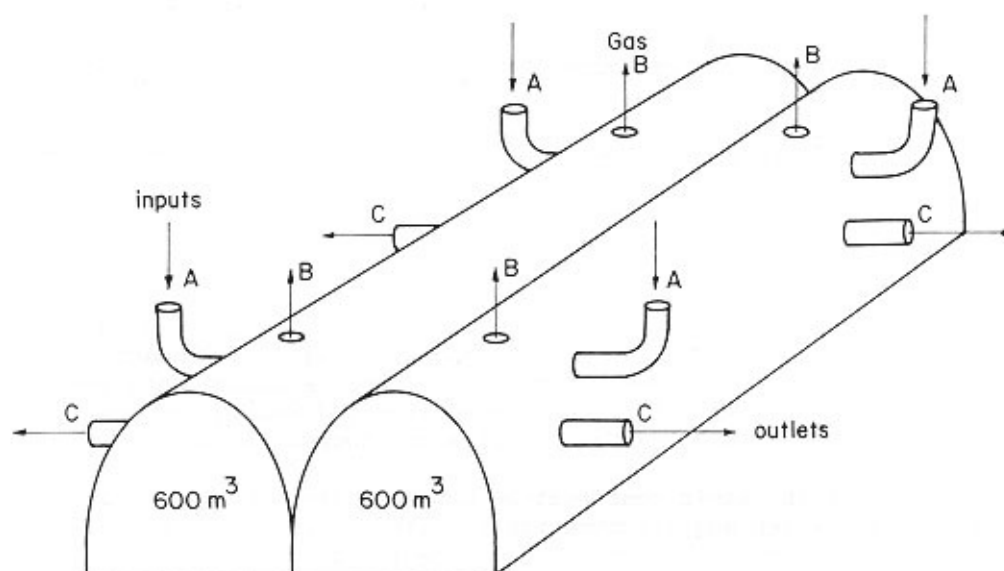


Figure 28. Design of inter-connected large-scale biogas digesters of 600m³ each at Pin Niu People's Commune, Jiangsu Province.

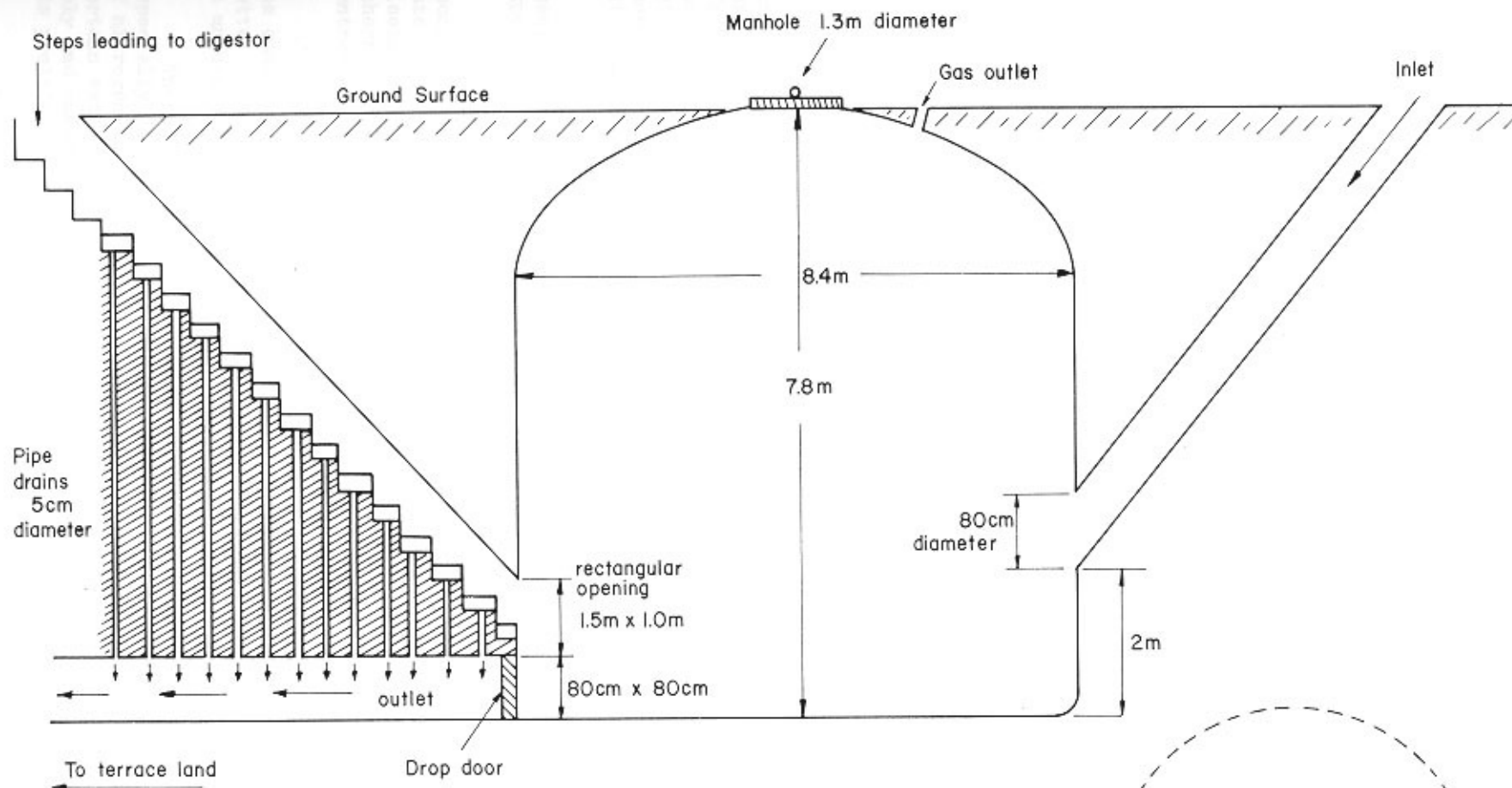
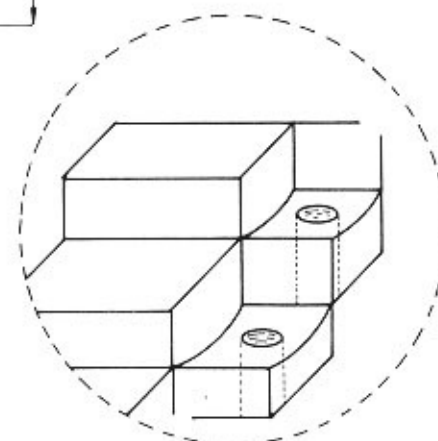


Figure 29. A 268m³ biogas plant under construction at the Weicheng People's Commune, Sichuan Province



Detail of drain pipes through steps

3.1 Extension of Azolla technology

Following the UNDP/FAO study tour on organic recycling in China (1977; FAO Soils Bulletin 40), information regarding agricultural use of Azolla was carried to several other Asian countries. In some cases this in itself was sufficient to initiate national programmes of research using locally occurring varieties of the plant.

In addition, FAO followed up the study tour by sending a consultant to certain countries in Asia to conduct short training courses in propagation and use of Azolla.

Thus, even before the present study tour took place, interest in the agricultural possibilities of Azolla had been aroused in the region and in some instances practical work had begun. It is as a result of the present study tour however, that widespread activities in Azolla cultivation are expected.

Reports from participants in the study tour show that in many cases positive action has already been taken by governments to take full advantage of Chinese experience. Thus for example, in Malaysia cultivation of Azolla as a source of compost and animal feed has been commenced in the numerous mining ponds. It has, however, been realized that it is not feasible merely to transfer directly the Chinese technology which demands good water control and high labour inputs; consequently modifications of the procedure are now under investigation.

Cultivation of Azolla in India is now being increased and introduced to all climatically suitable States. In Nepal work has started on forming a collection of native varieties of Azolla and testing them for nitrogen fixation, yield and fertilizer effect. Some countries, for example, Lao, Bangladesh and Nepal have requested FAO assistance to conduct training courses for extension officers in Azolla cultivation leading to pilot demonstration schemes. In Afghanistan, FAO consultant advice has shown that cultivation of Azolla is not feasible due partly to low winter temperatures but more especially to very low humidity.

It is clear that the countries of Asia not previously aware of Azolla and its uses, are now extremely interested and anxious to avail of known technology and experience.

It is suggested that in all cases a first step would be to identify locally occurring varieties of Azolla and to investigate them for nitrogen fixing capacity, rate of multiplication, resistance to temperature, acidity/alkalinity, salinity, disease, and so on. At all stages of investigation contact should be maintained with others carrying out similar investigations - especially at well established research centres.

When the stage is reached for larger scale applied research on Azolla cultivation, due consideration should be given to the conclusion formed in Malaysia that it may be better to adapt Chinese technology to local conditions rather than trying to introduce it unchanged.

There is little doubt that Azolla will grow well in most parts of Asia, especially as research extends its temperature tolerance. It is thus a potential source of nitrogen and green manure for crops, particularly rice, which could relieve to a certain extent the reliance upon mineral nitrogen fertilizers. It could also considerably and cheaply augment available feedstuffs for animals; generally speaking therefore, its proliferation is to be encouraged.

However, a sense of proportion should be kept. As already pointed out by T.A. Lumpkin*:

"Azolla is not a panacea. It can make a useful contribution to weed control and to the nitrogen economy of rice, but it is not as ubiquitous as rice nor will it provide all of the nitrogen required in every location."

3.2 Extension of biogas technology

Utilization of waste organic materials to produce biogas and manure is not a new concept and its technology is not confined to China. The value of the activities in China lies in the following facts: the national approach leading to widespread proliferation of the technology; the relative cheapness of biogas units attained by use of locally available materials and communal labour and; the unique basic design of the units wherein the digester acts also as gas holder.

In all other countries of Asia, with perhaps the exception of India, there is (at time of writing) no national policy to introduce biogas technology and this is almost certainly due to a lack of awareness of the multiple benefits to be obtained.

In some cases, Pakistan and Bangladesh for example, tentative efforts to commence biogas production had not been very successful and interest had waned. Such lack of success was due mainly to poor technology and partly to excessive costs. Both these faults can be remedied to some extent as a result of the study tour in China and Bangladesh has now commenced a new biogas programme based on Chinese experience.

By adopting the Chinese design of biogas unit the main source of expense, that is the floating gas holder, is eliminated. True, the floating gas holder has certain advantages over the Chinese system - better control of gas pressure for example - but the great saving in costs more than outweighs these. Furthermore, research will undoubtedly remedy the present defects of the system. Research may however also lead to cheaper models of the floating tank type and so it is not recommended that this technology be completely abandoned in favour of the fixed dome model.

As an immediate result of the study tours several countries have already started to introduce or extend biogas technology.

Thus India, which previously had exclusively constructed floating tank units, has now produced several modifications of the Chinese design and a considerable number have been built for demonstration purposes.

In Malaysia a biogas digester of Chinese design is planned as a cooperative venture between the Agricultural Research and Development Institute and the Agricultural University. In the tin mine areas integrated farming systems are planned involving biogas, Azolla and crops and animal production.

Lao has requested FAO assistance to commence biogas demonstration units in conjunction with pig farming. In Nepal national seminars on biogas have been organized including demonstration of Chinese biogas equipment such as cookers and lamps and a Biogas Newsletter has been commenced for extension work.

As in the case of Azolla cultivation, Chinese biogas technology cannot simply be transferred as such and without modification. Even in China itself, different regions have different technologies. Several factors must be considered; purely physical factors such as soil type, water table and climate; economic factors and even ideological factors.

* University of Hawaii

Most, if not all, of the physical factors have been discussed in this report which should aid those concerned in deciding upon the technology to be followed.* Six different models of biogas unit have been detailed and it should be possible to select a basic design suitable for local conditions. The other factors (economic and ideological) will vary between countries and must be considered by individual governments but there are no valid reasons why the use of small-scale biogas units should not be adopted throughout Asia as a means of cheap fuel and power for farming communities with concomitant improvement of the environment.

3.3 General

The countries of Asia are at different stages of development in respect to the technologies of Azolla cultivation and biogas production. Future programmes should therefore be planned according to relative needs and capabilities. It is suggested that each country formulates a programme having the following components:

- i) a plan to utilize and promote biogas and Azolla as part of integrated rural development;
- ii) short and long term projects with specific targets;
- iii) a national coordinating body to ensure cooperation of all relevant departments and organizations and to review progress;
- iv) a system for disseminating information to all concerned;
- v) training of extension workers for demonstration of techniques to farmers;
- vi) periodic seminars to discuss progress and problems; such seminars could be national or inter-country;
- vii) provision for initiating practical work in terms of personnel, equipment and supplies;
- viii) research in all technical aspects of biogas production and use;
- ix) research in use of biogas effluent and sludge for improving soil condition and fertility with emphasis upon the complementary use of mineral fertilizers and manure;
- x) studies on socio-economic issues affecting biogas production and use of the effluents;
- xi) research on health hazards of using biogas effluents as fertilizer
- xii) research on Azolla propagation with a view to selection of most suitable species and strains, improvement of nitrogen fixing capacity and resistance to adverse factors.

* FAO is presently occupied with a manual or handbook detailing all practical aspects of small-scale biogas technology in China.

Some countries already have one or more of the above programmes but not every country has the facilities for including all the suggested components - particularly those involving research. In every programme adopted the experience of the Chinese will be of immense value, even if it can not be utilized immediately at a practical level.

Cooperation and sharing of information - even of practical assistance - within the region is essential. In this respect the UNDP/FAO inter-country project RAS/75/004 "Improving Soil Fertility through Organic Recycling" (which initiated this Study Tour) will be of great use.

LIST OF PARTICIPANTS

BANGLADESH	Mr. Ahmed Hussein Rice Production Specialist Bangladesh Rice Research Institute Dacca
INDIA	Dr. R. Dwarikanath Director of Agriculture Government of Karnataka Bangalore
	Dr. L. Venkataraman Director of Agriculture Government of Tamil Nadu Madras
IRAN	Mr. Mohamed Nejad Shamlou Soil/Water Management Specialist Soil Institute of Iran Teheran
	Mr. Mansoor Olfati Soil Reclamation Specialist Soil Institute of Iran Teheran
LAO	Mr. Khamsing-Sayakone Director-General Ministry of Agriculture Vientiane
	Mr. Oroth Chounlamontry Technical Director Ministry of Agriculture Vientiane
MALAYSIA	Mr. Nik Abdul Halim Assistant Director Crop Production Branch Department of Agriculture Kuala Lumpur
	Mr. Kho Boon Lian Research Officer (Soil Science) Malaysian Agricultural Research and Development Institute, Kuala Lumpur

NEPAL Mr. Dhruba Joshy
 Soil Scientist (Biogas)
 Agricultural Department
 Kathmandu

 Mrs. Shanti Bhattarai
 Assistant Soil Scientist (Azolla)
 Agricultural Department
 Kathmandu

PAKISTAN Dr. G.R. Sandhu
 Nuclear Institute for Agriculture and Biology
 Lyallpur

PHILIPPINES Dr. Felicidad Mangali
 Assistant Regional Director
 Bureau of Animal Industry for Central Luzon (Biogas)
 Manila

THAILAND Mr. Chob Kanareugsas
 Chief, Rice Fertilization Research Branch
 Rice Division, Department of Agriculture
 Ministry of Agriculture and Cooperatives
 Bangkok

 Mr. Paitoon Nagalakshana
 Chief, Agricultural Engineering Training Section
 Agricultural Engineering Division
 Department of Agriculture
 Ministry of Agriculture and Cooperation
 Bangkok

FAO Dr. P.R. Hesse
 Team Leader and Coordinator, FAO/UNDP
 Regional Project on Organic Recycling in Asia and the Pacific

 Dr. E.P. Taiganides
 Project Manager, FAO/UNDP Project on Animal Waste Management
 and Utilization
 Singapore

 Dr. H. Matsuo
 Soil Fertility Officer, AGL Division
 FAO Headquarters, Rome

PROGRAMME

- May 21 Arrival of participants in GUANGZHOU
- Introduction and discussion of programme with
 Dr. Yang Ching-jao, Head of Soil and Fertilizer Office, Peking.
- Welcoming dinner by courtesy of Mr. Wu Tung-kiang, Deputy Director,
 Agricultural Bureau.
- May 22 Visit to Fushan City: treatment of sewage to produce electricity
 via methane.
- Guangzhou: Discussion with Chinese counterparts on Azolla and
 biogas in Guangdong Province.
- May 23 Travel by air to HANGZHOU
- Introductory discussion
- Film show
- May 24 Anshi People's Commune: Azolla
- Group discussion with members of the Revolutionary Committee
- Dinner by courtesy of Mr. Chiao Hsiang-chung, Deputy Director of
 Agriculture.
- May 25 Luang Chu People's Commune, Uhang: biogas
- Hangzhou Pig-breeding Station: biogas
- Group discussion
- May 26 Evergreen People's Commune, Chang Ching Production Brigade
 (Ten Shan Shin): biogas
- Travel by train to SHANGHAI
- Introductory discussion
- May 27 Discussion with Deputy Director of Agriculture and his staff,
 municipality of Shanghai
- Shu Ching People's Commune, Changpu: Azolla, biogas
- Ma Chiao People's Commune, Shanghai: Azolla, biogas
- Dinner by courtesy of Mr. Wang, Deputy Director of Agriculture.

May 28 Visit to Shanghai Industrial Exhibition

Travel by train to WUXI

Introductory discussion with officers of agricultural bureau
and members of the Revolutionary Committee

Dinner by courtesy of the President of Wuxi Revolutionary Committee

May 29 Mai Tsun People's Commune, Wuxi: biogas

Hsilang People's Commune, (Shian Yang Brigade) by Lake Tai Hu: Azolla

Group discussion

May 30 Travel by train to CHANGZHOU

Introductory discussion

Pin Niu People's Commune, Chen Hsiang Production Brigade: biogas,
Azolla

Discussion with Chinese counterparts

May 31 Hua Shi People's Commune, Hsi Production Brigade, Kiang Yin: biogas,
Azolla

Group discussion

June 1 Travel by train to NANJING

Introductory discussion with the Reception Committee of the
Agricultural Bureau

Visit to National Research Institute of Soil Science

Visit to Jiangsu Provincial Academy of Agricultural Science

Dinner by courtesy of Mr. Yang Yung-sheng

June 2 Travel by air to CHENGDU

Introductory discussion with Director of the Bureau of Soil
Fertility and specialists

Dinner by courtesy of the Director of Agriculture

June 3 Travel by road to MIANYANG CITY

Introductory discussion with members of the Revolutionary Committee

Yunghsing People's Commune, 7th Production Brigade: Azolla

June 4 Wu Ching People's Commune: biogas
 Hsin Chiao People's Commune: biogas
 Teh Yang County Orchard: biogas
 Travel by road to CHENGDU
 Group discussion

June 5 Tumen People's Commune, Azolla, biogas
 Discussion with Chinese counterparts

June 6 Chengdu; Seminar, biogas and Azolla

June 7 Travel by air to PEKING
 Meeting with Mr. Li Yung-kai, Director of Bureau of Foreign Affairs,
 Ministry of Agriculture and Forestry.
 Dinner by courtesy of Vice-Minister of Agriculture and Forestry

June 8-9 Group discussion
 Preparation of draft report outline
 Farewell dinner by courtesy of the Team Leader

June 10 Travel by air to CHANGZHOU

June 11 Travel by train to HONG KONG and departure of participants to home
 countries

PERSONS MET

PEKING

Ministry of Agriculture and Forestry

Hao Shih-chung, Vice-Minister, Agriculture and Forestry
 Li Yung-kai, Director of Foreign Affairs
 Chang Skih-chan, Head of International Division
 Yang Ching-jao, Head of Soil and Fertilizer Office
 Tsui Li-chuan, Staff member, International Division
 Yang Yung-hsing, Staff member, International Division
 Yin Pao-hsiang, Staff member, International Division

GUANGDONG PROVINCE

Agricultural Department

Wu Tung-Kiang, Deputy Director, Agricultural Bureau, Guangzhou
 Lei Ta-fang, Deputy Head, Agricultural Bureau, Administration
 Office, Guangzhou
 Liu Liang-jung, Session Chief, Science and Technology
 Chen Hai-tao, Provincial Agricultural Officer
 Han Hung-kuang, Staff member

Foreign Affairs Department

Chung Chung-chun, Head of Department, Guangzhou
 She Fang, Director, Fushan City

Academy of Agricultural Sciences

Ke Yu-tao, Research Worker, Soil and Fertilizer Division
 Tuen Pin-yuan, Assistant Research Scientist, Fertilizer Division
 Lu Jin-chum, Assistant Research Worker, Fertilizer Division
 Liu Shu-chan, Lecturer

Municipal and Environmental Sanitation, Fushan City

Chin Chen, Head of Administration

Hsinchiao People's Commune

Sung Wen-kuei, Vice-Chairman, Revolutionary Committee
 Yang Fu-hiang, Leader, 2nd Production Brigade
 Liu Yi-hsing, Leader, 2nd Production Team of 2nd Brigade

ZHEJIANG PROVINCE

Agricultural Department, Hangzhou

Chiao Hsiang-chung, Deputy Director
 Shu Yam, Head of Science and Education Department and Deputy
 Director of Administrative Office for popularizing biogas
 technology
 Hsu Tseng-fu, Technical worker in office for popularizing biogas
 technology
 Chang Lin, Technical worker, Agriculture Bureau, Hangzhou
 Pao Wei-han, Technical worker, Agriculture Bureau, Hangzhou
 Tsai Shue-fang, Technical worker, Agriculture Bureau, Hangzhou
 Hsu Chin-yin, Technical worker, Agriculture Yuhang County

Zhejiang Agricultural University

Chien Tan-shu, Lecturer and Director of Microbiological Research
Wu Chin-peng, Teacher

Jiang Yin County

Chang Chen-hua, Vice-Chairman, County Administrative Office
Chien Chi-hsu, Head of Agricultural Bureau
We Hseh-tang, Deputy Leader, Huashin Production Brigade

Anshi People's Commune

Yeh Yung-liang, Chairman of People's Revolutionary Committee
Yu Chin-yin, Deputy Chairman of People's Revolutionary Committee
Yeh Chi-mei, Head of Science Research Centre

Evergreen People's Commune, Kiungkhan district

Hsiang Kwin-lin, Chairman of People's Revolutionary Committee
Chin Hsueh-fen, Vice-Chairman of People's Revolutionary Committee
Chou Lian-ken, Vice-Chairman of People's Revolutionary Committee
Hsu Hsua-jung, Team Leader, 10th Production Team of Changching
Production Brigade

SHANGHAI SHI PROVINCE

Department of Agriculture

Wang, Deputy Director

Shu Ching People's Commune

Tang, Vice-Chairman, People's Revolutionary Committee

Machiao People's Commune

Wang Yueh-hsin, Vice-Chairman, People's Revolutionary Committee
Tsao Kwei-ti, Director of Farm Machinery Plant
Tang Ping-hua, Director of Health Clinic

JIANGSU PROVINCE

Department of Agriculture

Yang Yao-chung, Vice-Director, Wuxi County Agricultural Bureau
Shen Fu-lin, General Office of Provincial Bureau
Wong Yu-liang, Chief, Biogas Office of Wuxi County
Chen Wen-kuang, Deputy Director, Wuchin County Bureau
Wang Chia-chun, Head of Biogas Experimental Station, Wuchin County

Department of Foreign Affairs

Chou Lung-Ken, Staff member, Wuxi County
Ho Cheng-lin, Director, Changzhou City
Cha Yao-chung, Deputy Director, General Office of Wuchin County
Revolutionary Committee

Pin Niu People's Commune

Chou Shou-hai, Leader of Chenhsiang Production Brigade

National Research Institute of Soil Science, Nanjing

Hsueh Yi, Director
Win Chin-sia, Deputy Director
Huang Tung-mai, Responsible Member
Huang Yu-shin, Research Officer (bacterial fertilizers)
Chin Chih-pei, Research Officer
Tang Yu-keng, Assistant Research Officer (hydrology)

General Office of Academy of Agriculture, Nanjing

Yang Yun-sheng, Director

SICHUAN PROVINCE

Huang Liu, Vice-Chairman, Provincial Scientific Commission

Department of Agriculture

Chang Min, Deputy Director, Provincial Bureau
Yu Ching-kuei, Deputy Head, Biogas Promotion Office
Wang Shou-chien, Deputy Head, Soil and Fertilizer Department

Biological Research Institute, Chengdu

Hsu Chi-chuan, Biogas Technician

Academy of Agricultural Science, Chengdu

Liao En-chang, Biogas Technician

Mianyang County

Hsueh Pin-kuei, Responsible Member of Municipal Revolutionary
Committee
Teng Tsuo-you, Head of City Foreign Affairs Office
Lei Hsiao-chien, Head of City Biogas Office
Liu Lung-hui, Vice-Chairman, Yunghsing Commune Revolutionary
Committee
Pao Hsing-wu, Leader, 2nd Production Brigade, Yunghsing Commune
Lo Ting-fang, Head of Grain and Oil Processing Plant, Yunghsing
Commune
Chang Tao-chu, Chairman, Revolutionary Committee of Weichang People's
Commune
Lo Kuo-fan, Leader, 5th Production Brigade, Weichang Commune

Tehyang County

Wu Teng-teh, Director, State County Orchard

Chiakiang County

Fan Min-chung, Chairman, Revolutionary Committee, Tumen People's
Commune

Wang Fang-yao, Leader, Chiakiang Production Brigade of Tumen Commune.

VISITS OF GENERAL INTEREST

Interspersed with the purely technical items on the programme, were specially arranged visits of historical, cultural and general interest:

- The Mao Tse-tung Memorial Hall
- The Great Wall
- The Ming Tombs
- Tien An Men, Square of Heavenly Peace
- The Imperial Palace Museum (Forbidden City)
- Yiheyuan, the Summer Palace
- The Yangtze River Bridge, Nanjing
- The Mausoleum of Dr. Sun Yat-sen, Nanjing
- Tai Hu Lake, Wuxi
- The Industrial Exhibition Centre, Shanghai
- West Lake and gardens, Hangzhou
- Silk weaving factory, Hangzhou
- Tiger Spring, Hangzhou
- Liu Ho Pagoda, Hangzhou
- Ying Lin Temple, Hangzhou
- Folk and Handicraft Research Centre, Fushan
- Taoist Temple, Fushan
- Hill resort, Guangzhou
- House, garden and temple of Tu Fu, Chengdu
- Film show: "Dream of the Red Mansions" and several cultural shows and concerts.

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