UPDATED GUIDEBOOK ON BIOGAS DEVELOPMENT

ENERGY RESOURCES DEVELOPMENT SERIES
No. 27

UNITED NATIONS

ECONOMIC AND SOCIAL COMMISSION
FOR ASIA AND THE PACIFIC
Bangkok, Thailand

UPDATED GUIDEBOOK ON BIOGAS DEVELOPMENT

ENERGY RESOURCES DEVELOPMENT SERIES
No. 27

UNITED NATIONS
New York, 1984

ST/ESCAP/275

UNITED NATIONS PUBLICATION

Sales No. : E.84.II.F.14

Price: $US 17.50

FOREWORD

The first edition of this publication was brought out in 1980 to serve as a guidebook on the practical aspects of small-scale biogas development suitable for use in rural areas in developing countries, especially those of the ESCAP region. This publication is the second and revised version of the original guidebook and contains additional information on some aspects not covered earlier.

The publication is based on the recommendations of the Expert Group Meeting on Biogas Development held at Bangkok from 20 to 26 June 1978, with the financial assistance of the Government of Australia. Information on biogas technology in China made available by the Chinese authorities and collected by an ESCAP staff member during the Interregional Biogas Study Tour in China organized by the United Nations from 1 to 21 September 1979 was also included in the publication. The secretariat obtained the assistance of Mr. John Finlay of the Development and Consulting Services, Butwal, Nepal, in the compiling and technical editing of the first edition of the guidebook. Mr. R.V. Misra, Senior Scientist, Indian Farmers Fertiliser Co-operative Limited, New Delhi, assisted the secretariat in bringing out the present publication.

Grateful acknowledgement is made to the Government of Australia for providing funds for the Meeting and the publication of the book, to the Chinese authorities and to organizations dealing with biogas in ESCAP member countries, in particular the Khadi and Village Industries Commission (KVIC) in India, the Development and Consulting Services (DCS) in Nepal and FAO/UNDP Regional Project on Improving Soil Fertility through Organic Recycling, for making their technical and design information available to the secretariat, and the Government of Japan for its financial support of the Workshop on Uniformity of Information Reporting for Biomethanation Systems held at Bangkok from 2 to 6 May 1983.

CONTENTS

Page

VI. CLASSIFICATION AND DESIGN PRINCIPLES OF PLANTS

VII. DESIGN, SIZE AND SITE SELECTION

VIII. CONSTRUCTION OF DIGESTER

IX. GAS HOLDER AND GAS PIPE

X. HOUSEHOLD GAS APPLIANCES AND THEIR USAGE

XI. STARTING AND OPERATING A GAS PLANT

XII. SERVICING AND SAFETY

XIII. IMPROVING GAS PLANT PERFORMANCE

XIV. COMMERCIAL USES OF GAS

Page

XV. EFFLUENT AND ITS USES

XVI. GAS PLANT DEVELOPMENT PROGRAMMES

XVII. COMMUNITY PLANTS

XVIII. ECONOMICS

ANNEXES

TABLES

Page

FIGURES

Page

PLATES

INTRODUCTION

Over the last few years the Economic and Social Commission for Asia and the Pacific (ESCAP) has been giving special attention to meeting the need for energy in rural areas, with emphasis on the use of local resources and skills. This was in response to decisions taken at recent sessions of the General Assembly and the Commission. At its seventh special session, the General Assembly emphasized the need to develop scientific and technological co-operation and to ensure the application of science and technology to development. At its thirty-first session, the Commission emphasized the urgency of intensifying regional co-operation in all sectors of economic and social activity. It also recommended that the developing countries increasingly utilize the technologies developed by them and suited to their needs, "through genuine technological co-operation".

In the rural energy programme, workshops on biogas technology and use were held at New Delhi and Manila in 1975, an expert working group meeting on solar and wind energy at Bangkok in 1976, a workshop on biogas and other rural energy resources, particularly for Pacific island countries, at Suva in 1977, and a roving seminar on rural energy development in Indonesia, Iran, the Philippines and Thailand, also in 1977. In spite of these meetings on biogas, each of which has made a very useful contribution to the understanding and development of biogas technology, and in spite of the increasing amount of published material on the subject, there was still a general lack of simple published material suitable for use by those involved in rural extension programmes, or by individuals who wished to develop their own biogas plants.

With this need in view, the Expert Group Meeting on Biogas Development was held in June 1978 and 33 experts from countries in and outside the ESCAP region participated in the Meeting. The discussion concentrated on the design, construction, operation and maintenance of various types of biogas plants, uses of gas, including design and operational requirements for their use in domestic application such as lighting and cooking and as a fuel for prime movers, and various ways in which the effluent could be used as a fertilizer, including an input to compost-making. Non-technological requirements, such as those in the fields of education or public relations, which might assist in achieving the overall objective, were also considered.

A practical guidebook based on the deliberations of the Expert Group Meeting, covering most of the aspects of biogas was first brought out in 1980. It has been thought desirable to improve the contents of the guidebook through incorporation of new information and updating. The present publication is the revised and updated version of the original publication and includes additional chapters on prospects of meeting fuel energy needs through biogas, a review of biogas development, biogas fermentation process, and the microbiology of biogas fermentation. In the annex additional information on common methods of analysis, the report of the Workshop on Uniformity of Information Reporting for Biomethanation Systems, case studies on cost benefit analysis of biogas technology, and a list of institutions engaged in biogas research and development, has been provided.

It is hoped that those responsible for developing the use of biogas in rural areas as well as individuals who wish to build their own biogas plant will find the information in this book useful.

I. MEETING FUEL ENERGY NEEDS THROUGH BIOGAS IN DEVELOPING COUNTRIES

A. Energy needs in developing countries

Increasing population and depleting non-renewable energy resources are posing a serious threat to the low-income developing world in the endeavour to attain better standards of life. Living standards are correlated with energy consumption. Most of the developing countries of the world appear to be below the subsistence threshold in terms of commercial energy consumption. A study conducted by the Overseas Development Council of the United States of America has revealed that a threefold increase of the present per capita energy consumption would be required for the developing countries to ensure a more socially acceptable living standard.

Conventional energy supply systems have resulted in the creation of urban islands of energy affluence amid vast oceans of energy-deficient rural areas, and have more often than not proved inadequate to meet the needs of the rural population. A system based largely on non-renewable energy sources will not be in a position to meet the vast requirements of the rural sector in the future. Developing countries will find it increasingly difficult to obtain their fossil fuel requirements through imports. It is evident therefore that, if growth is to be maintained, given the limited availability of fossil fuel resources, renewable energy alternatives should be explored, particularly with a view to satisfying rural energy needs.

Energy demand in rural areas comes from four sectors, viz. domestic, agricultural, basic amenities and small-scale industry. In most of the developing countries, none of these sectors get their full requirement of energy. In some cases even basic amenities are non-existent, and the growth of agriculture and small-scale industries is severly restricted. The availability of even small amounts of energy for the rural areas is of critical value and can bring about a considerable impact.

B. Household energy requirements

Two thirds of total energy demands in rural areas comes from the household sector. Non-commercial fuels account for 95 per cent of household energy consumption. A survey carried out by the National Council of Applied and Economic Research in Northern India has revealed that per capita energy consumption of firewood, dung-cake and vegetable wastes is 120, 158 and 95 kg respectively.

In the rural areas of Asia, substantial parts of the energy requirements of a household are for cooking. In India, 91.4 per cent of the total energy consumed in the household sector is for cooking, and in Bangladesh 93 per cent.

C. Fuel energy sources in rural areas

Considerable portions of energy demand for cooking are met through the use of fuelwood. About 86 per cent of all wood consumed in developing countries is in the form of fuelwood. Of the various fuels used, fuelwood accounts for 30 per cent in Northern India, 70-75 per cent in Indonesia, 87 per cent in Nepal and 60 per cent in Sri Lanka.

The increased use of fuelwood resulting from growing population and fuel energy needs is leading to rapid deforestation. At the present rate of consumption, it is estimated, the fuelwood reserves in India will last only another 24 years. An annual deficit of 1,150 million m^3 of fuelwood is estimated for the world after another 20 years based on the current consumption level. The shortage of fuelwood is leading to the diversion of plant nutrient resources like cow-dung and crop residues to utilization as a fuel energy source.

Animal dung meets 70 per cent of the cooking energy needs in rural areas of India. Out of the 780 million tons of cattle dung (wet) available in the country, 26 per cent is used in the preparation of dungcakes for direct burning, which is considered as an inefficient way of fuel utilization (8). For India, energy and plant nutrient losses resulting through this faulty pattern of animal dung utilization are estimated as 31,107.2 m^3 of biogas and 0.74×10^6 tons of plant nutrients.

D. Biogas through anaerobic fermentation of rural organic wastes

The natural process of decay of organic materials in the absence of air, resulting in the production of inflammable gas (biogas), can be used to the great benefit of rural population as it produces not only fuel but also an excellent manure and soil conditioner, and in addition it destroys pathogens and parasites.

The experience gained from its use and social response to biogas technology reveal it to be appropriate for wide-scale application in rural areas in most developing countries. Biogas plants set up in villages can utilize animal excreta,

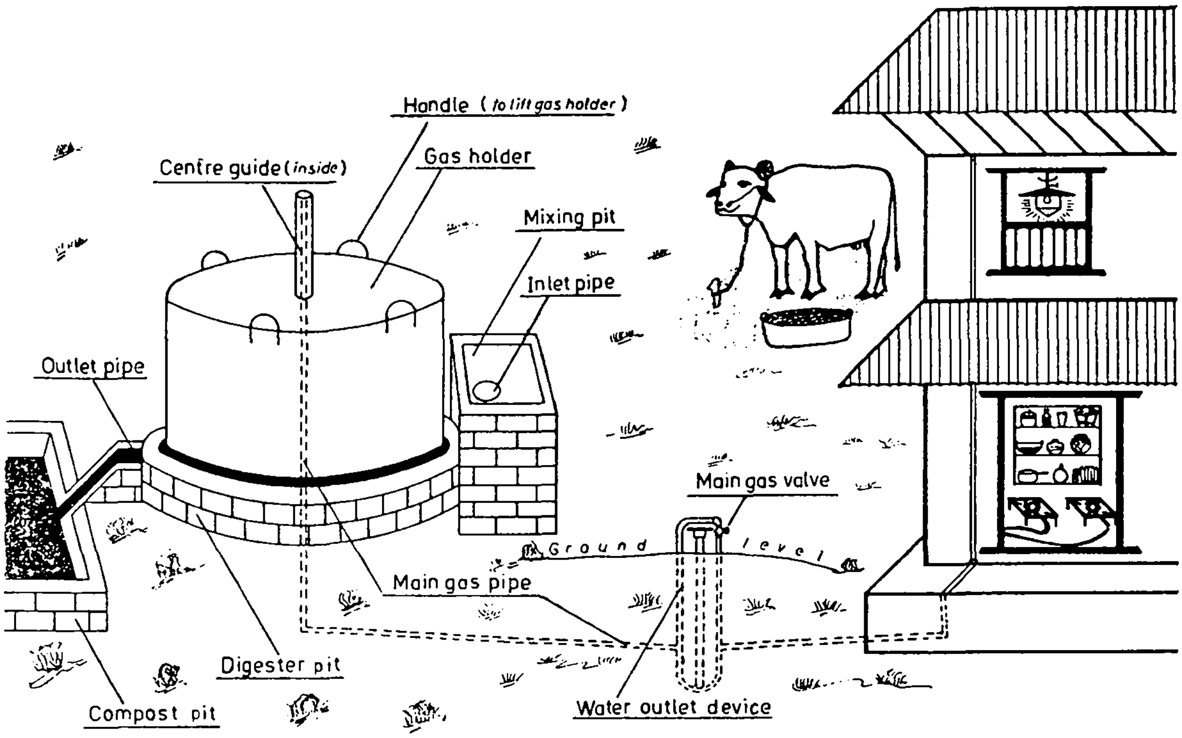


Figure 1. Floating gas holder type biogas plant (India and Nepal)

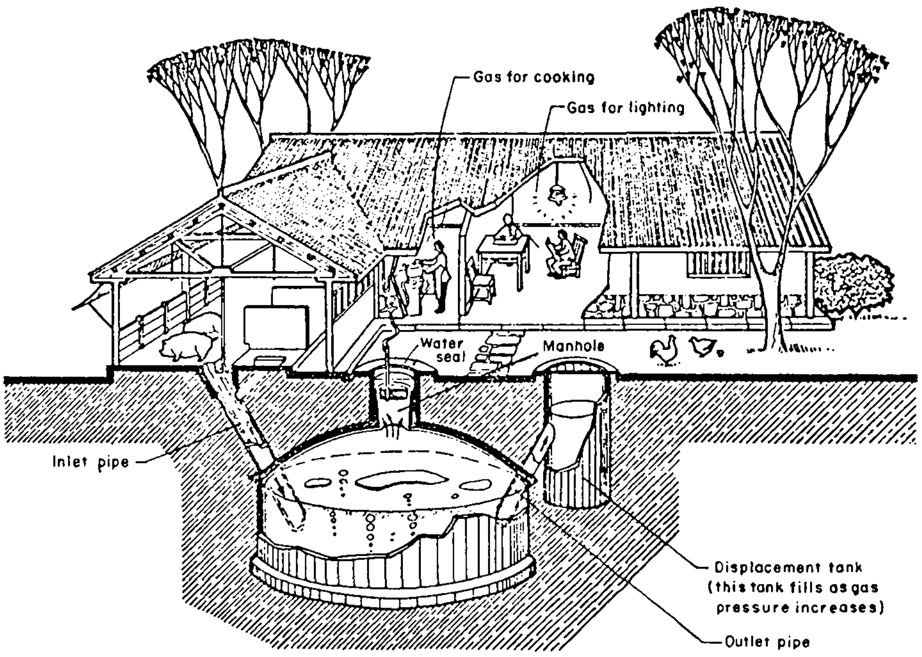


Figure 2. Fixed dome biogas plant (China)

and farm and human wastes, thus enhancing village sanitation. The technology has inherent advantages like simplicity, low cost, and capacity to produce a good quality fuel without any deterioration in fertilizing properties of the natural resources used as feedstock.

For Asia, it is estimated that routing of animal dung alone through biogas systems can result in availability of 109×10^9 m^3 of biogas per annum with an energy content of 931×10^{12} kcal. A countrywise account is given in table 1.

Table 1. Biogas generation potential of dung available through livestock and its energy value (per annum)(3)

Country area	*Biogas generation potential (million m^3)*	*Energy value of biogas (10^9 kcal)*
Afghanistan	2 611	14 360
Bangladesh	8 464	46 552
Bhutan	67	368
Burma	2 376	13 068
China	48 798	269 379
Cyprus	73	401
Democratic Kampuchea	300	1 650
Democratic Yemen	191	1 050
Democratic People's Republic of Korea	344	1 892
Hong Kong	26	143
India	63 888	351 384
Indonesia	2 893	15 911
Iran	4 557	25 063
Iraq	1 583	8 706
Israel	88	484
Japan	1 421	7 815
Jordan	80	440
Lao People's Democratic Republic	542	2 981
Lebanon	56	308
Malaysia	246	1 353
Mangolia	2 077	11 423
Nepal	2 850	15 675
Oman	53	291
Pakistan	9 511	52 310
Philippines	1 647	9 058
Republic of Korea	482	2 651
Saudi Arabia	374	2 057
Sri Lanka	611	3 360
Syrian Arab Republic	651	3 580
Thailand	2 748	15 114
Turkey	7 231	39 770
Viet nam	1 401	7 705
Yemen	946	5 203
Asia	169 186	931 505

E. Advantages and disadvantages of biogas

The advantages and disadvantages of biogas are hard to quantify and depend on what current practice is used as a comparison, e.g. gas compared with burning dung, firewood or kerosene.

The advantages and disadvantages also depend on the viewpoint taken e.g. the individual family, the community or the nation. Bearing these factors in mind, the following points can be considered.

At the *family level* the advantages are:

(a) Clean fast cooking fuel;

(b) Better lighting;

(c) Improved health (particularly of eyes and lungs) as a result of eliminating smoky fuels;

(d) Improved sanitation (resulting in better health), particularly if a toilet is attached;

(e) Better fertilizer and soil conditioner from effluent, resulting in improved crops;

(f) Less time-consuming than traditional fuels as there is no need to collect firewood or make of cowdung cakes.

The disadvantages at this level include:

(a) High initial capital outlay;

(b) Requirement to have enough livestock to give sufficient dung for the size of plant installed;

(c) Requires water, which sometimes is not readily available;

(d) Reduced gas production during the cold months.

At the *community level* the advantages are:

(a) Reduction in pollution from animal and human waste, resulting in improved community health;

(b) Creation of employment in biogas plant construction and related industries;

(c) Possible power source for village industry;

(d) Improved facilities in the village encourages bright young people to stay in the community and not to migrate to the towns and cities.

One of the disadvantages at this level is that rich farmers are often helped more than poor ones without cattle, thus possibly windening the gap between the rich and poor.

At the *national level* the advantages are:

(a) A saving in foreign currency normally spent on kerosene and fertilizer;

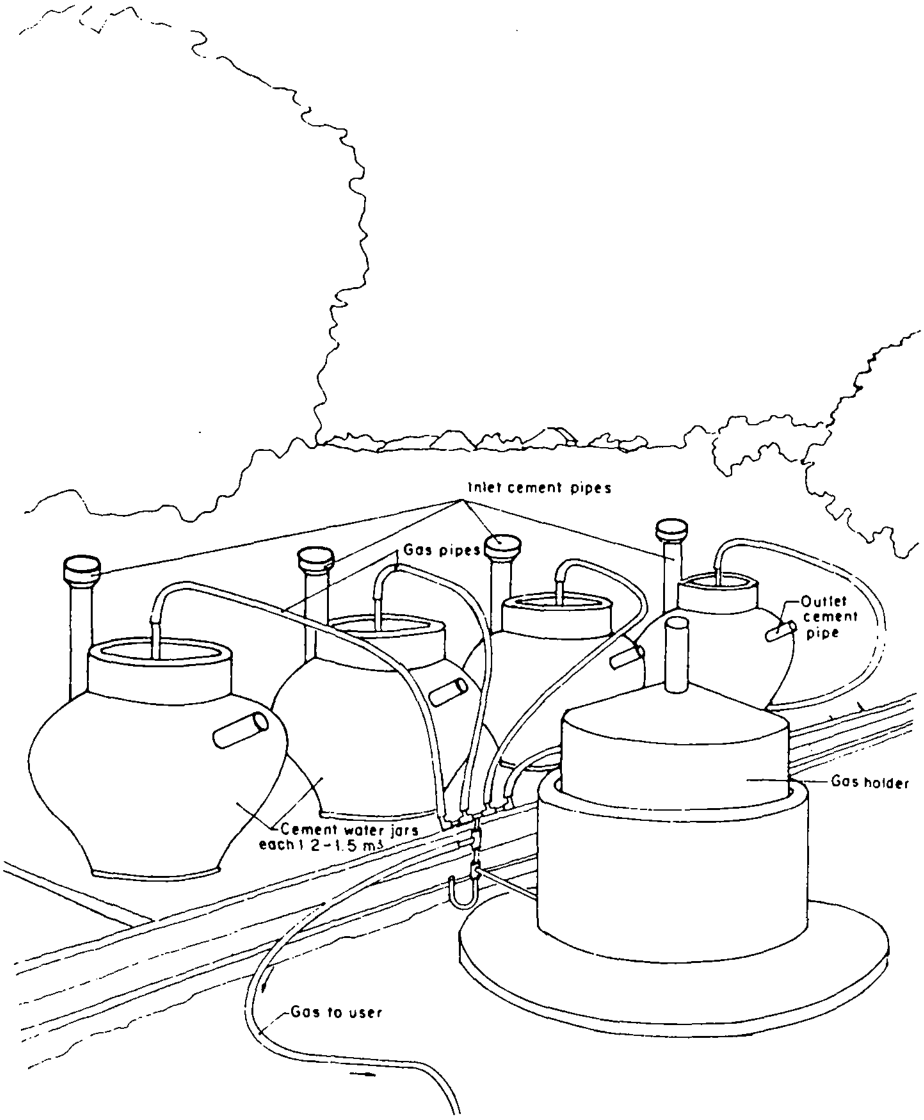


Figure 3. Separate gas holder jar type digester (Thailand)

(b) A reduction in the need for expensive distribution of energy in rural areas and a saving in non-renewable energy resources;

(c) Conservation of forests, thus preventing soil erosion, flash floods, landslides and river silting in the plains;

(d) Minimizing of environmental pollution by utilizing a cleaner energy source.

One disadvantage is that foreign currency is required for any biogas plant, if construction materials are not available in the country.

II. BIOGAS DEVELOPMENT – A REVIEW

A. General

Van Helmont (1630) was the first person to recognise the inflammable gas evolving through putrefaction of organic mass. Shirley (1667) also made mention of marsh gas. Volta (1776) concluded as the result of a series of observations that the evolution of marsh gas is a function of the decay of organic matter. Dalton, in 1804, derived the chemical formula for the inflammable gas, methane.

Bunsen (1856), Hoppe Seyler (1886), Becham (1868), Tappeiner (1882) and Gayon (1884) did work on the microbiological aspects of biogas production. Pasteur (1884) presented the experimental findings of Gayon at the Academy of Sciences in Paris. In 1875, Popoff demonstrated the production of hydrogen and methane from the fermentation of cellulosic material added to river silt. Traub, in 1877, envisaged the process as the transfer of oxygen from one part of a sugar molecule to another.

The use of gas obtained from septic tanks for lighting was demonstrated by Cameron in 1895 in the United Kingdom. A methane digester was installed in Bombay in 1897 to treat wastes and the gas so produced was used for lighting. Since then work on biogas development has continued in India.

The morphological characteristics of the methanobacterium were described by Schengon in 1901. A strain of methanobacteria was isolated by Omelianskii in 1916. The early 1930s saw the intensification of biochemical studies on anaerobic fermentation. In China, biogas was successfully produced and used in 1930. Zhou Peiyuan designed and built a biogas digester in 1936 in Jiangsu province. The technique for calculating the number of methanobacteria was also reported in 1936 by Heukelekian and Heinemann.

In 1950, Hungate established the anaerobic technique developed by Bryant. Further in 1967, Bryant purified *Methanobacillus omelianskii.* Recent work by Wolfe, Zeikus, McCarty and Woose have further added to our knowledge on the subject.

Most countries became aware of the biogas technology by the middle of the twentieth century. However, real interest in biogas was aroused from 1973 onwards with the onset of energy crises, which drew general attention to the depletion of fossil fuel energy resources and the need to develop renewable sources of energy such as biogas. The importance of biogas as an efficient, non-polluting fuel energy source is now well recognized.

International organizations like the Economic and Social Commission for Asia and the Pacific (ESCAP), the Food and Agriculture Organization of the United Nations (FAO), the United Nations Industrial Development Organization (UNIDO), the World Health Organization (WHO) and the United Nations Environment Programme (UNEP) have done considerable work in disseminating and developing biogas technology.

B. Asian and the Pacific region

1. Afghanistan

Biogas development has been initiated through a UNDP-supported biogas demonstration project. It has been proposed that demonstration plants be set up in each agro-ecological zone. Based on the experience obtained with the demonstration projects, extension programmes will be undertaken.

2. Bangladesh

Although research and development work on biogas has been undertaken since 1973 by the Agricultural Universities, little headway has been made in implementation of the programme at the field level. A few demonstration plants have been installed. Bangaladesh Agricultural University organized a training course at Mymensingh during 1981 with the assistance of UNESCO. Many of the plants so far set up are of KVIC design. However, experiments are being carried with fixed dome models. A comprehensive developmental plan, which would involve UNEP assistance, has been drawn up.

3. Burma

Even though Burma is self-sufficient in fossil fuel and fuelwood resources, deforestation, inadequate transportation infrastructure in certain areas and the anticipated increase in the demand of energy sources have necessited taking up measures for the development of alternative and renewable fuel energy sources. Research on various aspects of biogas technology has been conducted by the Central Research Organization for the last 10 years. The Agriculture Mechanization Department of the Ministry of Agriculture and Forestry is one of the main institutions involved in the development of a programme. The Department has developed a semi-industrial type biogas digester with a capacity of 50 m^3/day. In 1981 six continuous floating drum type digesters were constructed on co-operative and meat producing farms. About 40 floating drum digesters were constructed in 1982 in model village No. 1, near Rangoon. Biogas technology research is being carried out by the Agriculture Corporation. The Ministry of Agriculture and Forestry has established a project for biogas production and utilisation. During 1983/84, it is planned to cover 500 villages in 10 states under the biogas development project.

4. China

The first biogas plant was designed and built by Zhou Peiyuan in Jiangsu province in 1936. A movement to popularize the use of biogas in other provinces was initiated in 1950. However, the movement did not gain full momentum. In 1968, efforts were made to revive the programme especially by commune members in the Sichuan province. A remarkable development was achieved by the late 1970s with the necessary support of the Government.

China now has more than 7 million family-size fixed-dome biogas plants of 8-10 m^3 capacity in rural areas, benefiting about 30 million peasants. In addition, more than 36,000 large-scale plants have been built in recent years. Biogas produced from these plants is used for a number of operations such as driving internal-combustion engines, pumping water for irrigation, processing grains, cutting chaff, drying agricultural produce and generating electricity. The largest biogas unit set up is of 2,960 m^3 capacity in Rongxian county of Sichuan province. More than 700 small biogas motive power stations capable of generating power equivalent to 9,200 hp and 600 small biogas electricity stations with 5,000 kW capacity have been established. Anaerobic digesters for treating sewage sludge and night soil have been built in cities in Guangdong, Shandong, Shanxi and Jiangsu provinces. By the year 2000, the number of biogas plants is expected to reach 30 million.

A national office for biogas development and extension entrusted with the responsibility of policy formulation, planning, extension research and training has been set up. Administrative units provided at the provincial, municipal, prefecture and county levels help in the effective implementation of the programme. A number of institutions are engaged in biogas research.

Applied research work on aspects related to biogas technology, such as water hyacinth utilization, operation under cold weather, fermentation technology, and large-scale operation, is in progress at various institutions.

A scientific classification of the country, based on mean monthly temperatures, firewood shortage, resource availability for biogas production, and economic conditions has been attempted. Using these criteria, the classification in terms of priority into different district divisions varies from category A, with a serious shortage of fuelwood, abundant biogas resources and economically well-off to category E, with no shortage of fuelwood, limited biogas resources and poor economic conditions.

Under the Government's policy of promoting the biogas programme, commune members have to pay only for the materials used in building the digesters, while labour expenses are borne by the brigade. The cost of training technical personnel at county, commune or brigade level and carrying out experiments is borne by the State. The people's communes also provide a considerable amount of labour and capital to help commune members to develop biogas. Thus, the financing of biogas digesters in China comes mostly from three sources: (a) the farmers' own income, which covers 20-50 per cent of the total cost; (b) the investment funds of the team, brigade or commune, which cover from 20-50 per cent; (c) Central Government funds as subsidies, which range from 30-40 per cent. Banks also grant low interest loans to commune members to build digesters. Agencies have been identified by the Government to make arrangements for the supply of materials, equipment and needed apparatus.

The Chinese success in developing such a large biogas programme is mainly attributed to: (a) strong support organizations to provide training and advisory services; (b) a growing research system to back up development work; and (c) the vast capacity of the organizational system of rural China (commune, brigade, team and individual households) to mobilize financial and labour resources which would be difficult under individual farming systems.

Two international training courses, sponsored by FAO and ESCAP organized recently for Asian and Pacific countries at the Research and Training Centre, Chengdu, have further helped in the dissemination of technology in the region.

In Taiwan province, biogas development began in the 1960s. As early as 1973, 7500 family-size biogas plants had been established in the province. There are two prevalent designs, viz., a single compartment, double-walled digester, and a two-compartment digester. Bag digesters made of 0.55 mm hypalon laminated with neoprene and reinforced with nylon sheet and PVC inlet and outlet have been developed.

5. India

The possibilities of generating methane from the anaerobic digestion of organic wastes have been explored since 1897 when a methane digester was installed at Matinga Leper Asylum in Bombay. Around 1920, the

Indian Institute of Science, Bangalore, investigated the feasibility of generating methane through the anaerobic fermentation of banana skins and waste paper. At about the same time experiments were conducted at the University College of Science and Technology, Calcutta, on its utilization of water hyacinth for methane production.

The sewage purification plant set up in Bombay in 1930 made use of the methane gas it generated for various purposes like lighting and also for driving motors. Scientists of the Indian Agricultural Research Institute (IARI) visited the plant in 1938 and, thereafter, detailed studies on the production and generation of methane through anaerobic digestion of organic materials were initiated at the Indian Agricultural Research Institute, New Delhi, in 1939. The first small-scale biogas digester using cow dung as a feedstock was built in 1941. A modified design was evolved in 1946.

Meanwhile attempts were being made at other institutions, like Khadi Pratisthan, Calcutta, and by the West Bengal Government to evolve low-cost designs. Experiments were carried out with digesters made from oil drums and also with bamboo thatch cylinders. However, the attempts to use bamboo were not successful owing to leakage problems and destruction of bamboo by rats, other small animals and insects.

The Government's interest in the propagation of biogas programme had increased by 1955. About 500 plants of IARI design were installed with government support. However, the programme was not very successful since many of the plants stopped functioning mostly because of a lack of maintenance and supervision, and faulty designs.

A design named "Gram Laxmi" with a digester and gas holder combined in one unit was evolved by J.J. Patel in 1951. The plant had many new features such as underground construction of the digester, daily loadings, automatic overflow of the digester slurry when new slurry was fed in and provision for breaking the scum layer through rotation of gas holder. The first digester of this type was installed in 1950 at Osmania University, Hyderabad. It was this design which was popularized all over the country by the Khadi and Village Industries Commission (KVIC).

The National Sugar Institute, Kanpur undertook some work on the production of biogas and biomanure from agricultural wastes utilizing the Hungarian semi-wet process. A pilot plant was set up at the Institute in 1960. Another plant was established at Arrey Colony, Bombay. The experience gained with these plants revealed that a plant consisting of underground fermenters, similar to the biogas fermenters using cow dung, could successfully make use of sugarcane wastes. Designs of such underground fermenters for processing agricultural wastes are being further worked out.

The Khadi and Village Industries Commission initiated a biogas development programme in 1961/62. It adopted Patels' design for the programme. The Commission provides incentives for promoting plants in the form of grants and loans. Most of the plants established initially were in Gujarat State. The experience obtained with these plants revealed certain bottle-necks such as high recurring and non-recurring costs, technical problems relating to welding of gas holders, choking of inlet and outlet pipes. It was considered that the cost of the plant needed to be brought down further, especially by replacing the steel parts.

The Planning Research and Action Division of the State Government of Uttar Pradesh established a small research station in 1961, which later on developed as the Gobar Gas Research Station, Ajitmal. The Research Station concentrated on the design and development of continuous-feed and batch-feed biogas digesters. The work was intensified further in 1973. The Station developed a low-cost biogas digester based on a Chinese design, which eliminated use of steel parts. The design was named "Janta Biogas Design". More than 1,000 plants of this design have been constructed since 1980. The Government is currently extending financial incentives for the construction of this type of plant. Efforts are being made to develop suitable designs for large-size community biogas plants. A community biogas plant has been established by the Research Station at Fateh Singh Ka Purwa in the Etawah district of Uttar Pradesh.

A number of other institutions like the Maharashtra Association for the Cultivation of Sciences, the Structural Engineering Research Centre, Roorkee, the Indian Institute of Science, Bangalore, the Department of Physics, Lucknow University, and the Punjab Agricultural University, Ludhiana are engaged in biogas research and development work. The Maharashtra Association for the Cultivation of Sciences is conducting research on micro-biological aspects such as the isolation and identification of microbes from raw materials and slurry, physiological activities of microbes, effect of microbial loadings on biogas production, the use of dry dung cakes for biogas production and so on.

The Indian Institute of Sciences is carrying out studies on the performance of conventional plants, optimization of plant dimensions, reduction of heat losses from gas holders, heating of plant by external resources and so on. The Institute has designed a new type of biogas plant which incorporates a solar water heater and solar still.

The Department of Physics, Lucknow University is carrying out studies in regard to burning velocity, blow off conditions, limits of inflammability of a biogas-air mixture and designing of burners for optimum performance.

The Punjab Agricultural University has evolved a family-size continuous-fermentation plant using household wastes. The plant is being further tested.

IARI, which has been engaged in biogas research work since 1938, is continuing further studies on factors affecting gas output. Research on the utilization of various cellulosic waste materials, stimulation of gas production through use of inoculum and materials like calcium ammonium nitrate, urea and molasses is being conducted. Techniques for production and maintenance of enriched cultures of methanobacteria are being developed and perfected.

The Structural Engineering Research Centre is engaged in the development of economic designs for family-size biogas plants. The use of ferro-cement in place of steel for the biogas holders is a major step in this direction. Other aspects such as the optimum retention period and rate of feed are also being investigated.

The Cotton Research Laboratory, Bombay, is exploring the feasibility of producing biogas from willow dust. Willow is a waste cotton material that is produced in large quantities. The material resembles in many ways cattle manure in its chemical composition. It is intended to use this material for the production of biogas through anaerobic digestion.

The National Environmental Engineering Research Institute, Nagpur, has been engaged in evolvement of suitable night soil digesters. General experience with digesters using just night soil is not encouraging. The main difficulty is that night soil in the digesters either settles to the bottom or if highly fatty, floats: it is difficult to keep it in suspension. The Institute has developed a digester which homogenizes the night soil into a slurry of about 5-8 per cent solids prior to its feeding into the digester.

The Department of Science and Technology and the Indian Council of Agricultural Research, joined by other research institutions, have sponsored biogas research and development programmes. Under the first phase of the co-ordinated multi-institutional project, investigations on cost reduction, plant design, types of feed material, operational parameters, microbiological aspects, fermentation kinetics, designs of gas appliances, and socio-economic aspects have been carried out. In its second phase, the project has initiated work on community biogas plants.

Under the national project on biogas development, initiated by the Ministry of Agriculture, about 58,000 family-size biogas plants were built during the year 1982/83. It is planned to set up 400,000 plants during the period 1981-1985. Along with small family-size plants, it is also planned to set up 100 community biogas plants in the Sixth Five Year Plan period, 1981-1985. Efforts are being made to strengthen monitoring and maintenance services. The main components of the centrally sponsored project relate to subsidies, core staff to State Governments, service charges and provision of turn-key jobs, training of masons and extension workers and the establishment of a national research and development centre for biogas technology.

The FAO/UNDP regional project on improving soil fertility through organic recycling located in India has played a major catalytic role in disseminating biogas technology.

6. Indonesia

The biogas development programme in Indonesia is in the initial stages. Only a small number of plants exist, the reason being fuelwood's is plentifully available in most areas.

The Bandung Institute of Technology, its Bogor Biological Institute and other governmental institutions are engaged in research and development work. Efforts are being made to evolve an efficient model through suitable modification of existing Indonesian and Chinese designs.

Some demonstration units have been set up at places like Denpasar, Petung, Atuag, Bogor, Baruajak and Bali. The units are made of oil drums with floating gas holders. There is opposition to the use of pig dung as a feed stock by the Muslim population.

The Indonesian Board of Voluntary Services is promoting the biogas programme by putting on demonstrations at the village level to convince villagers and village leaders. The Bogor Biological Institute is also launching a biogas programme based on the use of agricultural wastes as a feedstock.

In 1981 the FAO/TCP biogas project was initiated in Indonesia with the objective of setting up a few demonstration units, providing training and preparing a comprehensive programme for incorporation of biogas technology in the integrated rural development programme. The Government is planning to formulate a national biogas development programme, with Bali as the focal development centre.

7. Iran

The Centre for Endogenous Development Studies is engaged in propagating a biogas development programme in western Iran. Trials are being carried out at Niazabad with KVIC-design plants.

8. Japan

In Japan, anaerobic fermentation research and development was viewed more as an anti-pollution measure, rather than as an energy alternative. Since 1973, nationwide efforts have been made to reduce pollution problems resulting from animal, human and industrial wastes. Several institutions like the National Institute of Animal Industry, Chiba, the Public Works Research Institutes, Fermentation Research Institute, Anage, Hitachi Plant Construction, the Ministry of Agriculture, and the Agency for Industrial Science and Technology have been working on anaerobic fermentation of organic wastes.

Big digesters to treat industrial wastes, particularly from alcohol distilleries have been set up. High temperature digestion in thermophilic range, especially for industrial wastes, is being adopted. There are no differences in the quantity of gas produced in thermophilic and mesophilic digestion procedures. However, thermophilic digestion has the advantage that it allows for the reduction of the retention period to five-seven days and makes possible higher loading rates (2.5 times), thus increasing the scope for reduction in digester size.

In 1974, the Sun Shine Project was initiated with the objective of developing new energy technology. Among other subjects the Project includes investigations into anaerobic digestion of animal, human and solid urban wastes.

Interest in small digesters has again been renewed. Small digesters, using a steel tank with an agitator and a water coil for heating the slurry, have been developed. The digester has a double wall for insulation against low temperatures.

9. Lao People's Democratic Republic

A number of demonstration units have been set up with the assistance of FAO, most of them of the Chinese fixed-dome design. A training course on biogas technology has also been organized.

10. Malaysia

Biogas technology is new for Malaysia. Even though there are ample supplies of oil and natural gas, the Government has been giving attention to reducing dependence on conventional energy sources, especially on the part of small land-holders. One of the main hindrances to the propagation of biogas is the religious tradition which prohibits the handling of animal wastes, especially of swine. Many biogas plants have been installed for reasons of sanitation rather than energy production. Some oil palm plantations digest the waste materials as treatment before disposal. However, the gas produced, is not collected.

Research developments in biogas technology are coordinated by the National Institute of Scientific and Industrial Research.

11. Nepal

The country has no proven resources of oil, coal or natural gas and therefore, commercial energy resources have to be imported. The search for cheap alternatives is being continued. Biogas is regarded as an important alternative source.

The first biogas plant was built in 1963 using oil drums. The Development and Consultancy Services of the Butwal Technical Institute, the Department of Agriculture and the Energy Research and Development Group (ERDG) of Tribhuvan University are engaged in research and development of biogas technology. Subjects like plant design modifications to suit various conditions, cost reduction, alternative construction materials, and pressure control devices are being actively investigated. There are more than 1,200 biogas plants, mostly, in the capacity range of 1-3 m^3/day. A few community plants have also been set up.

12. Pakistan

The Federal Ministry of Petroleum and Natural Resources, the Ministry of Natural Resources, and the Appropriate Technology Development Organisation are engaged in biogas development. More than 100 plants of the floating gas-holder type had been set up by 1975. It was planned to set up 1,000 plants during 1981. The Government is providing incentives to the beneficiaries for the plants in the form of free appliances and gas-holders. The Ministry of Natural Resources has plans to create alternative energy sources in 50 selected villages mainly through the establishment of biogas plants. Some 35 biogas plants have been established by the Appropriate Technology Development Organization.

Attention is being given to the development and establishment of fixed-dome design plants because of their lower costs and the non-requirement for steel in their construction.

13. Papua New Guinea

Work on integrated biogas systems, which include necessary provisions for the utilization of effluent for growing algae and acquatic plants, pisciculture and fertilizer has been in progress since 1970. A bag-digester type of plant, much cheaper than the conventional design, is also being developed. The digester is made of 0.55 mm thick hypalon laminated with neoprene and reinforced with nylon sheet.

14. The Philippines

Interest in biogas development grew with encouraging reports of the official mission of the Philippine Coconut Administration after its return from a European tour in 1965.

In earlier days, the main interest in biogas stemmed from its pollution prevention and public health aspects rather than from its fuel energy generation potential as firewood was plentifully available. Now biogas is considered as the most feasible form of renewable energy resource for rural areas. A variety of feedstock consisting of domestic urban wastes, agricultural and animal wastes and food processing, distillary and industrial wastes are available for biogas generation.

Maya Farms owned by Liberty Flour Mills has been the pioneer in the development of biogas technology since 1972. In order to obtain the necessary experience and to assess the suitability of different types of plants, demonstration models of Indian, Chinese and European types were set up. The models were later modified and used as pilot plants. A farm workers' dormitory night soil biogas digester has also been designed. Biogas produced at the farm meets 40 per cent of the total power requirement of the farm and is used for home applications, cooking vats in the canning plant, operation of an alcohol still, fuelling of burners for heating retorts and gasoline engines, running a feed mill, operating a 60-kVA electric generator and running farm vehicles.

The organizations engaged in extension of biogas technology are the National Housing Authority, the Engineering Battalion of the Military, and the Department of Community Development. The Development Bank of the Philippines grants loans to farmers at low interest rates.

As a part of the development efforts, a "crash programme" aimed at establishing plants in every region, province, town and locality, was initiated as early as 1976. More recently, the Bureau of Animal Industry (BAI) in co-operation with the Energy Development Board, launched the Biogas ng Barangay programme in 1980. Loans are made available to livestock owners through financial institutions. Demonstration projects at the regional and provincial levels have been established by BAI. About 450 plants have been established under the programme. Fresh pig manure availability is estimated at 8.9 million metric tonnes per year, indicating a biogas production potential of 502 million m^3 per year. The Indian design with a floating gas-holder is more popular. Recently, 10 digesters with a fixed-dome design have been established.

The National Institute of Science and Technology (NIST), University of Philippines, Central Luzon State University and Maya Farms are the institutions actively engaged in research. Various aspects such as optimum requirements for biogas production, loading rates, feedstocks and their suitability, and microbiology are being investigated. Ten methanogenic isolates to be used as starter culture have been developed by NIST. Integrated biogas systems which involve cultivation of algae, fish and rice as components of the system are being developed at the University of Philippines.

15. Republic of Korea

The Institute of Agricultural Engineering and Utilization, the Rural Guidance Bureau of the Office of Rural Development (ORD) and the College of Agriculture undertake research, development and extension. The Rural Guidance Bureau provides technical assistance and financial loans to farmers. However, there is no regular loan system and a 33-50 per cent governmental grant system has been discontinued. Most of the biogas development programme is being undertaken by the farmers themselves.

Rapid urbanization and the shortage of animal wastes slowed down the construction of family units in rural areas. The emphasis has shifted to the establishment of village-size units, gas storage and purification, and power generation.

Many of the plants are not operated during the cold months, viz. December – March, when temperatures drop as low as –17°C. Various attempts to maintain the temperature of the gas-holders through the provision of protective covers of straw or vinyl did not meet with much success. Provision of heating for the smaller plants was not justified. Conditions are more amenable in the southern part of the country which remains comparatively warmer during winter months.

ORD has helped install more than 30,000 small plants in the country by 1975. Farmers are not totally dependent on biogas for their energy needs. It supplies only 3-6 per cent of home heating, and less than half of the cooking needs. Each farming family has a cooking fire in addition to an unmodified LPG burner for biogas. The change of emphasis to large village-sized plants is intended to provide for most of the heating, cooking and power needs. Cow and pig excreta are the main feedstocks.

ORD is engaged in the development of village-scale digesters. A 40-family, 155 m^3 digester is operated at the Livestock Experiment Station, Suweon established under the Korea-UK Farm Machinery Project. The plant utilizes 2.4 tonnes of dung obtained from poultry and 170 cattle and has a retention time of about 40 days. Part of the gas is used to heat the digester to maintain the optimum temperature. Many more such units are being set up. Experiments are continuing on the use of biogas in kerosene engine applications and home heating. The Institute of Agricultural Engineering and Utilization is experimenting with PVC and concrete fixed-dome digesters. The College of Agriculture, Suweon, is working on a two-stage digester of reinforced plastic insulated with paddy husk. Use of night soil in biogas plants is also receiving attention. A plant using night soil as a feed-stock is operating in Kyong Jushi.

16. Singapore

There is not much scope for small-scale biogas plants in Singapore. Biogas produced at the sewage treatment works is used for operation of dual-fuel engines to generate electricity.

17. Sri Lanka

Of the total energy consumed, 60 per cent derived from fuelwood. Some 80 per cent of the fuelwood is used in the rural areas. The forest reserves are being depleted and the availability of fuelwood is declining. Interest in various non-conventional energy sources, e.g. wind, biogas and waste materials, is developing.

A demonstration plant was established by the Industrial Development Board as early as 1974. Further research work is being carried out at the Peradeniya and Katubedda Universities. Biogas digesters are being established in a rural village under the Asian Rural Energy Project with the assistance of UNDP. Recently, two technicians underwent training in biogas technology in China. An integrated farming system with biogas as a component is being developed at the In-service Training Institute at Gannoruwa.

18. Thailand

Thailand obtains 74 per cent of its energy requirement from imported petroleum and so development of new and alternative energy resources is receiving attention. Besides energy considerations, sanitation is one of the important aspects responsible for biogas promotion. In earlier days, it was only the Department of Health that engaged in biogas development with the objective of controlling disease carriers like fruit and house flies. A number of other government agencies such as the Division of Agricultural Economics, the Department of Agriculture, the Applied Scientific Research Corporation, Mahidol University and Kasetsart University are now engaged in the development and promotion of biogas technology. There are 4,500 biogas plants in operation in Thailand. A large biogas development programme has been drawn up by the Government and it is planned to set up 50 plants every year. Agricultural banks provide loans for digester construction. Research and development work is in progress at many institutions.

19. Viet Nam

Tuliem Agricultural Station and the Institute for Electricals and New Energies, Hanoi, are involved in biogas research. Aspects like use of local construction materials, design of clay burners, and the use of different feedstocks and their mixtures are being investigated. A few demonstration units in different regions have been established. Two technicians have been trained in India under the FAO/UNDP programme. A national biogas development programme is being considered by the Government.

C. Latin American region

Very little information on biogas development is available for this region. The available information for various countries of the region is summarized below.

1. Argentina

A field extension programme is yet to be taken up. Prototypes of digesters are being developed at some institutions. The National Agricultural Technology Institute and the National University, Tucuman, are engaged in biogas technology research.

2. Brazil

The National Technology Institute has established prototype biogas digesters. Experimental plants to examine the feasibility of generating biogas from urban and industrial wastes have been established in Sao Paulo. Compania de Desenvolveimento Technologico and Centrais Electricas Brasilerras S.A. are conducting research on various aspects of biogas technology.

3. Chile

A few prototype biogas digesters have been established and various aspects of the technology are being investigated.

4. Colombia

The National University and the research and development unit, Regional Ecosystems, are engaged in development of prototype digesters. A prototype anaerobic digester for coffee pulp has been developed.

5. Costa Rica

Research and development work is being undertaken at the Institute Technologico de Costa Rica. Biogas digesters developed by the Institute are being tested further.

6. Guatemala

The first biogas plant was constructed in 1953 at the University of San Carlos de Borromeo. By 1958, technological advances in regard to the utilization of biogas for operation of gas ranges, generators and automobiles had been made. Anaerobic digesters for processing coffee pulp, sugarcane bagasse and sawdust have been evolved. The Mesoamerican Appropriate Technology Centre and the Central American Industrial Research and Technology Institute have developed prototypes for use on a commercial scale.

7. Mexico

Prototype digesters for demonstration and experimentation have been established by institutions like the Metropolitan Autonomous University, Xochimilco, Michoacan University, San Nicolas Hidalgo, and the Electric Research Institute. A community biogas plant with 35 m^3 capacity has been established. Institutions like Ecodevelopment systems and Bioconservacion S.A. are also engaged in biogas research.

8. Peru

Biogas technology has not received much attention so far.

9. Trinidad and Tobago

The Government of Trinidad and the University of West Indies (Chemical Engineering Department) are conducting biogas research. Efforts are being made to develop a suitable anaerobic digester for sugarcane bagasse.

D. European and other countries

1. Austria

Not much information is available in regard to biogas technology. A few plants based on the Darmstadt design were set up. However, they did not function properly.

2. Belgium

The State Agricultural Research Institute, Gembloux, initiated biogas research in 1942. Some large size digesters (30-75 m^3) were in operation in 1952. The Government laid some stress on biogas development during the period 1949-1952. Interest in biogas technology declined after the 1950s mainly due to its having been found uneconomic in Belgian situations.

3. Czechoslovakia

A 100 m^3 digester was reported to be in operation in Levocskych Lu'Kach in 1955. Attempts were made to improve and mechanize some French designs. Interest in the technology, however, seems to have waned away subsequently.

4. Denmark

Based on the experience of the Federal Republic of Germany, a few digesters were reported to have been set up in Denmark in 1952. The operation of these plants was however, not found to be very satisfactory. The investment costs were also considered to be high. Therefore, not much progress could be made.

5. France

In 1883, Gayon, a pupil of Pasteur demonstrated that energy can be generated through anaerobic fermentation of organic substances. Dubaquie in 1931 suggested digester designs for biogas production. In 1938, Isman and Ducellier started their work at the Ecole Nationale d'Agriculture in Algeria. Patents for digester designs evolved by them were applied for in 1941 and 1942 in France. Both of them worked on the feasibility of using various vegetative wastes, the microbiology of the process and the digestion of manure and vineyard stalks. By 1948, a number of commercial firms had become active in the construction of digesters. There were between 500 and 1,000 digesters in France in 1949. Meanwhile work relating to cost reduction was being conducted by the Société Centrale d'Approvisionnements aux Agriculteurs de France (SCAAF). Prefabricated elements and reinforced concerete were used for the construction of digesters. Another firm, Salubra was also active in building digesters. The Provincial Department of Agriculture (Le Génie Rural) granted 50 per cent subsidy towards the cost of installations during 1951-1952. The Suez crisis provided an opportunity for focusing national attention on measures for self-sufficiency in energy. Therefore, a mission was sent to the Federal Republic of Germany in 1958 to investigate the prospects of energy generation through anaerobic fermentation but made no optimistic conclusions. In recent years there have not been many developments in regard to the extension of the technology.

6. German Democratic Republic

Progress in biogas development have followed the developments in the Federal Republic of Germany. However, not many plants have been set up. At the University of Jena it was found that in thermophilic digestion, the hygienic properties of manure improve further, digestion is quicker and extra heating costs are compensated for better. In the 1950s the Technical University, Dresden, undertook research and development work on biogas technology, Various modifications of the Allerhop design were tried to assess their suitability. Cost reduction and gas storage studies were made. A gas storage system consisting of a gas sack made of cotton and rubber with pressure devices was developed. However, by the end of the 1950s less emphasis was placed on the programme mainly owing to its having been found uneconomic.

7. Federal Republic of Germany

There has been much interest in the development of biogas technology from 1945 onwards. A symposium was held in May 1947 at Ludwigsburg. Initial work on the generation of biogas through sewage treatment was taken up by Imhoff and Popel. Later, it was realized that the experience obtained with sewage sludge digestion was of little use when agricultural wastes were to be used for digestion. A number of institutions like the Technical University, Berlin, the Technical University, Darmstadt, the Institute for Soil Science and Agricultural Chemistry, Göttingen, Hohenheim University, München University, the Technical University, Hanover, the Federal Research Institute for Agriculture, Volkenrode, and the Kuratorium für Technik in der Landwirtschaft, Frankfurt, are engaged in research and development work. Many types of designs like "Darmstadt", "Berlin" and "Hanover" were evolved for small-scale application, 'München', "Hohenheim" and "Untersontheim" were for medium-scale application and "Allerhop" for large-scale use. Most of the designs had some provision for heating the digester contents. All the designs except "Allerhop" proved to be very sophisticated. The designs were displayed from time to time for the information of the general public and farmers but did not generate much interest. In terms of energy production an anaerobic digester was not an economical proposition especially on a small scale.

The large-scale "Allerhop" design was the most successful one and was produced as an effective way of processing manure in liquid form at minimum labour costs. Gas collection was considered a secondary objective. Around 50 digesters with an annual gas production capacity of 18,000-300,000 m^3 were reported to have been set up. In most cases, gas production is used only for heating the digesters and driving central motor pumps.

8. Hungary

Work on biogas technology started in the year 1956 at the Institute of Heat Transfer at Budapest. In 1958, research and development work was taken up at the Agricultural University, Szekers, the Research Institute for Soil Science and Agro Chemistry, and the State Design Office of Civil Engineering. Many aspects, such as the fertilizer value of digested manure, optimum conditions for digestion and techno-economical feasibility of various designs, were investigated. However, not many of the anaerobic digesters set up in Hungary seem to be in operation.

9. Italy

Interest in methane generation started from 1910. In that year, biogas was used to run a motor pump. An indigenous plant design was developed in 1941.

Although the technology has been developed, owing to practical and economic problems, not many digesters were installed during the Second World War period. Many digesters, mostly of large size, were reported to have been set up during the period 1950-1955 for such institutions as schools, universities and monastries. These large installations were provided with cranes for loading and unloading. Some commercial biogas manufacturing concerns, like Biogas and Pergas, were established. Turin and Milan Universities have been carrying out biogas research. As in other parts of Europe, interest in anaerobic digesters at the farm level diminished after 1958.

10. Poland

Some work was taken up in 1955, starting with investigations concerning the reduction of nutrient losses, especially nitrogen, in processing manures. A few pilot plants were set up in Skierniewicach around 1960 to investigate the kinetics of digestion at different temperatures and solid concentrations, along with manure quality.

11. Spain

Interest in anaerobic digestion developed much later than in other parts of Europe. The National Agricultural Research Institute, Madrid, has conducted biogas research. A few batch type digesters based on a French design were established. However, not much information is available on their performance.

12. Switzerland

A design for a biogas plant was developed in 1943. However, not very many digesters have been installed. The Swiss State Agricultural Research Institute has been working on the technology. Anaerobic digesters have been found to be uneconomical in Switzerland.

13. Union of Soviet Socialist Republics

The first digester seems to have been set up in Georgia in 1948. During the 1950s, biogas research work was taken up at institutions like the All-Union Research Institute of Fertilisers, Agronomy and Soil Science, Moscow. A large-size experimental plant has been in operation in Tulskoi since 1957. The digester design is similar to the "Allerhop" or "Dresden" designs. Between 30 and 60 per cent of the gas produced is used for heating the digester. Five large-scale biogas digesters are known to have been in operation in 1958. However, these installations were found uneconomic later.

14. United Kingdom of Great Britain and Northern Ireland

As early as 1929, a plant was developed and installed at Rothamsted. The plant had a large 300 m^3 digester using straw and manure as feedstock. No other reports on working of large-scale digesters are available and it is considered that setting up large-scale digesters was found to be not economical.

A small-scale digester was developed in 1954 by Tolle Mache. At the same time British Organic Products developed another small-scale design. However, the experience obtained with these plants has not been very encouraging. In a joint report prepared by the representatives of the Rothamsted Experimental Station, the National Agricultural Advisory Service and the Agricultural Land Service in 1958, it was concluded that though the process was technically sound, it was not economical, Similar conclusions were drawn in another report prepared by the National Institute of Agricultural Engineering in 1961.

15. United States of America

There has not been much interest in the development of small-scale biogas plants mainly because of the ready availability of commercial energy sources. However, research was motivated on account of several of factors particularly concerning pollution control. Institutions like the State Water Survey Division, Illinois, the United States Department of Agriculture; the Biological Waste Laboratory, Beltsvelle, and the Iowa State University have been involved in basic biogas research. Many important contributions regarding the theory of anaerobic fermentation, and the digestive properties of organic wastes have been made. Interest in biogas generation through anaerobic fermentation declined as it was found to be too expensive to compete with other kinds of fuel. In the early 1960s, interest was revived but the emphasis was on anaerobic digestion of animal wastes generated at large animal farms.

III. THE PROCESS OF BIOGAS FERMENTATION

A. Biogas process

Biogas fermentation is a three-stage process, viz., hydrolysis, acid producing and gas producting, and is accomplished by four classes of microbes. These are:

(a) Fermentative bacteria;
(b) Obligate hydrogen-producing, acetogenic bacteria;
(c) Methanogenic bacteria;
(d) Homoacetogenic bacteria.

1. Hydrolysis

Exoenzymes, produced by the fermentative bacteria, hydrolyse the organic compounds. In this step polysaccharides are hydrolysed into monosaccharides, proteins into peptides or amino acids and fats into glycerol and fatty acids. The polymers, converted to individual monomers, are fermented to various intermediates, primarily acetate, propionate and butyrate. The kind and quantity of bacteria in the digester undergo change with the type and quantity of organic materials involved.

2. Acid production

In this step higher fatty acids and aromatic amino acids produced at the first stage undergo catabolism to yield hydrogen and acetic acid.

3. Gas production

Simple compounds like acetic acid, hydrogen, formic acid and carbon dioxide are used by the methanogenic bacteria to form methane and carbon dioxide.

B. Methane formation

Van and Niel in thirteenth century proposed that under all conditions, methane-producing organics must be converted to carbon dioxide and then reduced forming methane.

$$\begin{array}{lcl} 4\ H_2A & = & 4A\ +\ 8H \\ 8H + CO_2 & = & CH_4\ +\ 2H_2O \\ \hline 4H_2A + CO_2 & = & CH_4\ +\ 2H_2O \end{array}$$

In the equation, H_2A represents compounds capable of being used by biogas microbes, and carbon dioxide is generated from substrate oxidation.

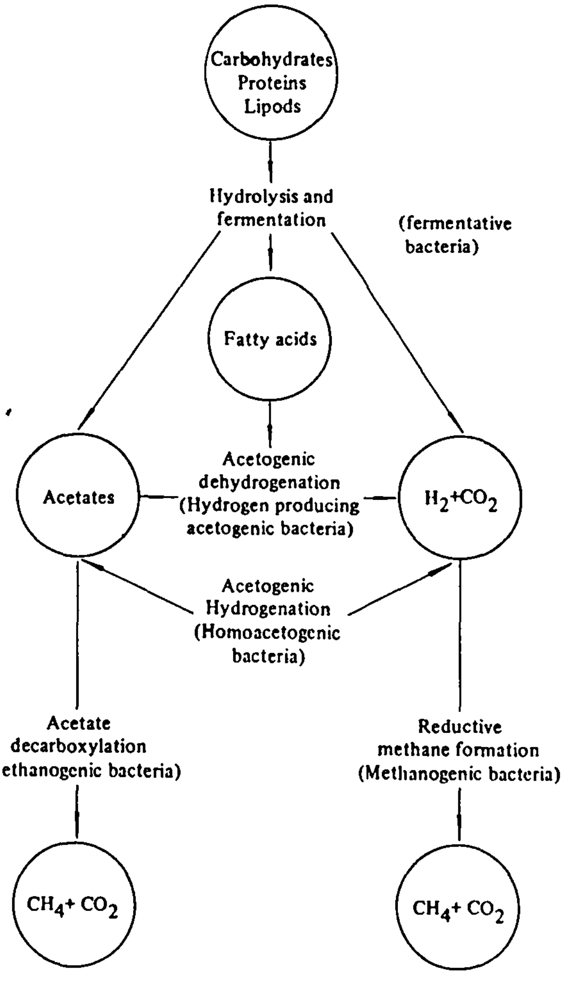
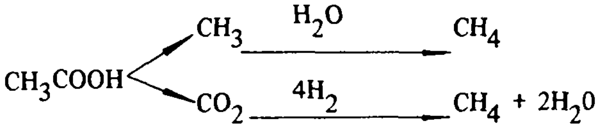


Figure 4. Biogas fermentation process.

According to another theory developed by Buswell and Sollo in 1948, methane can be generated directly from the methyl group.

$$14\ CH_3COOH \longrightarrow 14CH_4 + CO_2$$

Currently, it is considered that methane formation takes place through two pathways. While on the one hand, the methyl group of acetic acid is reduced directly to form methane, the carboxyl group of acetic acid is first converted to carbon dioxide, and then is reduced further to form methane.



$$CH_3COOH \begin{cases} CH_3 \xrightarrow{H_2O} CH_4 \\ CO_2 \xrightarrow{4H_2} CH_4 + 2H_2O \end{cases}$$

Barker proposed a hypothesis based on these theories. According to the hypothesis, under anaerobic conditions,, carbon dioxide methanols or acetates, all should be converted to CH3 X which can be further reduced to form methane.

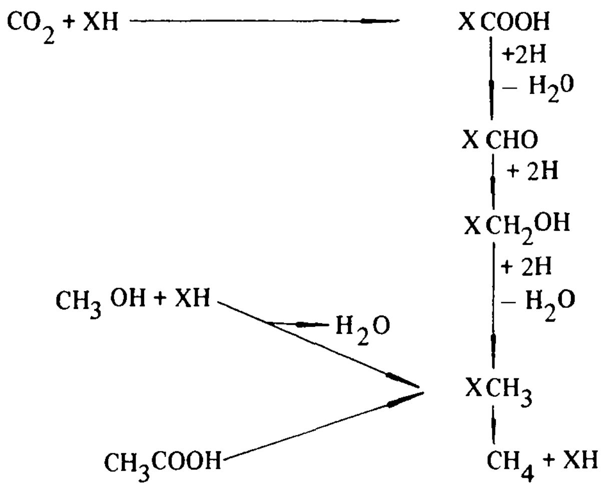


Figure 5. Methane formation (XH = unknown carrier)

C. Metabolism of complex organic compounds

During the process of anaerobic fermentation, polysaccharides, proteins and fats are commonly converted into acetic acids. Polysaccharides and fats may be converted into propanic acids, which turn into acetic acid. Ultimately, the acetic acid is converted into methane.

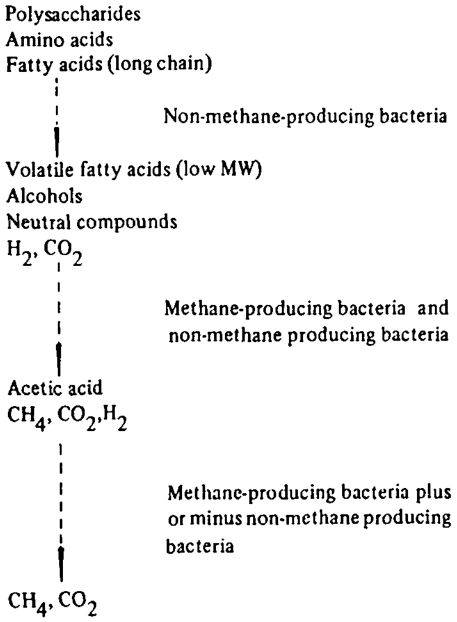


Figure 6. Metabolism of complex organic compounds.

Polysaccharides, viz., cellulose, hemi-cellulose, starch, xylose etc., are the main materials for fermentation. Under anaerobic conditions, polysaccharides are hydrolysed to glucose, which undergoes anaerobic glycolysis to form pyruvic acid. It has been suggested that in biogas fermentation, glucose may metabolize through a pentose phosphate pathway to form glycerol phosphate and then pyruvic acid. Pyruvic acid, the principal intermediate may then be split into various products such as formic acid, ethanol, lactic acid, propanic acid and acetic acid. Acetic acid is easily converted into methane and two thirds of methane is formed from acetic acid.

Each molecule of glucose can produce three molecules of methane and three molecules of carbon dioxide.

$$C_6H_{12}O_6 \dashrightarrow 2CH_3\,COCOOH + 2H_2$$

$$2CH_3CO\,COOH + 2H_2O \dashrightarrow 2CH_3\,COOH + 2CO_2 + 2H_2$$

$$2\,CH_3\,COOH \dashrightarrow 2CH_4 + 2CO_2$$

$$CO_2 + 4H_2 \dashrightarrow CH_4 + H_2O$$

$$C_6H_{12}O_6 \dashrightarrow 3CH_4 + 3CO_2$$

The overall metabolic pathways of glycolysis are as follows shown in figure 7.

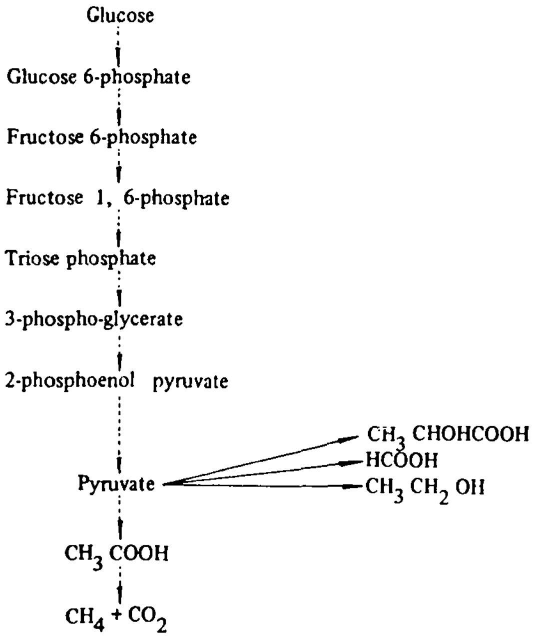


Figure 7. Anaerobic degradation of glucose.

D. Anaerobic degradation of cellulose

Cellulose together with hemi-cellulose constitutes about 50-60 per cent of the total solids of straw and 30-50 per cent of those of dung resources. Pure cellulose is easily degraded by biogas microbes, while naturally occurring ones, due to its combination with lignin etc., are not easily split by the microbes.

Through the action of enzymes, cellulose is hydrolysed into glucose. The enzymes are of two kinds, one is an exoenzyme dissolved in the fermenting fluid and the other is a cell surface bonded enzyme.

In the process of fermentation, butyrate-utilizing microbes grow tremendously. When the fermentation is blocked, there is a marked increase in the amount of butyric-acid and acetic-acid-utilizing microbes which may increase their number thousands of times. The following splitting pathway is indicated:

glucose → butyric acid → acetic acid → methane formation

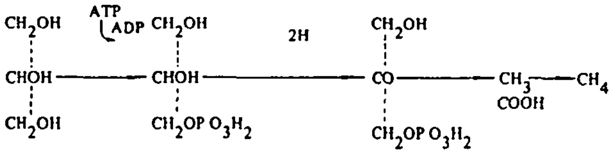
E. Metabolism of hemi-cellulose, pectin-gel and starch

Under anaerobic conditions, hemi-cellulose, pectingel and starch are hydrolysed into pentose and hexose, which undergo further degradation as in the saccharide fermenting process.

Some of the materials commonly used for biogas fermentation contain large quantities of lignin. Pig dung contains about 21 per cent lignin in its solid contents, cow dung about 35 per cent and rice straw about 12 per cent. Lignin is hardly degraded by micro-organisms.

F. Metabolism of lipids

Fats are hydrolysed into glycerol and fatty acids. The glycerol is furthur converted into dicarboxyl-phosphoacetone and thereafter to pyruvic acid.



Fatty acids metabolise through an oxidation pathway forming acetoacyl-coenzyme A (CH_3 CO-S CoA) and then acetic acid. The hydrogen released in oxidation can be reduced to form methane.

G. Metabolism of proteins

In biogas fermentation, proteins are hydrolysed into peptides or amino acids. Peptides and amino acids can be either utilized by microbes for synthesizing cellular substances or further degraded into lower molecular weight fatty acids, H_2S, amines, phenols, ammonium etc.

Low molecular volatile fatty acids and amine can further be converted to form methane. Ammonia can either be utilized as a nitrogenous source for synthesizing cellular components or forming ammonium bicarbonate (NH_4HCO_3), thereby the HCO_3^- ion is increased, raising the buffer capacity in the fermenting fluid and favouring methane formation.

proteins → amino acids $\xrightarrow{NH_3S\text{ etc.}}$ acetic acid → CH_4

IV. MICROBIOLOGY OF BIOGAS FERMENTATION

A. Biogas micro-organisms

Micro-organisms involved in biogas fermentation include organic material-splitting organisms commonly called non-methane producing organisms, and methane producing organisms. These microbes degrade complex organic materials to form methane. The combined and co-ordinated metabolic activity of these microbes is essential for the fermentation process to proceed effectively. The excess or lack of any of the groups or their activity results in failure of the fermentation process.

Biogas microbes can be categorized into four trophic groups:

(a) Fermentative bacteria that hydrolyse saccharides, proteins, and lipids;

(b) Hydrogen-producing acetogenic bacteria which act upon fatty acids and neutral end products;

(c) Homoacetogenic bacteria which metabolize unicarbon compounds (e.g. H_2/CO_2 or HCOOH) besides hydrolysing multicarbon compounds to acetic acid;

(d) Methanogenic bacteria which metabolize acetate and unicarbon compounds to form methane.

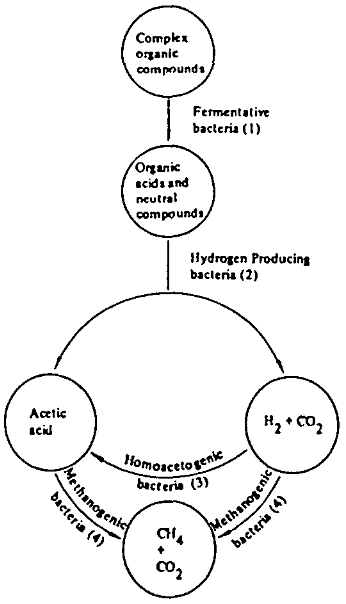


Figure 8. Involvement of different microbial population groups in biogas fermentation.

B. Non-methane producing micro-organisms

Non-methane producing microbes convert complex organic compounds into simpler compounds. This group consists of the fermenting bacteria and the hydrogen producing, acetogenic bacteria. The micro-organisms involved in this group include anaerobes and facultative anaerobes. The varieties and amount of these micro-organisms change with the variety and quantity of materials under fermentation.

Non-methane producing micro-organisms may be divided into three groups, bacteria, fungi and protozoa. Among these groups bacteria are the most important.

1. Bacteria

Non-methane producing bacteria are of numerous types and their amount is also large. However, the microbes having hydrolytic activity account for only a small group in the overall colonies. Among the population capable of hydrolysing organic compounds, the obligate anaerobes dominate and their population is 100 to 200 times that of faculative anaerobes.

The obligate anaerobes play an important role in the process. Included in this group are bacteria like *Clostridium butyricum, Bacillus lactum,* Gram's positive cocci and a few others.

Non-methane producing bacteria can be divided into seven groups based on their physiological activities, viz., cellulose-splitting, semi-cellulose splitting, protein splitting, fat splitting, hydrogen producing and other specific groups such as thiovibrio- and lactic acid-utilizing.

2. Fungi

A great number of fungi and yeasts have been isolated from anaerobic digisters. Cook isolated 36 genera of fungi. The fungi and yeasts take part in the digestion process and get their nutrition through the decomposition of substrate.

3. Protozoa

The main species of protozoa that have been isolated belong to the plasmodium, flagellate and amoeba groups. In all 18 species have been identified. However, their quantity is small and they are supposed to play only a minor role in the digestion process.

C. Amount of non-methane producing micro-organisms

The number of bacteria in several digesters has been found to be $39 \times 10^7 - 10^9$/ml for obligate non-methane producing bacteria, and $8 \times 10^5 - 1 \times 10^8$/ml for aerobes and facultative aerobes. The amount of anaerobic bacteria is often 100 times that of aerobic ones.

The quantities of physiological groups have been reported by many workers. Hungate (1950) reported a population of $0.8 - 2.0 \times 10^3$/ml anaerobic cellulose-splitting bacteria in digesting sludges. The number in domestic wastes was found to be 4×10^5/ml. The amount of semi-cellulose-splitting bacteria was similar to that of cellulose-splitting bacteria, being 10^4/ml or a little more. The amount of protein-splitting Gram's positive bacteria in sludges under digestion has been reported as 7×10^4/ml. Sulphur-reducing bacteria in digesting sludges have been found to be in the range of $3–5 \times 10^4$/ml. The population of lactate-utilizing bacteria in pigsty waste has been indicated as 3×10^7/ml. The amount of aerobic protein-splitting bacteria and aerobic fat-splitting bacteria in digesters have been reported as $1–10 \times 10^5$/ml and $2–16 \times 10^4$/ml respectively.

D. Action of non-methane producing micro-organisms

The carbohydrates, proteins and fats are catabolized into soluble, simpler compounds by the non-methane yielding micro-organisms through the liquification process. These simpler compounds undergo further change, after entering the bacterial cells, and ultimately yield organic acids, alcohol, ketones, carbondioxide, hydrogen, ammonia, hydrogen sulphide etc.

Cellulose-splitting bacteria break cellulose into smaller compounds of low molecular weight, to be utilized by methanogenic bacteria to yield methane. These bacteria are similar to *Bacteroides succinogenas.* Under anaerobic conditions, *Clostridium omelianskii, Cl. thermoceilum, Cl. dissolvens* and similar group members split cellulose to simpler compounds.

Another group of bacteria split semi-cellulose to produce xylose, arabinose, galactose and mannose and are known as semi-cellulose-splitting bacteria. These belong to *Bacteroides ruminicola.*

The starch-splitting bacteria break down starch to form glucose. The amount of starch-splitting bacteria is related to the starch content of the fermenting material. From pigsty wastes, bacteroides, Gram's positive cocci and *Bacterium butylicum* were isolated. *Clostridium acetobutylicum,* which catabolises starch to acetobutanol, butyric acid, acetic acid and hydrogen, has been isolated from underground sludge.

Protein-splitting bacteria break down protein to amino acids, to be degraded further into organic acids, thioalcohols, ammonium and hydrogen sulphide. These bacteria are mainly Gram's positive ones predominant with *Clostridium.*

The fat-splitting bacteria catabolize fats to produce short-chain fatty acids. Vibrio has been found to be the richest among the group. There are also some bacillus, alcaligenes and monas.

A number of products like alcohol, volatile salurated organic acids like butyric acid and propanic acid cannot be used by methane-producing bacteria, unless they are converted into acetic acid, carbon dioxide and hydrogen. The hydrogen-producing acetogenic bacteria degrade propionate, long-chain fatty acids, alcohols, and aromatic and other organic acids to produce acetate, hydrogen and carbon dioxide. Chengdu Institute of Biology, China, has isolated 24 strains of hydrogen-producing bacteria from biogas digesters, belonging to *Enterbacteriaceae* and *Bacillaceae* families.

There are a number of other bacteria which take part in anaerobic digestion such as sulphate-reducing bacteria and lactic-acid utilizing bacteria which include *Streptococcus sp., Bacteroides sp.* and *Clostridium sp.*

E. Methane producing micro-organisms

Methane producing bacteria are the key organisms in methane production. These organisms break down acetate and hydrogen to gaseous end-products. They are very sensitive to oxygen and oxides and require a strict anaerobic environment for growth.

Methane producing species utilize simple organic and inorganic compounds as substrates. Most of them require only mineral salts with carbon dioxide, ammonia and a sulphide as extraneous minerals Acetic acid is a critical substrate accounting for about 74 per cent of the substrates. Amino acids or peptides are not required as nitrogen sources for growth but ammonia is essential. For their sulphur source, some species can make use of cysteines instead of sulphides. Methanogens are slow in their reproduction and growth, doubling time usually ranging from four to six days.

F. Morphology and classification of methane producing micro-organisms

According to their forms, methanobacteria can be divided into four groups, viz., octanococcal, bacillar, globular and spiral.

Methanosarcina are variations in the envelops of this group. Their shape and size are different from those of true sarcina and give an appearance of sand particles piled together.

Methanosarcina Barkeri

Methanobacterium ruminantium

Methanococcus

Methanospirillum

Figure 9. Morphology of methanobacteria

Methanobacillus are bacillar, usually curved, like a chain or a long filament. However, *M. arbophiccum* is short and straight.

Methanococci have globular round or oval-shaped cells, which are paired or chained.

Methanospirilla cells appear regular, curved and finally form spiremes.

Methanogens have been grouped into three orders, nine families, seven genera and 13 species (see table 2).

G. Amount of Methane producing bacteria

The amounts of methanobacteria in digesters have been reported as $10^6 - 10^8$/ml. In a fermenting sludge digester, the following population has been observed:

Formate methane producing bacteria	$>1\text{x}10^{7}$/ml
Methanosarcina barkeri	$>1\text{x}10^{6}$/ml
Methanobacterium sp.	$>1\text{x}10^{8}$/ml
Methanococcus sp.	$>1\text{x}10^{6}$/ml

Table 2. Classification of methanobacteria

Order	*Family*	*Genus*	*Species*
Methanobacteriates	Methanobacteriaceae	Methanobacterium	M. formicicum M. bryantii M. thermoautotrophicum
		Methanobrevibacter	M. ruminantium M. arboriphilus M. smithii
Methanococcates	Methanococcaceae	Methanococcus	M. rannielii M. voltae
Methanomicrobiates	Methanomicrobiaceae	Methanogenium	M. caraci M. marisnigri
		Methanospirillum	M. hungatei
		Methanomicrobium	M. mobile
	Methanosarcinaceae	Methanosarcina	M. barkeri

V. FACTORS AFFECTING GAS PLANT DESIGN AND OPERATION

There are many biogas plant designs and most work well. They are illustrated in the next chapter. However, it is important to select the right type and size of plant in a particular case. One type made in various sizes may be used in a country if conditions are fairly uniform. Examples showing how to use the information given in this and the next chapters are included in chapter VII on design, size and site selection.

A. Social factors

1. The benefits of a biogas plant

The three main benefits are gas, fertilizer (compost) and hygiene. Most people in ESCAP countries want the gas. The fertilizer benefit is of secondary importance. However, as time goes by, more and more emphasis is being placed on the fertilizer benefit. Hygiene is hardly considered. In China the main benefits are fertilizer, gas and hygiene. Other benefits are the saving of firewood for other uses and an increase in crop yield (due to an increase in the amount and improvement in the quality of fertilizer).

2. The national characteristics of farmers

Every country has its own national characteristics. In some countries the farmers, as a whole, are industrious and ingenious. They do not mind maintaining and improving their equipment. In other countries the average farmer takes life in a much more leisurely way or does not have the materials, knowledge or initiative to look after his equipment properly. These characteristics have an important bearing on the type of biogas plant and equipment which is appropriate to a particular country.

B. Factors affecting the design

1. Availability of building materials

In all countries building skills depend on the nationally (or regionally) available building materials. These may be stone or brick masonry, concrete, etc. The digester can be made out of many materials. If there is a shortage of steel sheets, an all-plastic or all-masonry design may have to be used.

2. The level of the water-table

The level of the water-table is the level to which water rises in a hole dug in the earth. When the water comes up to a point near the surface of the ground, this is called a "high water-table". Special designs of biogas plants are available for high water-table areas.

3. Input material to be used

Biogas can be produced from a very wide range of vegetable matter and from all types of dung. However, there is only one design (fixed dome) which can digest vegetable wastes without previously powdering them. The majority of biogas plants are designed to work on either pig or cattle dung (including buffalo dung). A few plants are designed for chicken dung or human faeces or a combination of types of dung.

When only dung is used, the gas plants are usually run on a continuous basis. This means that every day fresh slurry is put into the plant and an equivalent amount of effluent comes out of it.

In view of the light density of the vegetable matter used, the material will not flow through the plant. Therefore, if this type of material is used, the plant must have at least 70 per cent of the contents cleaned out and refilled once or twice a year. This type of plant is called a batch-type plant. There will be no gas while this work is being done and until the bacteria have started to produce gas once more. This is not a source of inconvenience when the emphasis is on fertilizer and hygiene rather than on gas.

4. The amount of gas required for different applications

Gas is primarily used for cooking and lighting. On rare occasions it is used for running engines, refrigerators, incubators, etc. The amount of gas required for these applications is given in figure 10.

(a) *Cooking*

The amount of gas per person per day needed by different households varies according to the following factors:

- Type of cooking (such as frying, boiling or baking);
- Type of food;
- Number of meals and snacks per day;
- Economy in fuel when cooking for a large number of people;
- Skill of cook in reducing gas flame size after a pot has been brought to the boil.

The average figure for gas consumption for cooking meals per person per day is 0.3 m^3 (from 0.28 to 0.42 m^3, i.e., 10 to 15 cu ft).

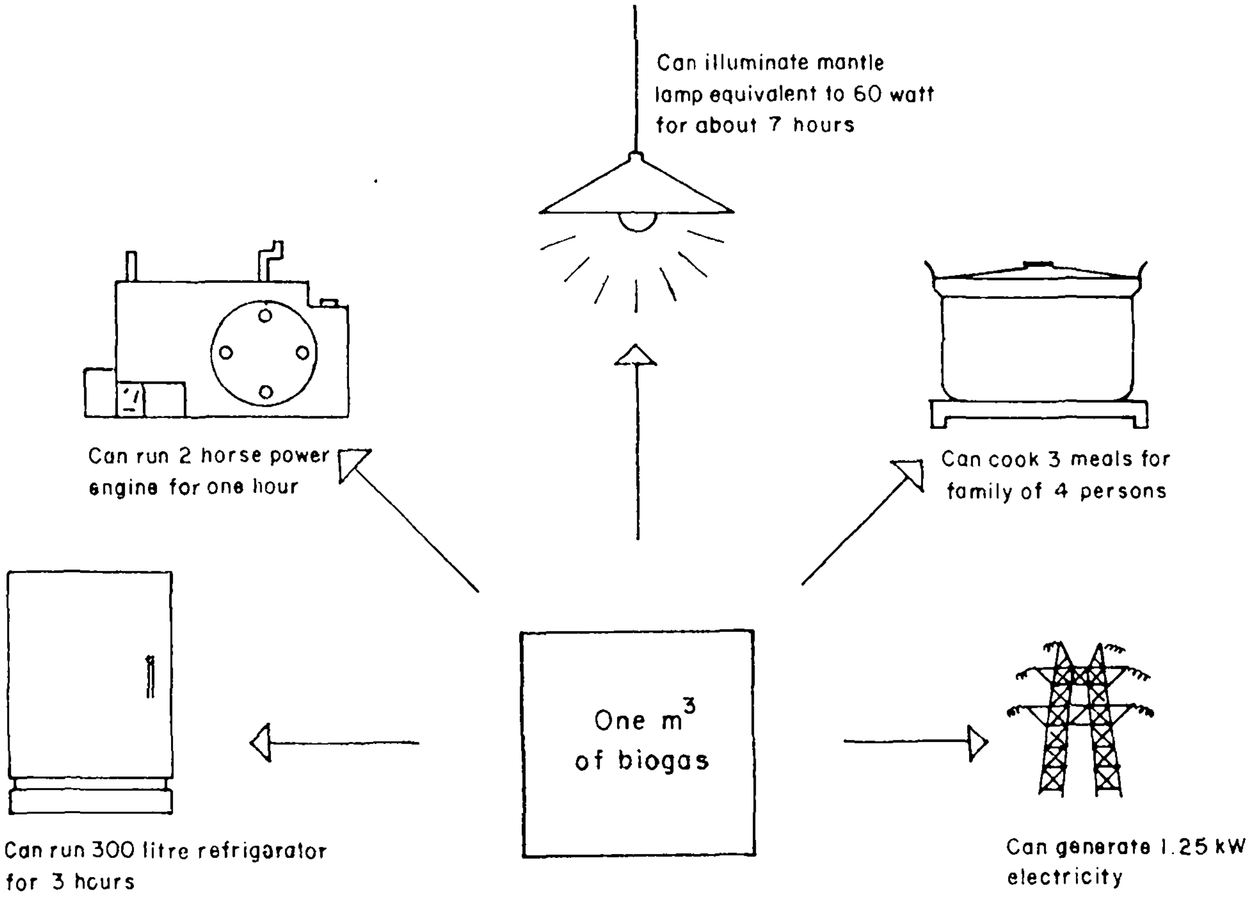


Figure 10. Possible applications of biogas

(b) *Lighting*

Lighting is justifiable only if electricity is not available, as lighting consumes gas inefficiently and regular attention is required to keep lamps burning well.

One mantle lamp requires 0.11 to 0.15 m^3 (4 to 5.5 cu ft) per hour. This is approximately equivalent to a 60 watt electric light bulb.

(c) *Other applications*

Because other applications are not common, they are detailed separately under "commercial uses of gas". For rapid estimation the following gas consumption figures can be used:

- Refrigerators, about 0.6-1.2 m^3 per m^3 (0.6-1.2 cu ft per cu ft) of refrigerator volume per hour;
- Incubators, 0.5 to 0.7 m^3 per m^3 (0.5 to 0.7 cu ft per cu ft) of incubator volume per hour;
- Engines, 0.60 to 0.70 m^3 (21 to 25 cu ft) per kWh = 0.45 to 0.54 m^3 (16 to 19 cu ft) per brake horse power (bhp) per hour.

5. Gas production from different input materials

Gas production from different materials depends on a number of factors. There is a great lack of reliable information on this subject but, five main points can be considered:

(a) Temperature and retention time: these are very important and interrelated; they will be discussed below;

(b) The plant must be operated correctly; instructions are given in chapter XII;

(c) Stimulating gas production in cold weather (see chapter XIII);

(d) Other factors which in village situations cannot easily be controlled. Information on this will be found in annex II;

(e) Feed given to the animal and the health of the animal.

Bacteria are most active and produce most gas at a temperature of 35°C, i.e., about the body temperature of the animals in whose gut the dung was produced. The lower the temperature the less active are the bacteria; all gas production basically stops at about 10°C. Gas plants in villages are not heated and the temperature of the slurry usually falls in the range 18° to 32°C, varying through the year depending on the season. Unfortunately, most research work has been carried out at 35°C, when for realistic village purposes it needs to be done at 25°-30°C. Also, it has been done in laboratories on a batch basis rather than on a continuous feed basis. Fifty days retention time is the average retention time for most tropical countries. If the area is hot all the year round, the time could be reduced to about 40 days. It is in winter that most gas is required. If it is cold in the area, the retention time could be increased to at least 60 to 70 days. It is more reliable to relate the biogas production figures to the solid contents of the input material. The information available at present is given in table 3.

Table 3. Biogas yield of some input materials

Input material	*Biogas yield (m^3/ton solid contents)*	*Methane contents (per cent)*
Livestock manure:		
Cattle dung	260-280	50-60
Pig dung	561	
Horse dung	200-300	
Plant waste		
Fresh weeds	630	70
Flax or hemp stalks	369	
Wheat straw	432	59
Green leaves	210-294	58
Rice husks	615	
Sewage waste	640	50
Liquid waste from wine or spirit-making factory . .	300-600	58
Compounds:		
Carbohydrates	750	49
Lipids	1 440	72
Proteins	980	50

Sources: (a) Sichuan Provincial Office of Biogas Development, "Biogas technology and utilization", Chengdu Seminar 1979, China.

(b) *A Chinese Biogas Manual*, translated from the Chinese by Michael Crook and edited by Ariane van Buren from the original by the Office of the Leading Group for the Propagation of Marshgas, Sichuan province, China (London, Intermediate Technology Publications, 1979).

Some field tests have been done but they do not show consistent gas production figures.

Until better information becomes available, the figures, indicated in table 4 may be used. Under average conditions (40 to 60 residency days) to produce 1 m^3 (35 cu ft) of gas per day the following amounts of dung would be required:

Cattle dung:	32 kg per day
Pig manure:	20 kg per day
Poultry manure:	12 kg per day

Table 4. Gas production of various types of dung

Type of dung	*Gas production per kg dung*
Cattle (cows and buffaloes) . .	22 to 40 litres (0.8 to 1.4 cu ft)
Pig	40 to 60 litres (1.4 to 2.1 cu ft)
Poultry (chicken)	65.5 to 115 litres (2.3 to 4.1 cu ft)
Human	20 to 28 litres per person using toilet (0.7 to 1 cu ft)
Pretreated crop waste	34 to 40 litres
Water hyacinth	40 to 50 litres

6. The amount of fertilizer expected out of the gas plant

During processing in the plant some solids are broken down by bacteria into water and gas. About 70 per cent of the total solids put in can be expected to come out. Processing does not increase any fertilizer nutrients such as nitrogen, phosphorus or potash. Digestion does, however, change, the form of part of the nitrogen, but the effluent will contain almost exactly the same amount of nutrients as were put in.

7. The amount of dung that can be collected per animal, bird or human

The amount of dung that can be collected depends on various factors: size of the animal, diet of the animal and degree of confinement, i.e., whether the animal stays in a shed or grazes in the field for part of the day. The only reliable way to check this is to measure the actual amount for three consecutive days and take an average. For estimating purposes the following figures can be used:

Cows:	10 to 15 kg of dung per day
Buffaloes:	15 to 20 kg of dung per day
Pigs:	2.5 to 3.5 kg of dung per day
Chickens:	90 g of dung per day

A village buffalo may give as little as 6 kg per day whereas some of the largest bred buffaloes can give as much as 36 kg per day. Therefore it is essential to measure the actual dung available.

Note: Often scales are not available. A standard four imperial gallon (18 litres) kerosene tin can be used. When dung is well pressed down to avoid any air spaces and filled level to the top this tin will hold about 19 kg of dung. If loosely filled, it will hold about 15 kg.

8. Other feed materials

Other feed materials may be used but these are mostly employed in a batch-type plant.

(a) *Dung which is bead-like,* e.g., goat. The beads have to be broken down before feeding into a continuous-type digester. If this is not done, the beads float to the surface and cause a scum problem.

(b) *Coarse dung,* e.g., elephant. This contains many large pieces of vegetable matter which float to the surface and cause a scum problem.

(c) *Grass, straw, leaves, weeds and animal bedding, including sawdust.* Again, because of their light density and the formation of scum, these materials are only recommended for use in batch-type gas plants.

(d) *Water hyacinth.* It is well known that this material is a good gas producer. People have tried to use it in continuous plants. The hyacinth is allowed to rot in the sun for two days to break down air pockets and it is then chopped into small pieces. Even after this processing it may float, causing a scum problem. A batch digester is the appropriate type for this material. A mixture of 50 per cent water hyacinth, 50 per cent cow dung gives a better gas yield and a better performance in cold weather than cow dung alone. For more details on the input material, see chapter XI.

C. Factors affecting the operation

1. The amount of water needed

Usually about one litre of water per kg of dung is required.

2. The use of sea water or brackish water

Sea water cannot be used. It will hinder bacterial generation. Brackish water can be used in some cases, depending on the impurities and concentration of salts. Advice from a national centre should be obtained.

3. Additional input materials

For the ordinary running of gas plants no material is needed apart from animal dung and water (and vegetable matter where a batch-type digester is used).

4. The expected life of a gas plant

Biogas technology is a relatively new concept in many countries and also a long-term investment. Most people talk about a life of 20 or more years for the masonry work and 8 or more years for the steel gas holder, depending on how well it is protected from rust and how well it is maintained. (The life of a steel gas holder can vary from as little as 2 to 5 years if thin steel is used and no protection is given to as long as 20 years if it is regularily painted.) There are no known figures for the life of the pipework and gas appliances. These items usually account for no more than 20 per cent of the total installation cost and much less for large plants.

When deciding whether or not to install a plant, potential customers must think of it as a long-term investment. They must consider points such as the future number of animals on the farm and future uses of the gas. It may be better to install a plant which at present is too large, but which will be necessary in a few years time.

5. The effect of scum formation in a continuous-type digester

Scum can be a major problem in gas plants run on a continuous basis. It is formed from:

(a) Undigested vegetable matter, e.g., straw;

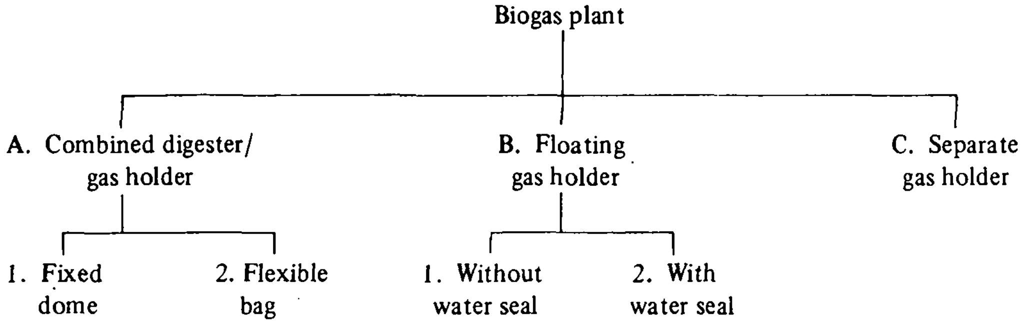
(b) Bedding, e.g., straw, sawdust;

(c) Animal "clothing", e.g., pig hairs and chicken feathers.

Although the slurry is a thick liquid, it can nevertheless float upwards and make a thick layer called scum. If there is only a small quantity it can be dispersed by mixing, providing the slurry is not too watery. When a lot of scum collects, it is necessary to remove it.

VI. CLASSIFICATION AND DESIGN PRINCIPLES OF PLANTS

Gas plants can easily be classified by the arrangement used for collecting the gas.



A1. Fixed dome digester: commonly called "Chinese" design, as it is mainly used in China. It is usually operated on a "batch" basis but with daily small additions of dung and human faeces. A long retention time is used, which helps to kill harmful pathogens and parasites. In this type of plant the emphasis is more on fertilizer and removal of pathogens and parasites. No gas is available when the sludge is removed, the new slurry is put in and until the bacteria start producing gas again (2 to 3 weeks maximum).

A2. Flexible bag digester: usually called "bag digester", although the bag holds both the slurry and gas. It is run on a continuous basis.

B1. Floating gas holder digester without water seal: commonly called "Indian" or "KVIC"* design; it is run on a continuous basis.

B2. Floating gas holder digester with water seal: very clean but more expensive than type B1.

C. Separate gas holder digester: still uncommon because of its relatively high cost. Large-size digesters have been restricted to large commercial organizations which run a series of batch plants. Some cheap new designs are finding their way into rural areas.

All these types of gas plants are made in different sizes. Unfortunately, the sizes are defined in different ways. Common definitions are given below.

Fixed dome A1 and Flexible bag A2	Defined by the volume of the digester, i.e., the volume of the slurry and gas storage combined

Floating gas holders and Separate gas holder	B C	Defined by (*a*) Expected volume of gas produced per day (this is the most common) (*b*) Volume of slurry contained in the digester pit (*c*) Volume of gas holder

Throughout this guidebook the definition used, unless otherwise stated, is "volume of digester in m^3" in the case of the fixed-dome digester and "expected volume of gas produced per day" in the case of the floating gas holder digester. This is a rough but meaningful description of a gas plant size. Of course, gas production varies from day to day and from season to season.

A. Fixed dome (A1)

(a) *Circular type* (figure 11)

The main features of this type are:

- The digester can be made of at least four different construction materials.
- The volume of the digester equals the volume of slurry and gas combined.
- The weight of the soil on the top of the digester is usually as great as the upward gas pressure in the digester, i.e., if the maximum gas pressure is 1,000 mm water gauge, then the thickness of the soil is also 1,000 mm.
- For input materials consisting of plant, animal and human waste the average gas production as reported in Sichuan province in China is 0.15 to 0.2 m^3/day per m^3 of digester volume (1), but in

---

* Khadi and Village Industries Commission is an Indian Government agency promoting biogas.

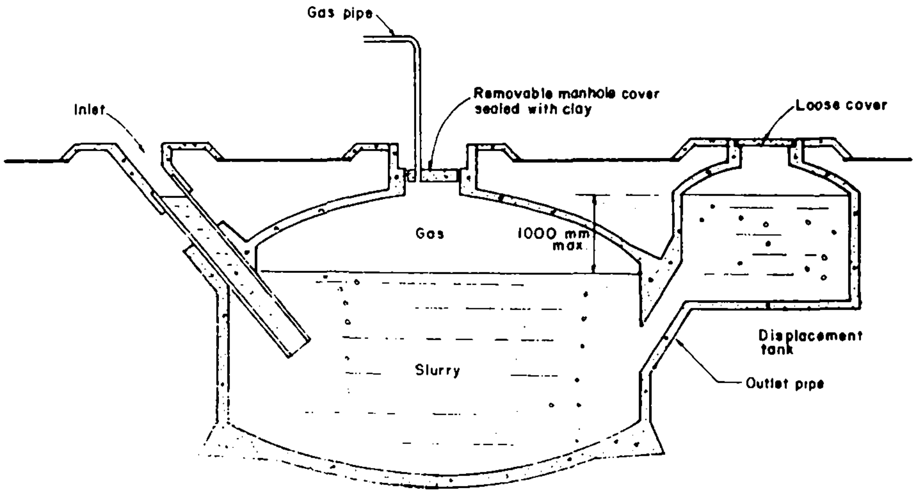


Figure 11. Common circular fixed-dome digester (China)

tropical areas it can be as much as 0.3 to 0.4 m^3/ day per m^3 of digester volume.

- Millions of such plants are operating in China, using plant, pig, cattle and human waste.

(i) Advantages:

- No steel sheets required;
- Generally it runs on a batch-continuous process, i.e., plant waste may be included;
- Its total cost is normally less than that of the digester with floating gas holder. The cost of construction in China is about $US3.5 to 5 per m^3 of digester volume (1);
- It provides more fertilizer than the continuous type because plant waste is used.
- The digester and the gas holder are both built below ground level, hence it is easier to insulate them in cold regions. Besides, less earth surface is being used for the biogas plant.

(ii) Disadvantages:

- Normally no provision for stirring the slurry in the plant can be fitted through the dome;
- The necessity of removing the sludge twice, or more often, a year;
- Outside China this type has not yet become popular in view of a lack of construction and plastering experience.

(b) *Square type* (figure 12)

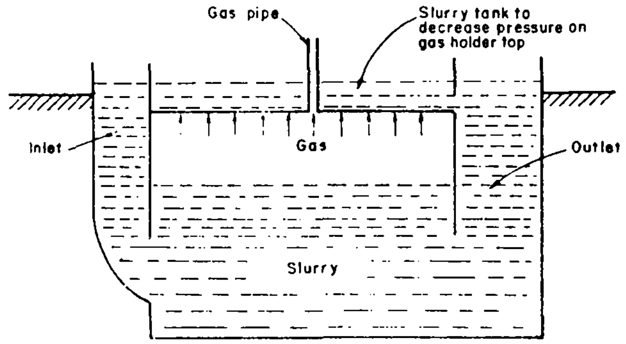


Figure 12. Square fixed-dome digester (China)

This is an early and commonly reported fixed dome design from China. The plant is basically square and when gas is collected the displaced slurry flows onto the top of the gas holder.

This design has been superseded by the previously illustrated circular design because of high stress and gas leaks at the square corners.

The equalization tank on top of the gas dome is no longer recommended. Although the gas pressure is low, the area subjected to pressure is great and cracks can occur, allowing the gas to escape. The tank also collects rain water, dries out in the sun, allows flies to breed, causes odour and aerates the slurry. None of these is desirable.

B. Flexible bag (A2) (figure 13)

The advantages and disadvantages of this type are given below:

(a) *Advantages*

- Portable;
- Constant gas pressure may be obtained;
- Relatively quick to erect;
- Low capital cost.

(b) *Disadvantages*

- Must be made of strong plastics resistant to ultraviolet rays (usually Hypalon-Neoprene coated fabric is used);
- Cost depends on local price of plastic material (if available);
- Plastic can be accidentally cut during handling and erection;
- Should be provided with safety valve for pressure release, otherwise the bag may explode;
- Rodents (rats and porcupines) have been known to bite and destroy the plastic bag;
- No provision for removing scum;
- Stirring not possible;
- Bends in inlet and outlet may cause blockages.

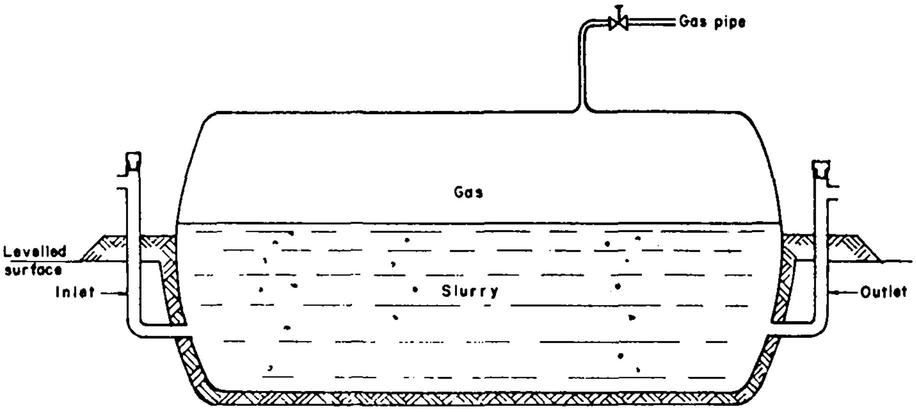


Figure 13. Flexible bag type combined digester/gas holder

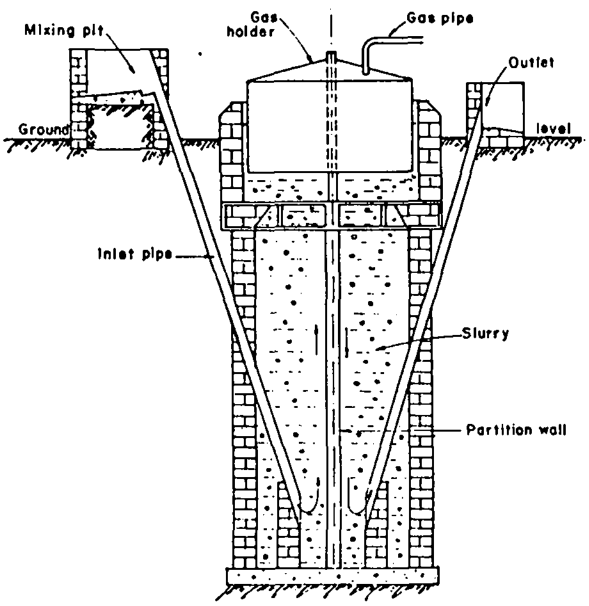


Figure 14. Common circular digester with floating gas holder and no water seal (India)

C. Floating gas holder (B1)

(a) *Vertical type* (figure 14)

This type has the following main features:*

- Digester made of masonry;
- Inlet and outlet are straight to facilitate clearing of blockages;
- Many thousands are in use and fed with cattle dung only;
- Runs on a continuous basis;

---

* A toilet attachment can be fitted to all gas plant designs. It uses a separate inlet pipe.

- For cattle dung average gas production is 0.3 to 0.4 m^3/day per m^3 of digester volume; for pig dung it is 0.4 to 0.55 m^3/day per m^3 of digester volume.

In addition, it has the following advantages and disadvantages:

(i) Advantages

- Gas holder can be lifted off to facilitate removal of any build up of scum;
- Constant gas pressure;
- Gas holder can be rotated to give limited stirring (mixing bars are fitted inside the gas holder).

(ii) Disadvantages

- Steel gas holders are the most commonly used, but they are expensive, usually being 35 to 40 per cent of the total cost of a plant;
- The cost of the construction materials in India is about $US20 to 30/$m^3$ of digester volume;
- The exterior of the sides of the gas holder rusts badly as it moves in and out of the slurry. Ideally the sides should be sandblasted and painted with epoxy paint (see chapter IX);
- The flexible pipe joining the gas holder to the main gas pipe is a major maintenance item. It is damaged by ultraviolet rays in the sun and twisted when the drum is rotated for mixing.

(b) *Horizontal type* (figure 15)

This type, which is a modification of the previous design to suit high water-table areas and uses exactly the same gas holder, has the following advantage and disadvantages:

(i) Advantage

- Safer and easier for workers than the deep hole used for the vertical design.

(ii) Disadvantages

- Requires reinforced cement concrete roof;
- 20 to 30 per cent more expensive than the vertical type.

(c) *Taper type* (figure 16)

This is another high water-table digester. It has the following features:

- Uses same amount of bricks and material as the straight design;
- Cost is the same as the straight design;
- Small amount of gas leak from taper wall (not sufficient to give noticeable gas reduction);
- Uses exactly the same gas holder;
- Safer and easier for workers than the deep hole used for the straight design.

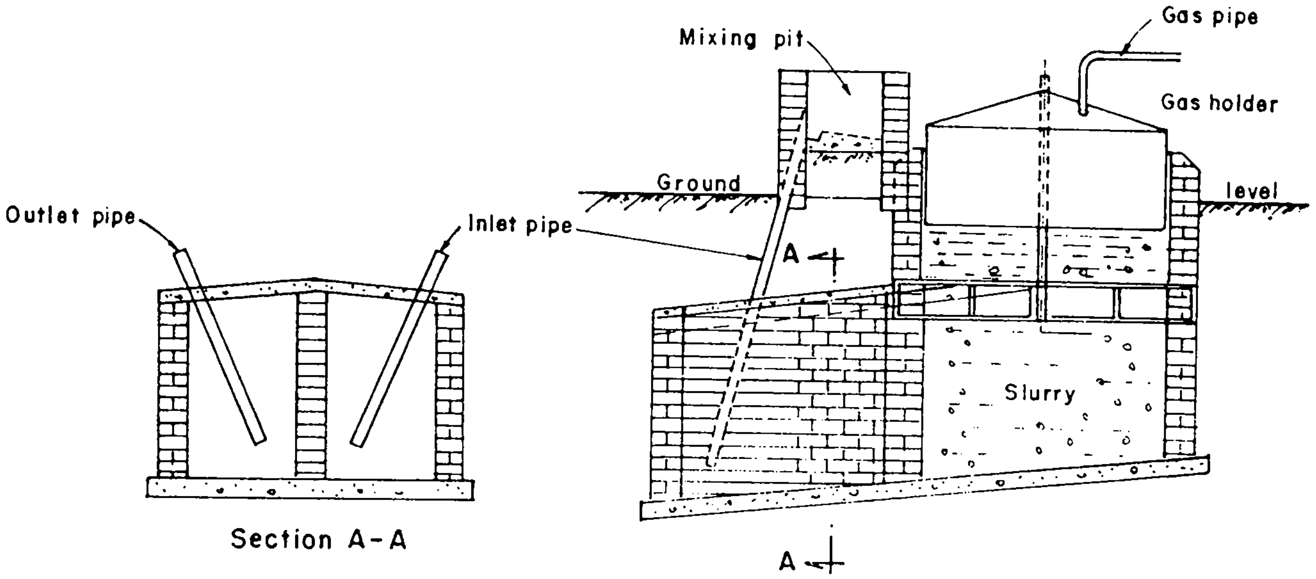


Figure 15. Horizontal flow digester with floating gas holder (India)

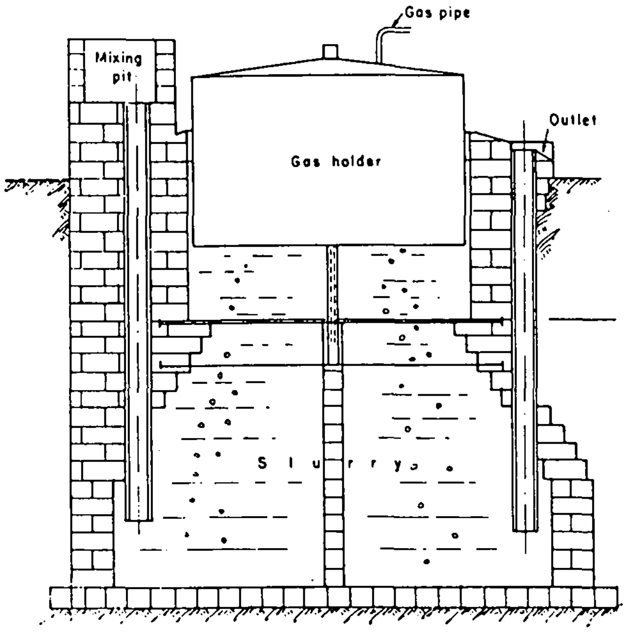


Figure 16. Taper digester with floating gas holder (Nepal)

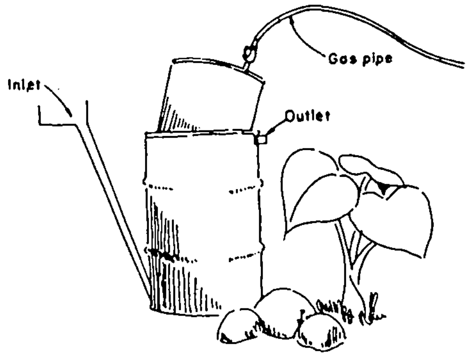


Figure 17. Oil drum digester (Indonesia)

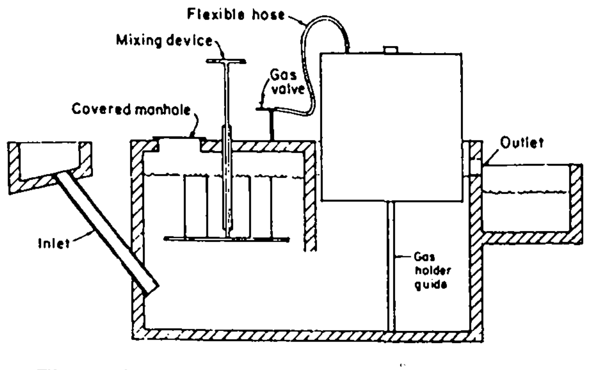


Figure 18. Two-chamber rectangular digester with floating gas holder (Philippines)

(d) *Oil drum type* (figure 17)

This digester, which is made from old oil drums, produces very little gas because of its small size; it is generally used only for research purposes. The oil drums tend to rust out within a few years.

(e) *Two-chamber rectangular digester* (figure 18)

This type of digester can be built without a water seal (figure 18) or with a water seal (figure 19). Both types are rectangular with a cube-shaped gas holder. The primary chamber is insulated with a concrete slab. Serious clogging problems have been experienced in the operation of this type of plant. This design is therefore not recommended until the clogging problem can be overcome.

D. Floating gas holder with water seal (B2) (figure 20)

This type has the following advantages and disadvantages:

(a) *Advantages*

- Water seal can be attached to any of the digesters mentioned in section 3 above;
- Ensures all gas is collected in gas holder;
- Reduced corrosion of gas holder, particularly if oil film is maintained on the water seal;
- Eliminates any smell generally produced in gas plants using human faeces;
- Square designs using this principle are also used;
- Offers a possibility for heating slurry by using solar energy to heat water in the water seal.

(b) *Disadvantages*

- More expensive;
- Provision of mixing bars could be more difficult as radial struts cannot be attached to sides;
- Maintaining water level and oil film is an additional operation.

E. Separate gas holder (C)

In this system from two to four digesters are usually connected to one gas holder. This system has been used by large industrial plants, and recently simple cheap systems have been introduced in the rural areas in China and Thailand.

(a) *Jar digester with separate gas holder* (figure 21)

This system has the following advantages:

- Less expensive than the floating gas holder digester;
- Construction, maintenance and repairs are easier than in the other two types (A and B);
- It allows a batch system with a continuous gas supply;
- The digesters can be completely insulated;

It has the following drawbacks:

- Separate mixing device is needed for each digester;
- In spite of its potential it has not yet been widely tested.

(b) *Fixed dome digester with separate gas holder* (figure 22)

This system, which has not been yet widely tested, has the following advantages:

- The digester dome is subjected to little pressure (determined by the weight of the gas holder); hence it is easy and cheap to construct the digester;
- The gas pressure is constant; hence appliances and engines may be designed and used at their optimum working conditions;

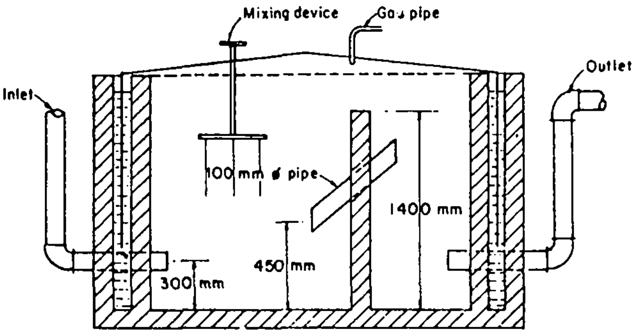


Figure 19. Two-chamber rectangular digester with floating gas holder and water seal (Philippines)

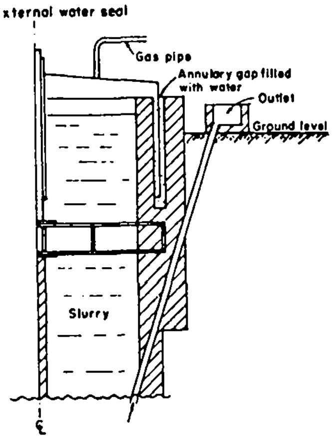


Figure 20. Digester with floating gas holder and water seal (Pakistan)

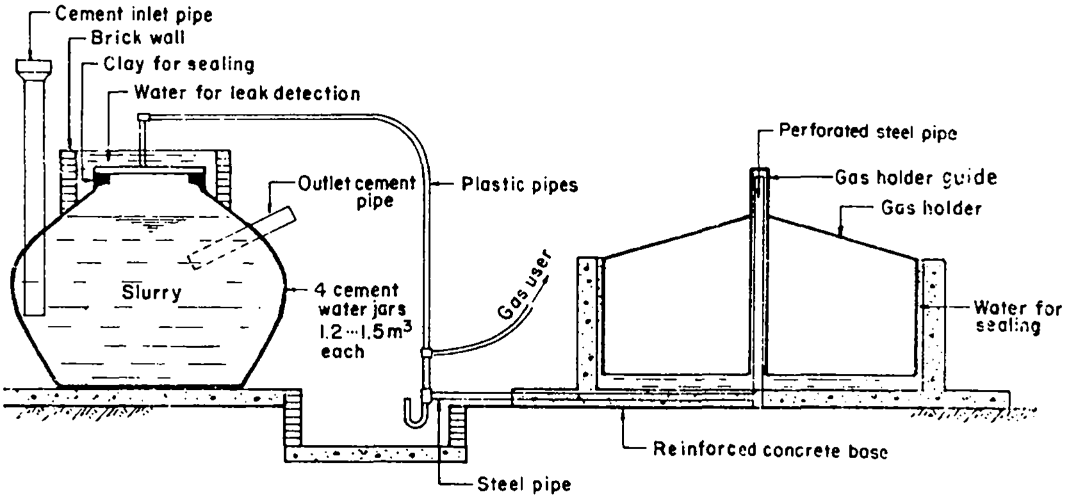


Figure 21. Jar digester with separate gas holder (Thailand)

- No steel sheets or reinforcing steel bars are needed for the gas holder and it is therefore cheaper than the floating gas holder in the designs described earlier.

It has the following drawback:

- Additional work and cost in building the water tank and the gas holder.

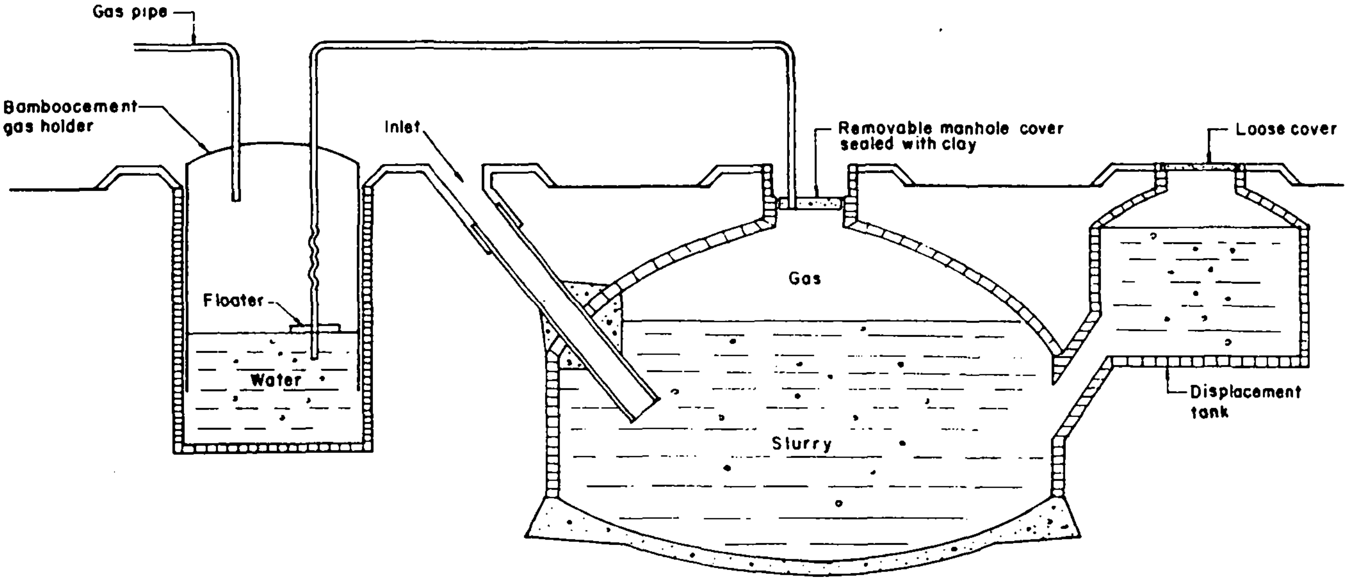


Figure 22. Fixed dome digester with separate gas holder (Sichuan, China)

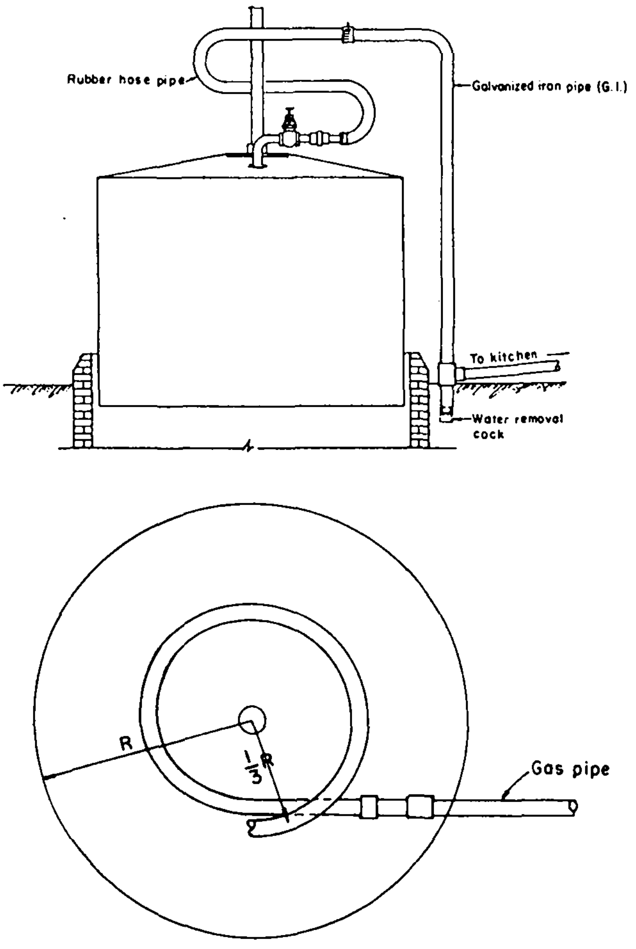


Figure 23. Gas removing system through a flexible pipe

F. Gas removing systems

There are a number of ways of removing the gas from the gas holder. They all relate specifically to B-type plants.

(a) *Flexible pipe* (figure 23)

This is probably the most common design, but a flexible pipe is often a serious maintenance problem in a gas plant. It has the following disadvantages:

- Rubber hose pipe deteriorates and needs replacement (good quality hose pipe is often not available in rural areas);
- Leaks at either end of flexible pipe can be a problem;
- Pipe gets twisted up and flattens in places, especially if plastic pipe is used;
- When soft pipe is used, it sags and condensate collects in the low points and requires daily removal;
- Centre support pipe rusts and breaks at times.

(b) *Hooked underside* (figure 24)

This system has few of the drawbacks of the flexible pipe system but still has the following disadvantages:

- Prevents gas holder being rotated as it interferes with internal braces (usually 4 or more struts are used so the gas holder can rotate 90° only);

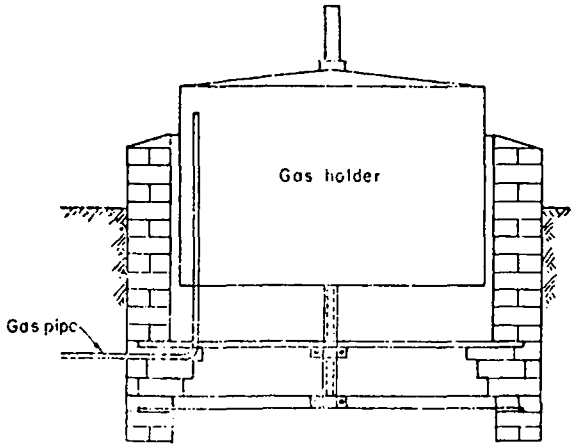


Figure 24. Gas removing system through a hooked pipe

- Easily damaged from being hit by struts;
- If the gas pipe is not long enough, slurry enters it and blocks it;
- The gas pipe is low in the ground for condensate removal (this can be overcome by using the water removal device shown in chapter IX).

(c) *Centre guide system*

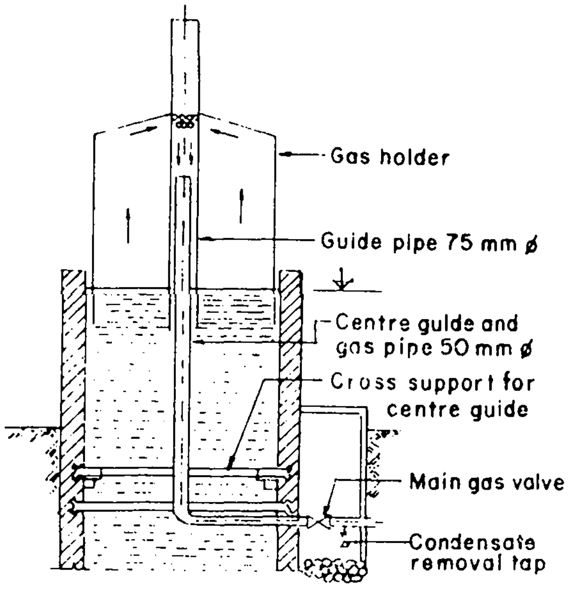


Figure 25. Gas removing system through a centre guide

This system, which has a gas pipe low in the ground for condensate removal, is commonly used in certain countries. It allows the gas holder to rotate freely for mixing purposes. Besides, by covering the centre support, the rust problem in this location is eliminated. In view of these advantages and in spite of its higher cost this system can be recommended.

G. Gas holder support system

There are various ways of supporting the gas holder, which all relate to B-type plants; they can be used for any type.

(a) *Internal centre guide* (figure 26)

This system has many advantages and can be recommended. The gas holder can be rotated for mixing.

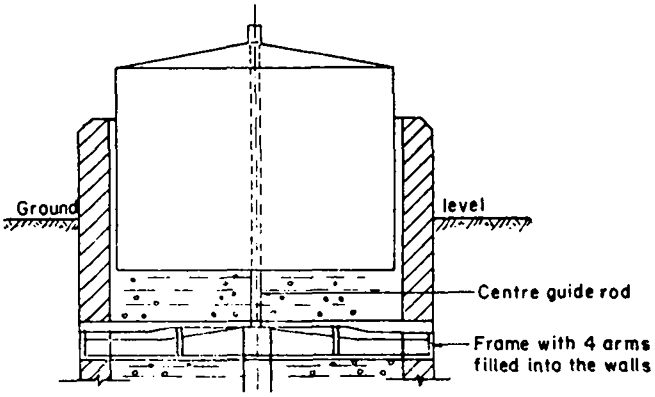


Figure 26. Gas holder internal guide system

(b) *External (overhead) centre guide* (figures 27a and b)

This system has the following features:

- The gas holder can be rotated for mixing.
- In the single cross bar structure (figure 27b), the gas holder can tilt and rub on cement walls. This

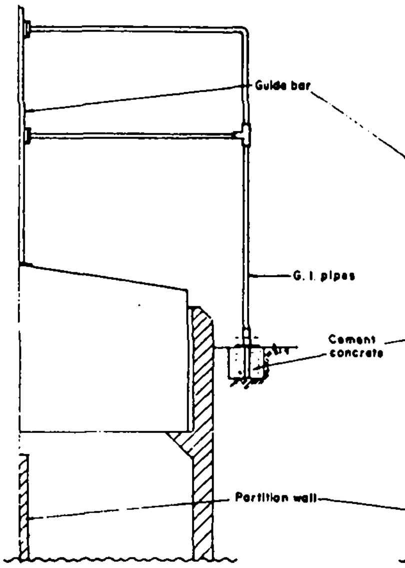


Figure 27 a. Gas holder external guide system fixed to the earth (for large sizes)

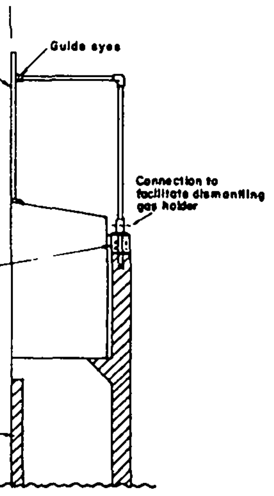


Figure 27 b. Gas holder external guide system fixed to digester wall

can remove paint and also affect gas pressure. It can be improved by having two guide eyes one spaced a bit above the other as illustrated in (figure 27a). This is always necessary for big units.

- The guide bars should be dismantled if gas holder needs to be removed.

(c) *Wheel system* (figure 28)

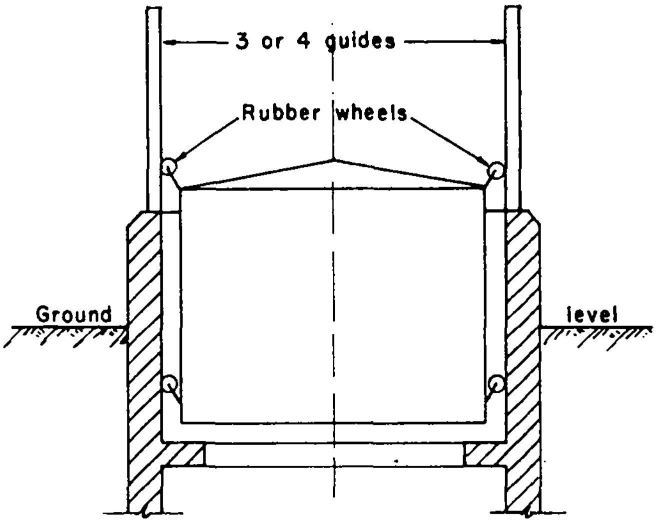


Figure 28. Gas holder with wheel guide system

This system has the following features:

- Unless wheels can be easily retracted, the gas holder cannot be rotated;
- Wheels need replacing from time to time;
- Wheels can get clogged with slurry and stop turning;
- Mainly used for ferrocement gas holders.

(d) *Counterbalance system* (figure 29)

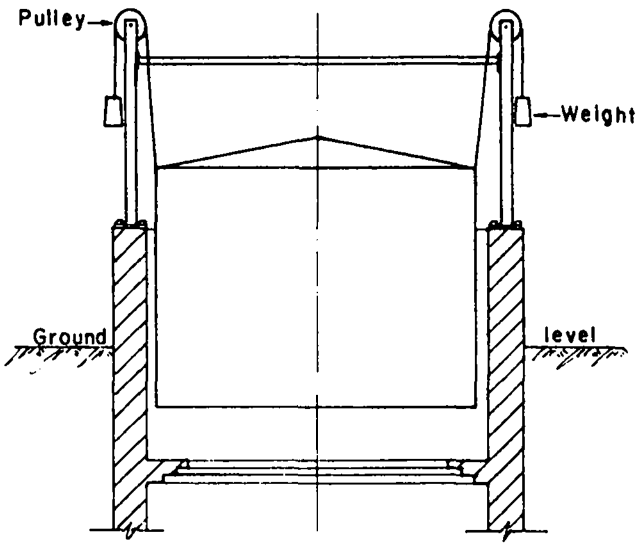


Figure 29. Gas holder with counter balance system

This system was suggested years ago because it was believed that by adding weights to reduce the gas pressure more gas would be produced. Although a correlation was found recently between the gas pressure and the gas production rate (1), the utilization of that system has to be justified, as it has the following disadvantages:

- Very unstable, as weights go out of balance extremely easily causing the gas holder to tilt, the gas to escape and the gas holder to jam;
- Weights must be removed from buckets and added to the top of the gas holder when gas is needed;
- Gas holder cannot be rotated for mixing.

VII. DESIGN, SIZE AND SITE SELECTION

In this chapter the information given in chapters V and VI is consolidated.

A. Design selection

Five main design types were illustrated in chapter VI. Full working drawings of standard sizes of these plants are given in annexes III to VI. Normally the most appropriate of these should be accepted, with minor alterations to suit local conditions. Chapter VIII on digester construction illustrates design features which need to be considered when a new design is contemplated.

When selecting a design the following points need to be considered:

(a) Availability of construction materials (especially steel sheets) and skills;

(b) Cost of materials;

(c) Feed materials to be used;

(d) Type of soil;

(e) Knowledge and experience of the organization or person promoting the gas plant.

Examples:

1. If a fixed dome digester is to be used, good plastering skills are needed. If this cannot be arranged, a steel gas holder or flexible bag digester will probably be more suitable.
2. If vegetable matter is to be used, a batch system is needed and a fixed dome digester is indicated. If plastering skills are not available, it may be possible to line the inside of the gas dome with metallic sheets or to fit a plastic membrane sandwiched between two layers of masonry. (For more details about labour training to acquire plastering and other skills in the construction of the fixed dome digester, see chapter XVI.)
3. If the materials and skills for the construction work are not available, but the proper quality of plastic sheets are available at low cost, if dung only is to be used and the year-round temperature is high, then a flexible bag type digester may be considered.

Many gas plant designs can be found in various publications. The fact that the design is in print does not mean that the type of plant has ever been built or that it has been proven over a period of time. Care should be taken in adopting these designs. Almost any design will work well for 6 to 12 months but it is only after that time that faults (e.g., blocked inlet/outlet pipes, scum removal problems) become evident.

It is only after a similar period that conditions settle down completely and an accurate gas production figure can be obtained. It is all too common to hear people say they do not get as much gas (especially during winter) as the designer claims should be produced.

B. Size selection

(a) *Gas plant size*

Common sizes of gas plant are:

- 2 m^3 (70 cu ft) gas production per day. (This size is not always economical. The next larger size is only slightly more expensive but produces 50 per cent more gas.) The corresponding size of the fixed dome digester is about 10 m^3.
- 3 m^3 (105 cu ft) gas production per day. The corresponding size of the fixed dome digester is about 15 m^3.
- 5 m^3 (175 cu ft) gas production per day. (This is probably the most common size built.) The corresponding size of the fixed dome digester is about 25 m^3.
- 10 m^3 (350 cu ft) gas production per day. The corresponding size of the fixed dome digester is about 50 m^3.

The size of a gas plant for any site must be individually selected. It depends on the amount of gas required and the amount of dung available.

Note: The sizes given above are the expected volume of gas produced per day for the floating gas holder type digester and the corresponding sizes of the fixed dome type digester.

(b) *Digester size*

The volume of the digester may need alteration to suit the temperature of the area and the type of input material used. The following are only rough guides:

(i) Cattle dung

Let us assume that 36 litres of gas is produced by 1 kg of cattle dung in 50 days when the slurry temperature is 27°C and 1 litre of water is mixed with each kg of dung. In other words, for a daily production of 36 litres of gas we need to use daily 1 kg of dung (12).

If 1 m^3 of gas is required per day, then

$\frac{1{,}000}{36}$ = 28 kg of dung is required per day, i.e., about 2 head of cattle.

If we assume that 1 kg dung = 1 litre volume, then the volume of digester to produce 1 m^3 of gas per day = (28 + 28) x 50 = 2.8 m^3.

It is always wise to make the digester a bit larger because a certain amount of material may settle at the bottom of the digester, thus reducing the effective digester volume.

The above figures are typically accepted figures for cattle dung in Asian countries, except the very hot and very cold areas, where the volume would be smaller or greater respectively.

(ii) Poultry

We will assume that 44 litres of gas are produced by 1 kg of poultry dung in 30 days when the slurry temperature is 27°C and 1 litre of water is mixed with each kg of dung (12).

If 1 m^3 of gas is required per day, then

$\frac{1{,}000}{44}$ = 23 kg of dung is required per day, i.e., about 260 chickens.

If we assume that 1 kg dung = 1 litre volume, then the volume of digester to produce 1 m^3 of gas per day = (23 + 23) x 30 = 1.38 m^3.

(iii) Human

We will assume that 200 g (or 200 ml) of night soil, 800 ml urine and 1 litre of flush water per person, with a slurry temperature of 27°C in 60 days gives 24 litres of gas per person using the toilet.

If 1 m^3 of gas is required per day, then

$\frac{1{,}000}{24}$ = 42 persons per day need to use the toilet.

The volume of digester to produce

1 m^3 of gas per day = 2 litres x 42 persons x 60 days = 5.04 m^3.

(iv) Pigs

We assume that 45 litres of gas is produced by 1 kg of pig dung in 40 days when the slurry temperature is 27°C and one litre of water is mixed with each kg of dung.

If 1 m^3 of gas is required per day, then

$\frac{1{,}000}{45}$ = 22 kg of dung is required per day, i.e., about 9 pigs.

Assuming that 1 kg dung = 1 litre volume, then the volume of digester to produce 1 m^3 of gas per day = (22 + 22) x 40 = 1.76 m^3.

(v) A mixture of plant, animal and human waste

As mentioned earlier, the digester capable of fermenting such a mixture of input materials, including plant waste, is the fixed dome digester, which usually operates on a batch-continuous basis.

Accordingly, the present example is based on the normal practice of feeding the digester in Sichuan Province. China (1), (7). A recommended mixture of human, animal and plant waste is 10 per cent human excreta (including the liquid fraction), 40 per cent animal and plant waste and 50 per cent water. With this mixture, it was found that 10 per cent of the gas was produced from human waste, 40 per cent from animal waste and 50 per cent from plant waste.

Assuming that in the fixed dome digester:

24 litres of gas are produced by 1 kg of human excreta,

34 litres of gas are produced by 1 kg of pig dung,

30 to 40 litres of gas are produced by 1 kg of composted plant waste,

then for producing 1 m^3 of gas we shall need:

a. $\frac{1{,}000 \times 0.1}{24}$ = 4.2 kg/day of human waste. Assuming that each person produces a total of 1.3 kg/day of waste (see note 2 below), the number of people to produce 4.2 kg/day of human waste is $\frac{4.2}{1.3}$ = 3.5 persons, i.e., about three adults and one child.

b. $\frac{1{,}000 \times 0.4}{34}$ = 11.8 kg/day of pig dung. Assuming that each pig produces a total of 6 kg/day of dung (see note 2 below), the number of pigs to produce 11.8 kg/day of dung is $\frac{11.8}{6} \cong$ 2 pigs.

c. $\frac{1,000 \times 0.5}{30}$ = 16.7 kg/day of plant waste. In practice, however, the plant waste is added twice a year, whereas the human and animal waste is added daily.

Hence, in order to produce 1 m^3 of gas per day we need 16.7 x 180 = 3,000 kg of composted plant waste each six months, plus a daily input of the waste of a family of three adults and one child and of two pigs.

In Sichuan (latitude about 30°), the annual average gas production of this type of digester is 0.15 m^3/day per m^3 of digester volume (see note 4 below).

Hence the size of digester needed to produce 1 m^3 of gas per day is $\frac{1}{0.15} = 6.7 m^3$.

Notes:

A wide margin should be provided in applying the above figures. They may be used as a guide until more reliable information becomes available. As stated in chapter V there is a serious lack of facts on this aspect of biogas technology. The following points should be also taken into consideration:

1. Most designers are optimists and tend to give higher figures for gas production than are generally obtained in villages (i.e., they quote figures obtained under particularly favourable conditions such as hot weather).

2. The amount of waste per unit of animal or human given by Chinese sources is usually a little more than the same amount given by other countries, mainly because the general practice in China is to collect and weigh both the solid and liquid fractions.

3. A better temperature for gas production tests is 25°C as this is known to be the mid-point temperature for most plants in villages in Asia.

4. In Sichuan (latitude about 30°N), the average temperature is 22 to 26°C and in winter the temperature is in the range 10 to 16°C. Accordingly, the gas production rate is low, 0.1 to 0.3 m^3/day per m^3 of digester volume. For countries of tropical climate such as south China, the gas production rate could be as high as 0.4 to 0.5 m^3/day per m^3 of digester volume.

5. Many people do not know how much gas is produced or how to measure gas production (details of how to do this are given in chapter XIV). They give a figure told to them by someone, which is often very inaccurate.

6. Gas production can be greatly affected by correct or incorrect operation of the plant, e.g., the correct water/dung ratio (see chapter XIV).

7. The diet and condition (health) of animals can affect the dung and also the gas production.

(c) *Gas holder size*

The gas holder collects and stores the gas when it is not in use. If the gas is only used for a refrigerator, which is constantly in use, then a very small gas storage capacity is needed. At the other extreme, if all the gas is used to run an engine for 3 hours a day, then the gas holder must be able to store $\frac{21}{24}$ (= 88 per cent) of the daily gas production. Most plants are used to provide gas for cooking and lighting. From experience a gas holder which can store 60 per cent of the daily gas production is a good choice of size for this purpose.

In the fixed dome digesters, the gas accumulates in the space under the dome, which should never become less than 20 per cent of the total volume of the digester.

(d) *Examples of gas plant and digester*

Example 1. A farmer has:

2 bullocks, each produces about 10 kg/day	= 20
1 cow, which produces about 10 kg/day	= 10
3 buffaloes, each produces about 16 kg/day	= 48
Total	78 kg dung per day

78 kg x 37 litres/kg = 2.88 m^3 gas per day

He has plenty of water (for 78 kg dung he will need a minimum of 78 litres per day.)

He has to cook for his family of 6 people and he wants one lamp for 3 hours per day. He will accept reduced gas in winter and will use other fuels if necessary. He does not anticipate any change in family size or animal population for the next few years.

Gas required for cooking 6 people: 6 x 330 litres	= 1.98 m^3
One light for 3 hours: 1 x 3 hours x 150 litres	= .45 m^3
	2.43 m^3 per day

In this case a standard 3 m^3 gas plant would be recommended. The volume of digester (slurry) = 3 m^3 x 2.8 m^3/m^3 gas per day = 8.4 m^3. The farmer may not have enough dung so the residency time of the slurry in the digester will have to be increased.

In the cold months gas production will be less and the farmer may be a bit short of gas.

A farmer should not depend on dung supplied by a neighbour to run his gas plant. The neighbour may build a plant himself and need all the dung himself! He might see the value of the dung and start selling it instead of giving it away.

Example 2. A farmer has:

26 pigs* producing (26 x 3) kg
x 50 litres gas/kg = 3.9 m^3 per day
4 cows producing (4 x 10) kg
x 37 litre gas/kg ≅ 1.5 m^3 per day
5.4 m^3 gas per day

He has plenty of water.

He has to cook for his household of 5, which he expects to increase to 7 in the foreseeable future. He wants 3 lights, one for 3 hours per day, one for 4 hours per day and one for 2 hours per day.

Gas required: cooking for 7 (maximum number with maximum efficiency)
7 x 300 litres = 2.10 m^3 per day

Total lighting hours
(3 + 4 + 2) x 150 litres = 1.35 m^3 per day
3.45 m^3 per day

Standard sizes of plant available are 3 m^3 or 5 m^3/day

If money is a problem, it would be better for him to accept the smaller size plant and use alternative fuel as necessary.

If he can afford it, he could have a 5 m^3 per day plant. He would then be assured of sufficient gas supplies even during the winter months.

Assuming he decides to install a 5 m^3 per day plant:

(i) The volume of the digester (slurry) required, if the plant was run on cow dung only, would be 5 x 2.8 = 14 m^3. (ii) The volume of the digester (slurry) required, if the plant was run on pig dung only, would be 5 x 1.8 = 9 m^3. (iii) If the plant was run on mixed dung, and assuming that 1.5 m^3 of gas is produced from cow dung, the part of the digester volume to produce the gas from cow dung would be 1.5 x 2.8 = 4.2 m^3 and assuming that 3.5 m^3 of gas is produced from pig dung, the part of the digester volume to produce the gas from pig dung would be 3.5 x 1.8 = 6.3 m^3.

The volume of digester required would therefore be 10.5 m^3.

In actual practice it is often easier not to change the digester (slurry) volume because frequent changes confuse the builders and also any savings do not amount to much. The larger volume should always be selected. In this example 14 m^3 would be used. Again in actual practice most countries specialize in either pigs or cattle. Outside China it is not often that mixed dung is used. Mixed dung works very well in gas plants and each type seems to help the other to produce more gas.

Example 3.

A farmer has a family of 5 persons, he has 3 pigs and a lot of crop waste. He wants to use the human, animal and crop waste in producing enough fuel for cooking and lighting and effluent for land. He would prefer a fixed dome type digester.

The average gas need *per capita* is 0.3 m^3 per day, hence 5 persons will need 5 x 0.3 = 1.5 m^3 per day. This should be produced by the excreta of 5 persons, the dung of 3 pigs and a certain amount of plant waste.

(i) Amount of gas produced by 5 persons: assuming that each person produces 1.3 kg per day of excreta, 5 persons will produce 5 x 1.3 = 6.5 kg per day; assuming further that the gas produced per kg of human excreta in the fixed dome digester is 24 litres, then 5 persons will produce 6.5 x 24 = 156 litres per day.

(ii) Amount of gas produced by 3 pigs: assuming that each pig produces 6 kg of dung per day, 3 pigs will produce 6 x 3 = 18 kg of dung per day; assuming further that the gas produced per kg of pig dung in the fixed dome type digester is 34 litres, then 3 pigs will produce 18 x 34 = 612 litres per day.

The total amount of gas produced daily from the waste of 5 persons and 3 pigs = 156 + 612 = 768 litres.

The amount of gas that should be produced daily by crop waste = 1,500 – 768 = 732 litres.

(iii) Amount of crop waste needed to produce 732 litres of biogas per day: we assume that 1 kg of crop waste produces 30 litres of gas in six months. The amount of crop waste needed to produce 732 litres $\frac{732}{30} \cong 25$

---

*This number fluctuates between 20 and 30.

kg per day. As crop waste addition takes place every six months, partly because of its long fermentation period, the total amount of crop waste which should be added every six months to generate 732 litres of gas/day = 25 x 180 = 4,500 kg. Assuming that the digester will produce 0.15 m^3 of gas/day per m^3 of digester volume (7), the volume of digester needed will be $\frac{1.5}{0.15} = 10\,m^3$.

If the digester is to be built in a tropical country, the gas produced per day per m^3 of digester volume may be as high as 0.3 m^3 or even higher, hence a smaller digester will suffice. The high temperature in the tropical country will also speed up the fermentation process of crop waste, thus shortening its retention time. Accordingly, sludge removal and addition of plant waste may take place three times a year, or more often, instead of twice.

It is usually necessary to compost the plant waste for at least ten days before feeding it to the digester. Details on the way to do this are given in chapter XI.

C. Site selection

At every house where a gas plant is to be built a careful selection of the best site for the plant must be made (see figure 30 and 31). The factors which influence the decision are:

(a) It should be close to where the gas will be used – gas pipes are expensive;

(b) It should be close to the supply of input material (dung) – to save carrying it;

(c) It should be close to the place where effluent can be stored (e.g., compost pits) so that the effluent can flow into the storage pit without any handling;

(d) It should be 10 to 15 metres from any shallow wells – to prevent contamination;

(e) It should be free from any intrusion of bamboo or big tree roots, which may creep into the digester and cause damage;

(f) It should be in the sun – to keep the plant warm. This, however, is not essential. Some research indicates that constant temperature (i.e., in the shade) gives better gas production than fluctuating temperatures (i.e., in the sun);

(g) It should be away from low areas that could be easily submerged by water and buffeted by cold prevailing winds – to prevent heat loss;

(h) It should have suitable foundation conditions.

Slurry should be put in irrigation water (in season) using buckets and dried at other times in pits. Floors should be washed letting dung, urine and water flow to the mixing pit. If a lot of water is used, then excess water should be removed from the mixing pit and used to irrigate maize and vegetables.

In China (1), (14), the rule "three-in-one" has been widely adopted in the countryside. This means connecting the digester, the pigsty and the toilet together at the digester inlet (figure 32). This is convenient in feeding the input materials and in cleaning toilet and pigsty, as human and animal waste can flow by gravity into the digester. Besides, the gas pipe can be taken a short way to the rooms along the walls without supports.

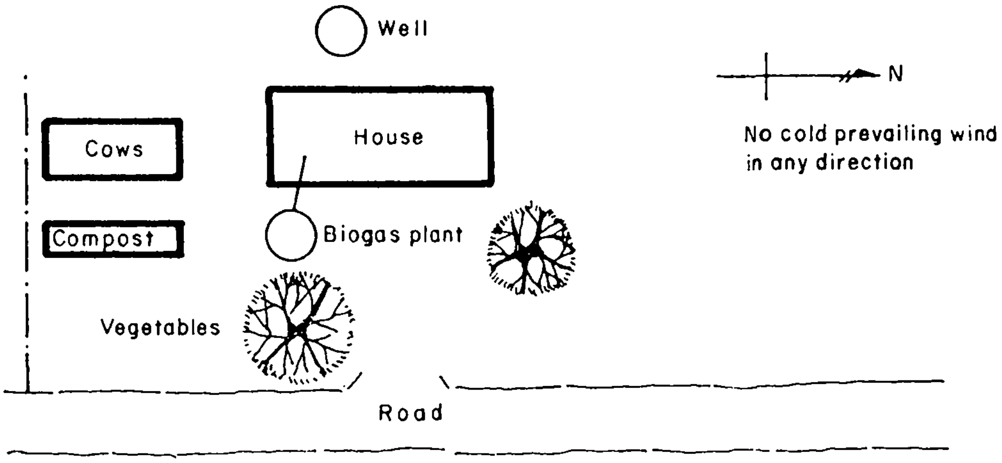


Figure 30. Example 1, flat type

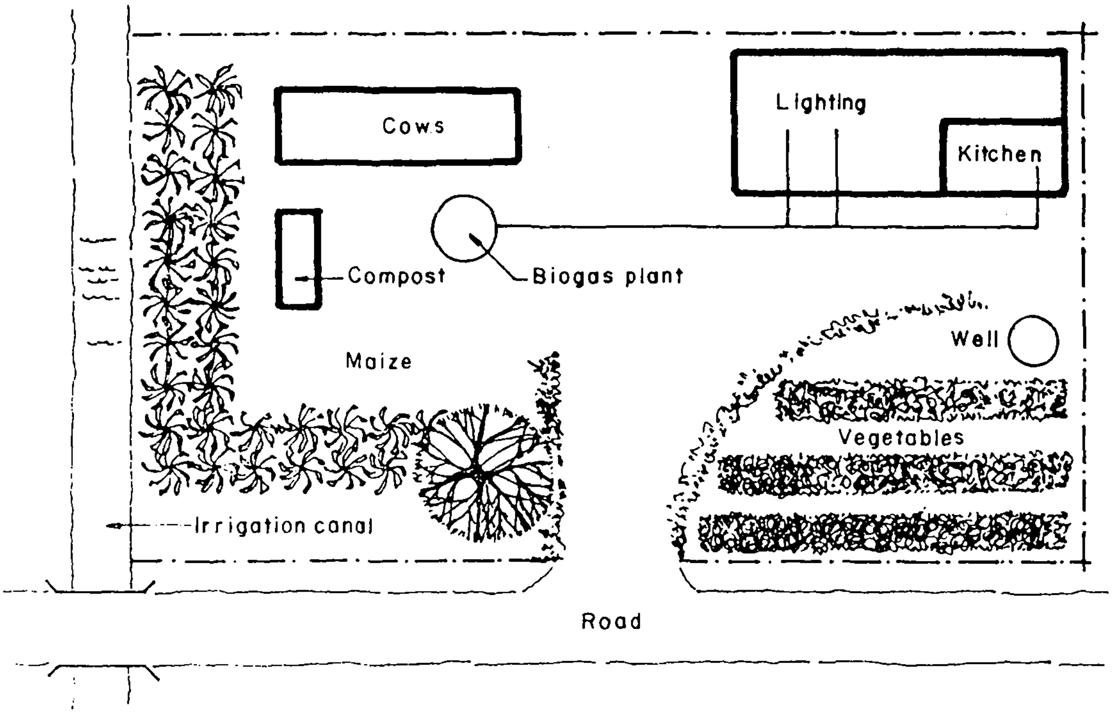


Figure 31. Example 2, steep slope down towards north

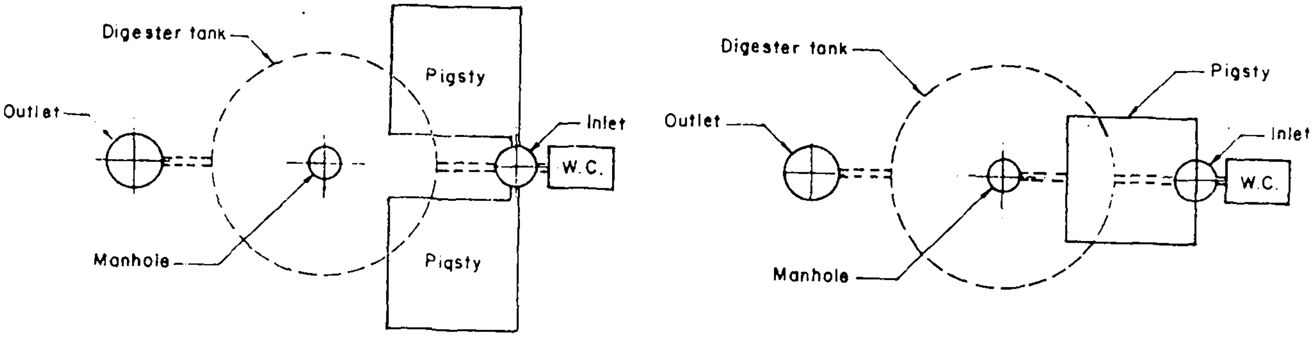


Figure 32. Example 3, the rule of "three-in-one" (China)

VIII. CONSTRUCTION OF DIGESTER

Digesters and associated masonry work can be made out of any of the usual building materials except unburnt bricks and mud mortar, which are not satisfactory as both of these deteriorate over time. Choice is normally a matter of what is available at the lowest cost.

A. Materials needed

(a) *Bricks.* They must be burnt.

(b) *Stones.* They must be clean. Walls tend to be thicker when stones are used and require more cement.

(c) *Sand.* It must be free from vegetable matter and mud, etc. To test for cleanliness, fill a bottle 1/3 with sand and 2/3 with water; shake it. Allow to settle until the water is clear. This may mean leaving it overnight unless some salt is added, which makes the impurities settle more quickly. If the impurities (mud. etc.) form a layer more than 6 per cent of the total height of the sand, the sand must be washed. If this is not done, the mortar will be weak. If the sand is very fine, it takes a higher cement to sand ratio to give a similar strength to the mortar. Poor quality sand is a common problem in certain areas and causes weak masonry work, which only lasts a short time before breaking.

(d) *Cement.* Ordinary Portland cement is satisfactory. Additives are not necessary. If it is stale, i.e., lumpy, then a richer mortar mixture is necessary (cement is usually sold in 50 kg bags = 0.04 m^3).

(e) *Gravel, broken stones.* These should be free from vegetable matter and soil, etc.

(f) *Cement mortar.* The mortar should be the same strength as the bricks or stones it binds together. The ratio of sand to cement depends on the quality of these materials. Typical ratios are 1:9 for good quality cement and sand right down to 1:4 for poor quality cement and sand. The materials are normally measured in villages by volume.

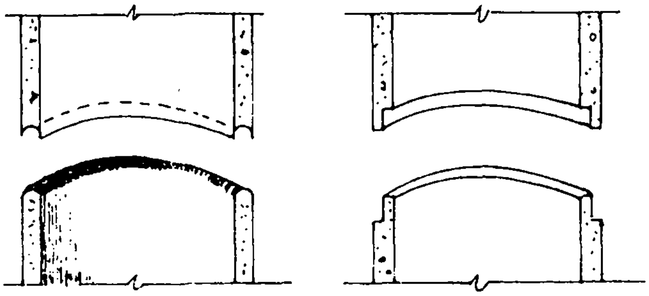
(g) *Mud mortar.* This is not recommended for general use. However, when stone walls are used, these tend to be wide and use a lot of mortar. Using cement mortar for at least 150-250 mm (6-9 in) from the inside face of the digester wall and mud mortar from there outwards could be tried.

(h) *Concrete.* Occasionally this is one of the cheapest methods of construction and it works well provided it is compacted to eliminate air pockets (5 per cent air voids in concrete = 50 per cent less in strength). A typical mixture of cement, sand and gravel would be 1:3:6.

(i) *Lime concrete.* This is one of the Chinese traditional building materials. It is composed by volume of one part of lime, 3 parts sand and 6 parts of crushed stones or bricks. It should be well tamped layer by layer in building the walls and the digester top (16).

(j) *Lime clay.* This is another traditional Chinese building material. It has poor strength at an early stage, but becomes hard and strong gradually after a few chemical reactions. Usually a mixture by weight of one part lime to 9 to 19 parts clay is used. The optimum moisture content is 20 to 24 per cent (16).

(k) *Pre-cast concrete rings* (figure 33). In some places these are used for wells and are easily obtainable at a reasonable cost. They are very suitable. Where they are of large enough diameter and free from voids, joints should be cemented. If the rings are heavy, it may well be necessary to use lifting equipment to set them into position.



Concave-convex joint

Lap joint

Figure 33. Methods of joining precast concrete rings

(l) *Pre-cast concrete sections.* Those may be appropriate where concrete is not expensive and many similar plants are required (making the forms can be expensive). It is unlikely to be economic for irregularly shaped plants such as taper or horizontal plants. Sections should be made of such a size that they can be placed in position without lifting equipment. Sections are usually bolted together. Joints should be cemented to close any gaps.

(m) *Ferrocement.* Ferrocement is a composite material consisting of thin wire mesh impregnated with rich cement mortars. In other words, it is a reinforced mortar, but unlike reinforced concrete it has high resistance to cracking. It seems to have excellent possibilities and should be cheaper as fewer building materials are needed and a smaller hole needs to be dug, but it has not been tried in many countries.

(n) *Additives for increasing water impermeability.* Some people use these in cement but they are not generally needed.

B. Digester with floating gas holder

(a) *Floors.* Common materials are concrete and masonry. Concrete should only be used where it is cheaper or where the ground condition is very bad, thus making it essential. Usually it is much cheaper and simpler to use masonry materials. If the bottom of the hole for the gas plant is muddy or soft sand, a layer of broken bricks or stones must be pounded in until the ground is firm. The floor should be reasonably level. Bricks for the floor, including wall foundations, are set on their edge (not on their face). This method gives sufficient strength, except in the case of installations built above ground level, because the weight of the walls is not significantly greater than the weight of the soil removed. The bricks are laid out as illustrated in figure 34. This method spreads the load of the walls over a greater area to give added strength.

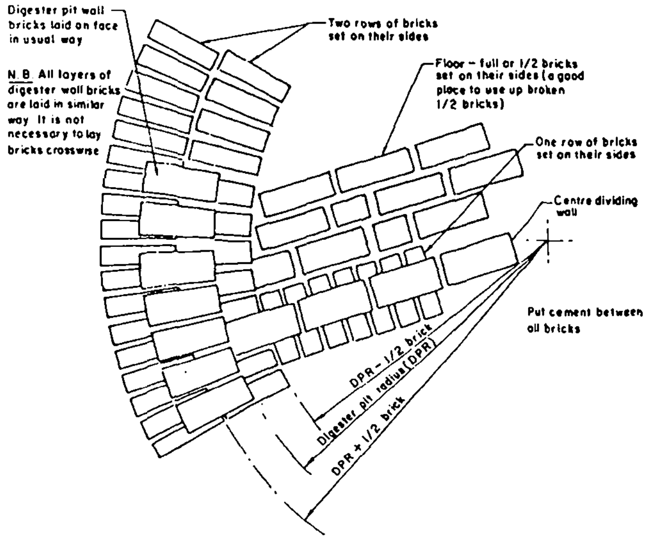


Figure 34. Construction of digester floor

(b) *Side walls.* Where concrete is used, a square or rectangular design will probably be cheapest. However, for bricks or stone work it is best to use a circular design as this requires less materials, is stronger and quicker to construct, using the gauge illustrated in figure 35 than a square design.

It is essential to backfill between the walls and the sides of the holes after every 30 cm (one foot) has been added to the walls. Sand is best. Otherwise, use dug-out material. Ram it into place thoroughly with a piece of wood and add water to help compact the soil. The digester walls are not retainer walls and must have a firm support. Failure to do this job properly is a major reason for gas plant walls breaking.

Normally digester walls rise not more than 30-35 cm (12-14 in) above ground level (figure 36). In certain cases it is necessary to build more than this above ground level and this can be done within reason. A big disadvantage is that the dung and water have to be lifted up to be put into a plant built above ground level.

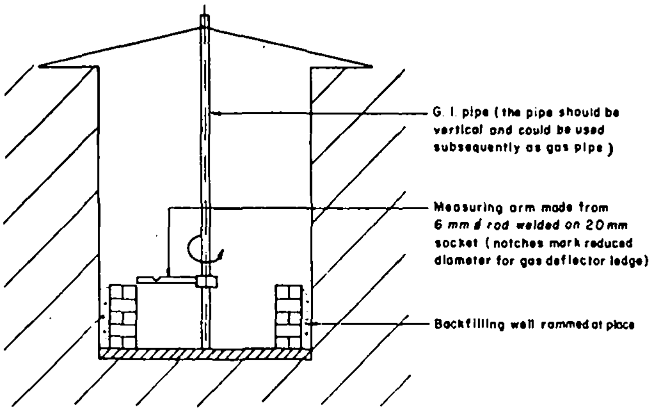


Figure 35. Construction of side walls under ground level

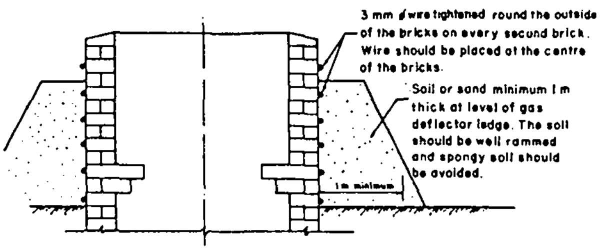


Figure 36. Construction of side walls above ground level

(c) *Partition walls.* These are commonly used in larger plants producing more than 3 m^3 (100 cu ft) gas per day. The theory is that they control the flow of the slurry. This theory is being challenged by another theory that all the contents, new and old slurry, should be mixed together. So far, insufficient proof has been given and the traditional method is commonly used. The wall only controls the flow of the slurry and requires no structural strength. A half brick wall (5 to 7 cm) is adequate. It is built up to the level of the top surface of the deflector ledge.

(d) *Deflector ledge.* This is essential if water sealing is not provided. It deflects gas forming on the sides of the plant into the gas holder. Failure to provide this can mean a 10 per cent gas loss and much more in the case of the horizontal or taper-type design (plants with water seal do not need it). The ledge is made to protrude about 100 mm (4 in) inside the gas holder circumference. If concrete rings or concrete sections are used, then thought must be given how to fit a ledge. One way is to put a series of pegs into the sides and tie two rod rings onto these. Chicken wire is attached to this and then plastered (figure 37). An alternative is to lay bricks on the rod rings and then plaster.

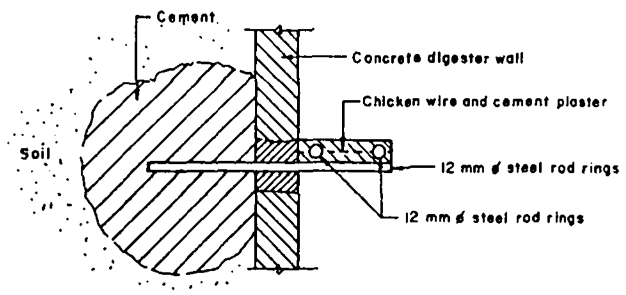


Figure 37. Construction of deflector ledge into digester concrete wall

This structure is not designed to take any load. Therefore the gas holder should be made to rest on the supports for the central guide or alternatively the number of pegs driven into the sides to support the steel rings should be doubled.

The deflector ledge should be level on its top surface. It can then be used as a convenient datum for measuring. The following dimensions apply to all sizes of plant (figure 38).

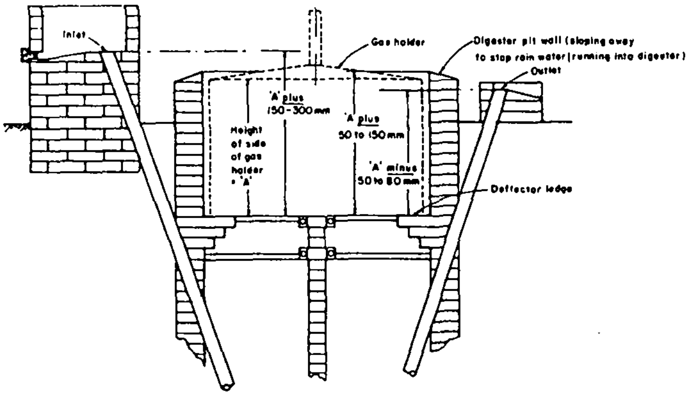


Figure 38. Digester height relative to deflector ledge

(i) From the ledge top surface to the top of the digester pit walls: this is normally the height of the sides of the gas holder plus 50-150 mm (2-6 in);

(ii) From the ledge top surface to the mouth of the inlet pipe: the height of the sides of the gas holder plus 150-300 mm (6-12 in);

(iii) From the ledge top surface to the mouth of the outlet pipe: the height of the sides of the gas holder minus 50-80 mm (2-3 in).

When the slurry enters the plant daily, the level of the slurry in the digester rises. It lowers slowly as the effluent comes out of the plant. With this design, the only time the slurry can possibly touch the roof is when the gas holder is completely empty and fresh slurry has been fed in, but insufficient time has been allowed for the old slurry to flow out and there is a thick scum on the surface – an extremely unlikely set of circumstances. This feature is important because when a flexible gas or hooked underside gas pipe is used, if any slurry enters the pipe, it can block the flow of gas and be quite difficult to remove. (This is not a problem when a centre guide gas pipe is used.) The level is not lower as for most of the time it would be impossible to extract all the gas from the gas holder as the slurry level would be too low.

(e) *Centre guide.* This must be vertical, otherwise the gas holder may not move up and down freely. A gap of 50 mm (2 in) is normal between the gas holder and the walls (figure 39).

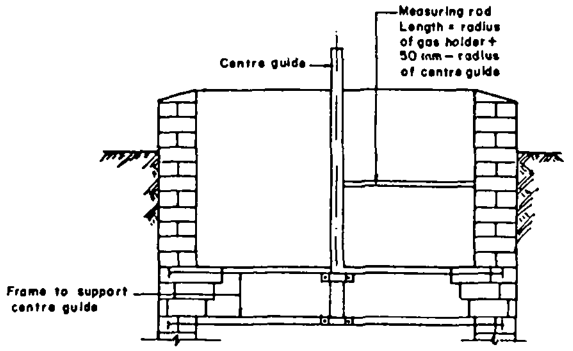


Figure 39. Construction of centre guide

(f) *Inlet (or mixing) tank.* It is usual to mix the dung and water in this tank. It is most convenient if it is designed to hold the correct amount of daily slurry, plus a margin of about 100-150 mm (4-6 in) in the height to prevent the slurry being spilt when it is being mixed. There must be no obstruction from any side wall of the mixing pit which would prevent a pole being pushed down the inlet pipe to clear any blockages.

The floor should have a distinct slope away from the inlet pipe (figure 40). A hole and plug need to be fitted at the lowest point. This is to collect any gravel, sand or earth

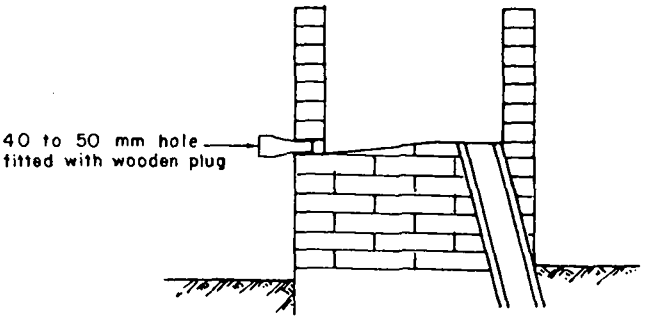


Figure 40. Construction of inlet (mixing) pit

and prevent it entering the gas plant. It also facilitates the washing out of the inlet tank as no extra water should enter the digester. A removable sieve can be fitted to the inlet to prevent lumps of dung going into the plant. When the slurry is being mixed, a plug (e.g., a stone wrapped in a bag) must be fitted over the inlet pipe. The inlet tank should not be built on backfilled ground as this may sink in time and break the inlet pipe.

(g) *Inlet/outlet pipes.* From experience 100 mm (4 in) diameter is the best size for inlet/outlet pipes, regardless of the plant size. Pipes smaller than that tend to have frequent blockages. Larger sizes add unnecessary expense. Any low-cost pipe can be used, e.g., asbestos, cement, concrete, burnt clay pipes. It is essential that there are no bends in the pipes as these cause blockages. This is a common cause of plant failure. This point cannot be stressed too much.

The lower end of the inlet is placed in about the centre of the compartment. This position is not vital, but what is important is that the fresh slurry moves all the old slurry from the bottom and dead patches of unmoving slurry are not allowed to form.

The mouth of the pipe is set about 300-350 mm (12-14 in) above the floor of the digester (figure 41). This facilitates any rodding (clearing blockages) of the inlet pipe and also provides some volume in case stones, sand, etc. get inside the plant and collect over a period of years. The lower end of the outlet pipe (if used) is constructed in a similar way. The only difference is that the mouth of the pipe is set about 250-300 mm (10-12 in) above the floor as it is not so likely that stones, sand, etc. will come down this pipe.

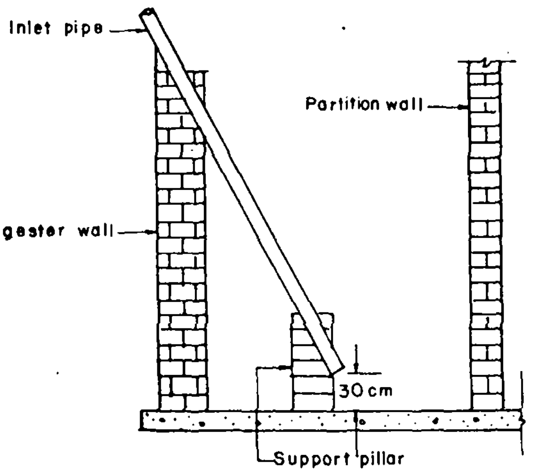


Figure 41. Inlet/outlet pipes

(h) *Outlet.* In small plants where no centre dividing (partition) wall is used, a notch in the top of the digester wall forms the outlet. The height from the deflector ledge to the bottom of the notch equals the height of the gas holder minus 50 to 75 mm (2-3 in). The notch is not less than 150 mm (6 in) wide as slurry tends to dry and effectively reduce the width of the notch.

Pipe outlets usually have some bricks around the mouth to prevent accidental damage or breakage of the pipe.

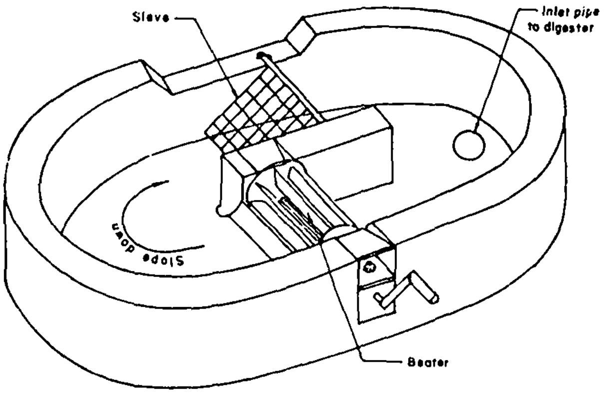


Figure 42. Slurry-mixing machine

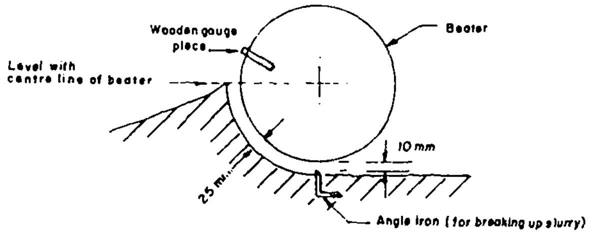


Figure 43. Setting of the beater

Both *notch and pipe outlets usually have a channel* running from them to compost pits or slurry-collecting tanks.

(i) *Mixing machine.* This is usually only justified for larger plants of 10 m^3 (350 cu ft) per day and more. The mixing machine (figure 42) is normally designed so that it holds all, 1/2, 1/3 or 1/4 of the daily input filled up to the level of the top of the slope beside the beater. Too much or too little slurry will make the machine difficult to operate well. If the radius at the front of the beater is not *correctly adjusted, then the slurry in the machine will not* circulate easily.

A piece of wood should be attached to one blade protruding 25 mm (1 in) and used as a measure (figure 43). Covers are usually fitted over the beater to avoid splashing. For the collection and removal of gravel, sand, etc., a channel can be made in the floor near the inlet pipe to the digester (the lowest point). This is run to the wall. In the wall a hole 40 to 50 mm diameter is made and a wooden plug fitted.

Annex V

BAG TYPE BIOGAS PLANTS

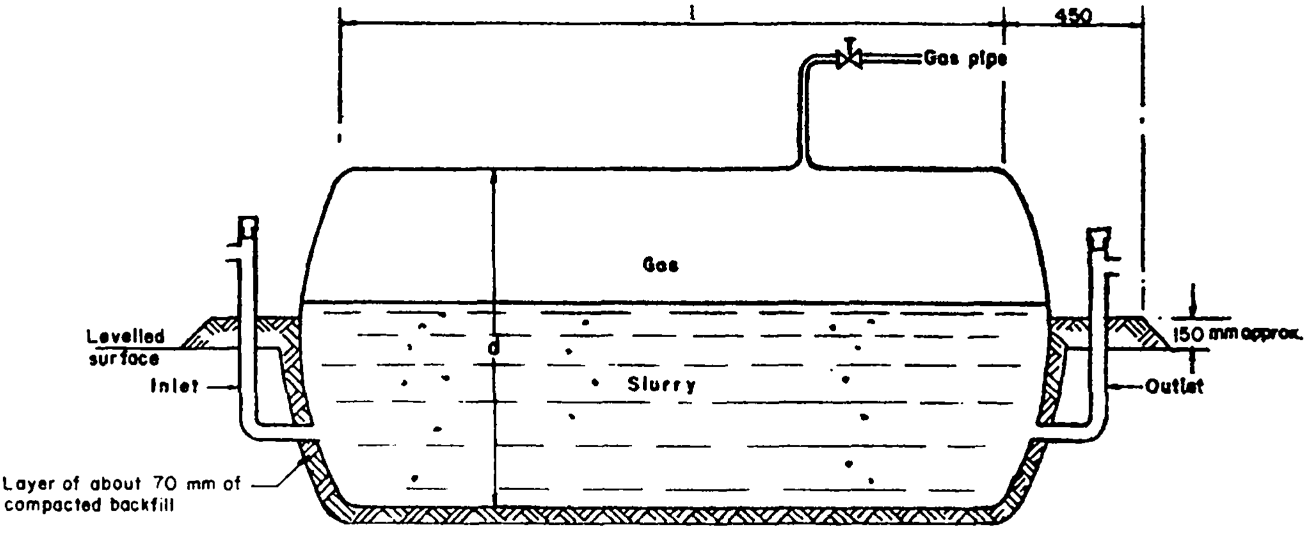


Figure 93. General arrangement of cylindrical type

Size m^3	l	d
5	3000 mm	1500 mm
10	3700 mm	1850 mm
30	5400 mm	2700 mm

Material: Hypalon-Neoprene coated fabric (Nylon) 0.55 ± 0.05 thick.

Other sizes: 15 m^3 (cylindrical)
50 m^3 (rectangular block)
100 m^3 (rectangular block)

The size of all bag digesters listed is the total volume of the digester, including gas storage chamber. (It is not the gas production per day – see chapter VII for expected gas production depending on type of input)

Annex VI

FLOATING GAS HOLDER TYPE BIOGAS PLANTS

The designs included in this annex are of two types.

(a) *The Development and Consulting Services (DCS) plants**

The drawings attached include the following designs:

(i) Digester for 2.8 m^3 gas per day straight type plant (figure 100)

(ii) Digester for 5.7 m^3 gas per day straight type plant (figure 101)

(iii) Digester for 10 m^3 gas per day straight type plant (figure 101)

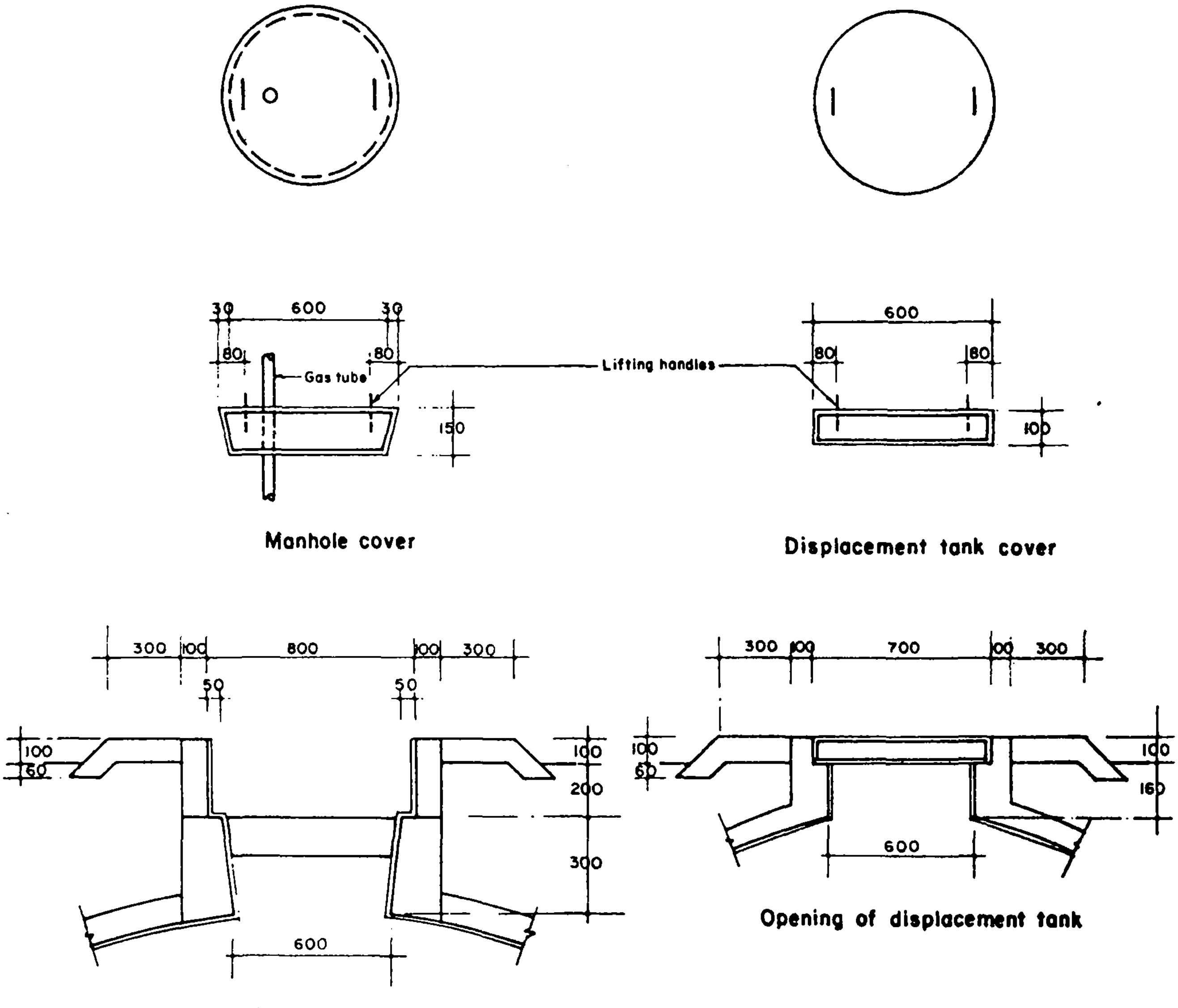
(iv) Digester for 10 m^3 gas per day taper type plant (figure 102)

(v) Gas holder for 2.8 and 5.7 m^3 gas per day plant (figure 103)

(vi) Gas holder for 10 m^3 gas per day plant (figure 104).

---

*These designs were provided by the Development and Consulting Services, Butwal, Nepal.



Manhole cover

Displacement tank cover

Opening for manhole cover

Opening of displacement tank

Notes :
1. Covers are made of # 150 concrete or slabs
2. Gas tubes are of steel, plastic or bamboo about 25 mm inside ⌀, 500 mm long
3. Inlet pipes and their connections are made of concrete

Not to scale

Dimensions in mm

Figure 98. Details of manhole and displacement tank covers

(j) *Water seal.* This has to be made accurately so that the gas holder does not rub on the masonry work. It should not be wider than necessary, otherwise more water will evaporate. It must be well plastered on the inside to prevent water leaks. Any cement which falls down during plastering must be removed.

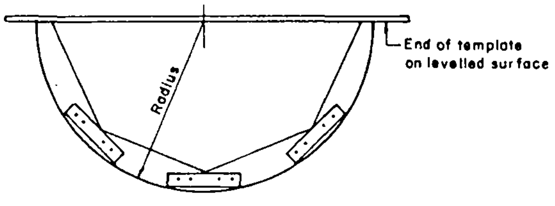
(k) *Compost pits or slurry-collecting tanks.* These can be dug in the ground or lined with masonry. The latter prevents weeds growing into the compost but is not essential. For the sake of safety it is suggested that compost pits are not more than 80 cm (2 ft 8 in) deep. The volume should be sufficient to receive the amount of slurry put in per day multiplied by the number of days between emptying pits. The slurry volume will reduce as water evaporates and this can accommodate any compost materials (e.g., animal bedding) which may be added.

If the masonry work has been done well then there is no need to plaster the inside of the digester. Some people do "paint" the inside of the digester with a cement/water wash. (If a thick plaster is used, this will significantly reduce the volume of the digester.) The slurry level will always be higher than ground water level: therefore, any water movement will be from the digester outwards. The solid matter in the slurry will seal any very small holes (not large ones). It is quite common to put a thin plaster on the exposed masonry work. This is only for decorative purposes.

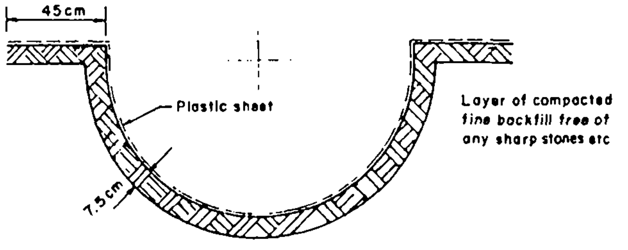
C. Flexible bag type digester

Although these digesters come as complete units, they must be installed properly. A flat site is needed. Half of the cylindrical bag digester is set in the ground (figure 13) and needs to be protected with 7.5 cm (3 in) of selected fine material which will not puncture the bag (figure 44). The trench is then lined with ordinary plastic sheets for extra protection.

The trench should be made a bit too long so that the inlet and outlet pipes can be put in place. It can be filled in after the bag is inflated and the right shape. Before installing the digester, seal the inlet and outlet pipes (basket-ball bladders work well) and close the gas pipe tap. Inflate the bag (use motorized knapsack sprayer air pump) and check for leaks. A special repair kit must be bought from the bag manufacturers. Having repaired any leaks, install the bag in the trench and backfill carefully around the inlet and outlet pipes using fine backfill.



i) Template for excavation



ii) Cross-section of the excavation

Figure 44. Excavation of a trench for flexible bag type digester

D. Fixed-dome type digester

This is usually an underground, circular, small and shallow digester.

The advantages of placing the digester underground are:

(i) Saving of farmland;

(ii) Making use of earth formwork in construction;

(iii) Providing better thermal insulation, thus avoiding the cracking of digester tank walls, which may occur in view of uneven temperature and moisture distribution;

(iv) Facilitating the connection of the pigsty and toilet to the digester inlet.

On the other hand, underground digesters need more excavation work and present some difficulties in high water-table areas.

Plate 1
Marking the site for the digester (Chinese fixed-dome)

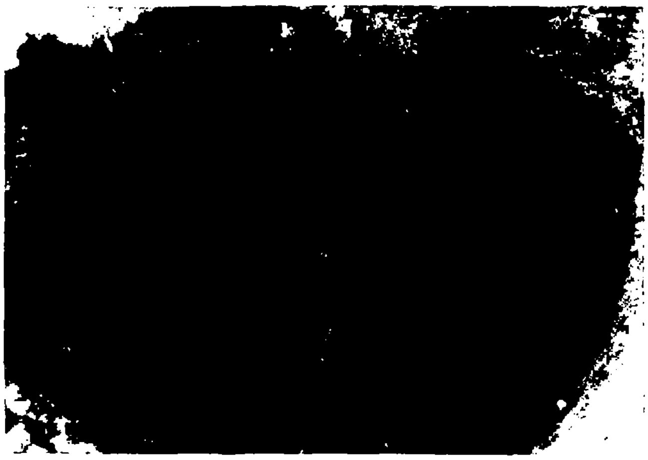


Plate 2

The digester pit. Inlet (1) and outlet (2) are also seen

Plate 3

Laying the bricks to raise the digester wall

The main advantage of having a circular digester is the uniformity of stress on the cylindrical shells (forming the walls) and spherical shells (forming the top and the bottom).

The small digester (6, 8, 10 and 12 m^3) is suitable for families of 3 to 7 persons with a relatively small gas consumption (0.2 to 0.3 m^3 *per capita* per day). Finally, the shallow digester needs less excavation work and is advantageous in high water-table areas. Besides, experiments have shown (16) that more gas is produced from the same volume of digester the larger the surface area of the fermented slurry and the lower the pressure above its surface.

(a) *Pre-construction actions*

The soil should be well examined first and the following measures and precautions considered:

(i) If the soil is formed of clay, which expands and contracts easily as the moisture content of the soil increases and decreases, the following actions should be taken:

a. Construction work can be promoted;

b. No disturbance to the primitive soil should be made;

c. Precautions against excess or loss of water should be taken;

d. Special attention should be paid to the drainage of surface water.

(ii) If the digester has to be built on two different kinds of adjacent soils, e.g., partly on rock and partly on another kind of soft soil, the following actions should be taken to prevent possible cracks of the digester due to uneven settlement:

a. A uniform kind of soil under the digester should be provided;

b. If this is not possible, a portion of the soft stratum should be removed and lime, concrete and rubble inserted in its place;

c. A part of the rock may be cut and medium and coarse sand, cinders, clay or clay with gravel may be laid as a mattress of about 30 to 50 cm thick under the entire tank of the digester.

(iii) If the water-table is high, the following actions should be taken:

a. An attempt should be made to build the digester in the low water season;

b. A trench should be dug around the digester to collect the water, which should be pumped out occasionally;

c. The ground water should be diverted to other places if possible (e.g., to well points);

d. The thickness of the backfilling over the digester tank should be increased to counteract the buoyancy force, which tries to lift the digester.

(b) *Construction technique of brick digesters*

The bottom is usually constructed of concrete but the walls and dome are constructed of bricks.

(i) Lay-out

a. Draw a circle, e.g., with lime powder, of diameter D = external diameter of digester + twice the thickness of the backfilling, which is 15 to 20 cm thick;

b. Determine the centre of the digester, e.g., by placing wooden stakes in the ground at one metre distant from the circle (figure 45). The centre of the digester is the intersection of these diagonal lines.

(ii) Excavation work

An over-all excavation is made. The pit should be round and the walls straight and vertical. No explosives should be used in the excavation work.

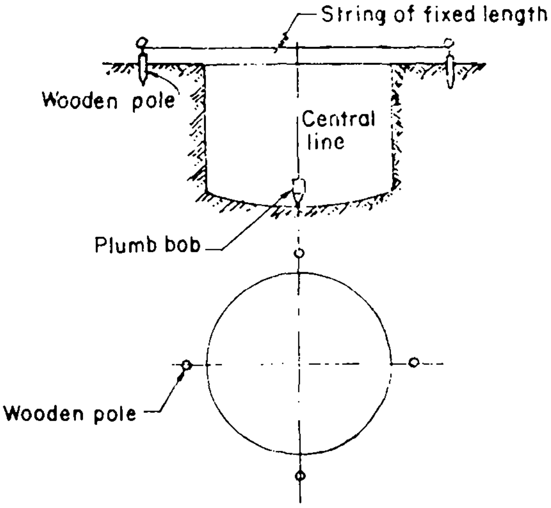


Figure 45. Laying out digester tank

Plate 4

Adjustment of outlet pipe

(iii) Bottom construction

a. The bottom should be shaped according to the dimensions given in the drawings;

b. The earth should be well rammed;

c. A bed of pebbles of 15 to 20 cm in thickness should then be laid and tightly packed;

d. The concrete may then be poured, plastered and rammed.

(iv) Wall construction

a. Locate the centre line using a central pole (figure 46);

b. Fix a movable arm-gauge to assist in the construction of the walls (figure 47);

Plate 5

The finished digester wall

Plate 6

Starting the construction of dome. The first rows of bricks being placed on the slant

c. When the bottom has attained a certain strength, start constructing the walls after soaking the bricks in water;

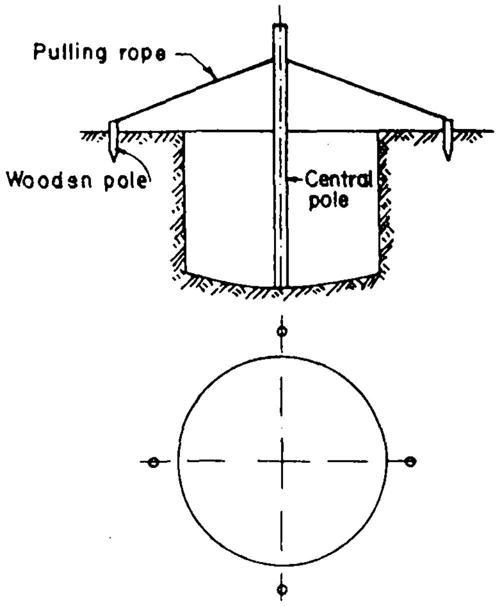


Figure 46. Fixing the centre line of the digester

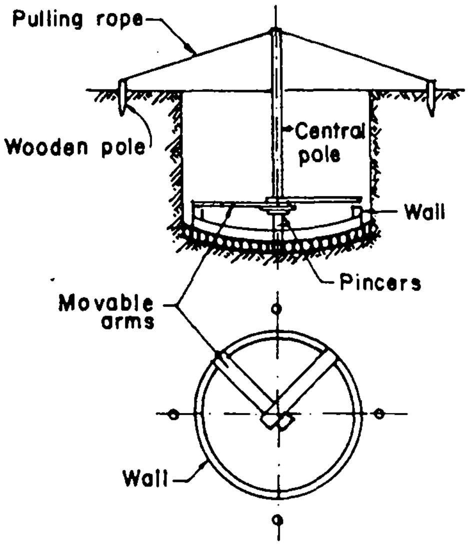


Figure 47. Construction of the walls using a movable arm-gauge

Plate 7

Dome construction in progress

Plate 9

Sealing of the dome from outside with coment and sand mix

Plate 8

Wetting of bricks

d. The horizontal bricks should be laid flat, and the vertical ones straight with a full application of mortar;

e. The mortar lines should be properly cleaned on both sides of the wall;

f. The wall should be sprinkled with water for preservation.

(v) Back filling

a. The water content in the earth used for back-filling should be in the range of 20 to 25 per cent;

b. Broken bricks and tiles, pebbles or gravel should be added to form 30 per cent of the total volume. If clay is used for backfilling, its density should not be less than 1,800 kg/m^3;

c. The backfilling should be tamped evenly and symmetrically each time a layer of about 15 cm is added;

d. The construction and the backfilling work of the inlet and outlet should be carried out at the same time (and at the same elevation) as the construction of the digester tank.

(vi) The construction of the dome support

a. The ring beam (figure 48) should be poured and tamped in sections using two pieces of wooden arch boards placed and held normally at both sides of the wall for pouring the low-flow-ability concrete;

b. Stone blocks with mortar (or cobble concrete) should be placed between the ring beam and the primitive soil to transmit the thrust uniformly to the primitive soil;

c. If reinforced concrete is used in the construction of the ring beam, there will be no need to construct the cobble concrete.

(vii) Construction of the dome

The mouldless arch method is described here (figure 49).

a. Bricks of regular shapes should be chosen, soaked in water and kept wet on the inside but dry on the outside, thus capable of absorbing more water;

b. Masonry mortar with good bonding properties should be used. For example, cement, lime and sand could be mixed in the ratio 1:1:4 respectively (7);

c. Bricks must be laid in interlacing courses with sufficient mortar;

d. A string gauge should be set with the radius of curvature to help fixing the bricks;

e. When laying the bricks a wooden pole (figure 49) or an S-shaped clip (figure 50) may be used to keep the bricks in their positions. It is also possible just to hold them by hand;

f. When each circle of bricks is laid flat, pebbles should be pressed into the gaps between the bricks. This gives the dome the form of a round shell and achieves a certain integral strength;

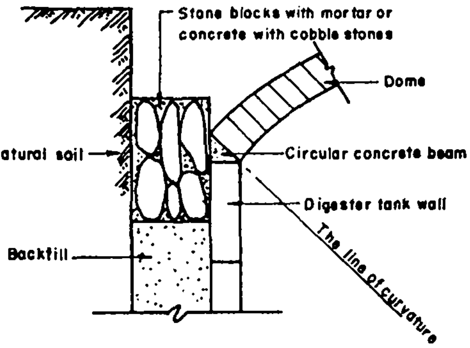


Figure 48. Construction of the dome support

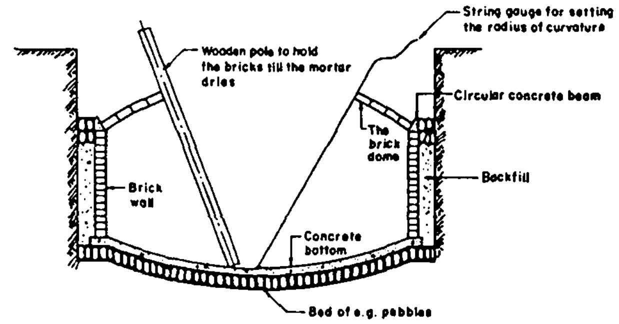


Figure 49. The mouldless arch method of constructing the dome

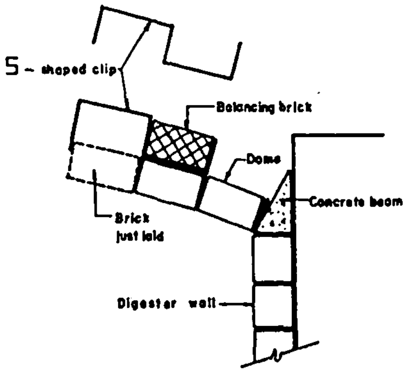


Figure 50. The use of an S-shaped clip for holding the bricks

g. When 3 or 4 brick courses are laid, backfilling should follow to facilitate the work later and to increase the stability of the shell structure;

h. Bricks cut in halves should be used for the course next to the central opening of the dome (manhole).

(viii) Plastering the internal surfaces

All the interior of the digester tank, outlet, inlet and the movable cover should have a layer of sealing coat.

Plate 10.

The completed dome, yet to be plastered

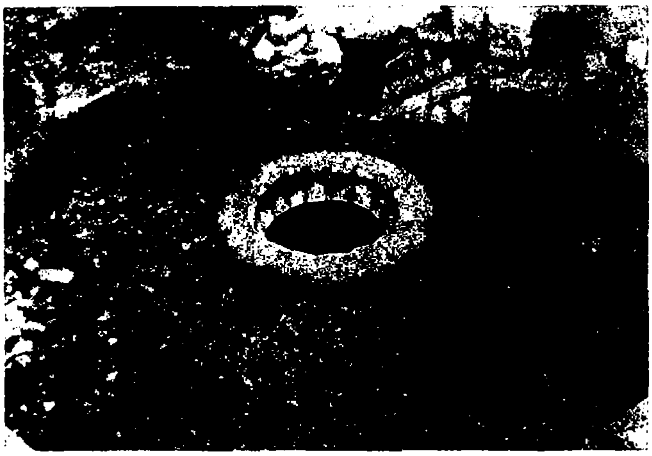


Plate 11.

The dome covered with backfill

a. Base coating: all bits of hose concrete and mortar should be removed and the surface should be cleaned with water, then brushed with a layer of cement and lime in the ratio of 5:1;

b. Plastering of the bottom layer: a layer of cement, lime and sand in the proportion of 5:1:15 of 5 mm thickness should be plastered, then pressed hard with a towel after 2 to 3 hours (when it is still half-dry);

c. Plastering of the middle layer: the same steps (plastering the bottom layer) should be repeated once more to form the middle layer;

d. Plastering of the surface layer: the cement, lime and sand in this layer should have the proportion of 5:2:15. The thickness of the layer should be also 5 mm. It should be pressed and smoothed twice with a towel. The surface must be flat and smooth with no protruding grains of sand;

e. Surface coating: an amount of iron oxide (Fe_2O_3) equal to 0.7 to 1 per cent weight of the cement should be added to the mortar. Then the whole surface should be brushed two or three times with the mixture.

(c) *Construction technique of concrete digesters*

This method is suitable for concrete, lime concrete or lime clay digesters. It has the following advantages over the previous method:

(i) The strength of the materials can be used to a greater extent;

(ii) Sealing is better;

(iii) The walls have better adhesion with the primitive soil, thus a lot of backfilling work is saved.

These are the main steps in constructing a concrete digester:

(i) A ring of trench as shown in figure 51 has to be excavated and well rammed.

(ii) A thin layer of coal ash or fine sand should be sprinkled on all the surfaces.

(iii) The wall has first to be poured and well rammed; then the dome has to be cast.

(iv) For large digesters the earth formwork may be reinforced using timber rods or bamboo mat (figure 52) before the dome is cast. This is done by digging a cavity half the diameter of the digester tank.

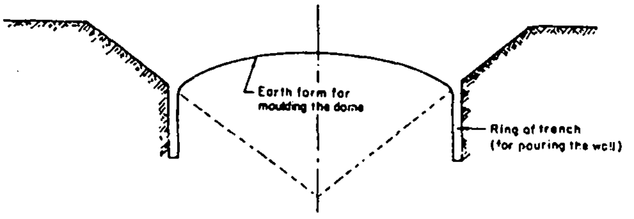


Figure 51. Excavation work of a ring of trench

(v) A backfilling of at least 30 cm is tamped, the mat is laid over it, then a layer of fine sand of 1 to 3 mm may be added to act as a parting agent.

(vi) When the strength of the dome develops to a certain extent, the core earth may be removed through the manhole, starting from the top downwards. The removed earth can be used as formwork on the dome.

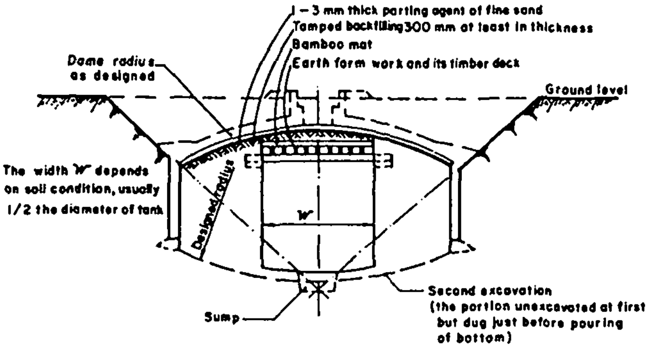


Figure 52. Casting of digester dome

Plate 12

Inside view of the digester which will be given wetting, and thereafter sealed

Plate 13

Cement coating of the digester from inside

(vii) If the soil at the bottom is found to be rather solid, it may suffice to ram it well. However, if it is loose and soft, then it should be tamped with concrete, lime concrete or lime clay.

(viii) It is preferable to excavate the bottom in the order indicated in figure 53 and to place bricks under the wall to balance and support the wall.

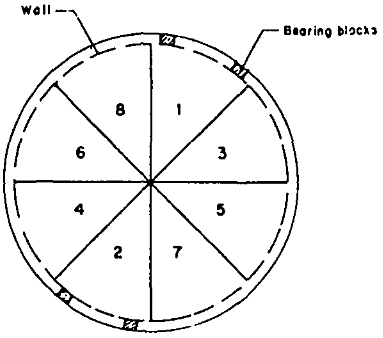


Figure 53. Excavation of bottom according to numbers

(ix) The bottom is then poured.

(x) The plastering technique described above for the brick digester may be applied here too.

(d) *Construction technique of cast-in-place and precast digester*

This method is used for either a precast or a cast-in-place digester, using low grade concrete or concrete made of clinker-free cement. The method of over-all excavation is applied. The bottom is laid first, then the wall is built next and finally the dome is cast. It is preferable to cast the bottom and top and to use precast walls.

(i) The lay-out, excavation and bottom construction are the same as in the brick digester.

(ii) Precast concrete slabs, stone slabs or masonry slabs may be used to construct the wall. The slabs should be fitted firmly into place so that they cannot move at all.

(iii) Each ring of slabs should be completed to the right measurements before beginning the next ring.

(iv) A space should be left at the sides and bottom of each slab and filled with suitable mortar (e.g., 1 cement: 1 lime: 4 sand for concrete or brick slabs and 1 lime: 2 sand for stone slabs).

(v) If the wall too is to be cast-in-place, then an outer mould should be used to work the primitive soil to form. As an inner mould, either a brick-laying or a wooden arch mould may be used.

(vi) *The dome is cast on backfilling earth formwork, which rests on an umbrella-shaped support made of bamboo or wood (figure 54).*

(vii) The casting of the dome should be done continually layer by layer and in strips, according to the order given in figure 55 to facilitate pouring work.

(viii) The plastering technique described above for the brick digester may be applied here too.

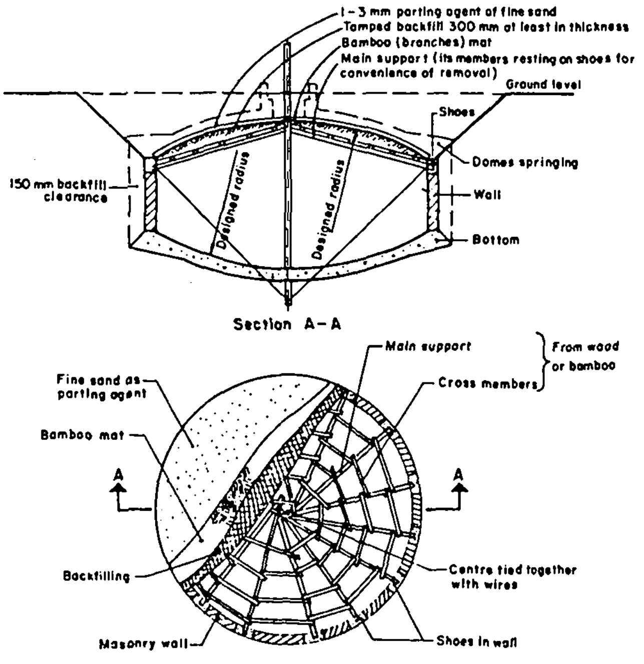


Figure 54. Overall excavation with cast dome on timber (bamboo) support

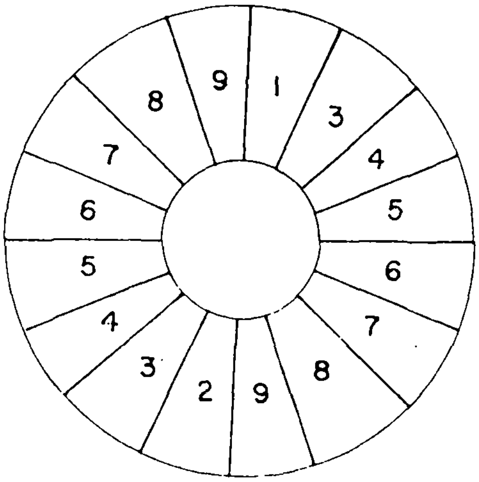


Figure 55. Casting of dome according to numbers

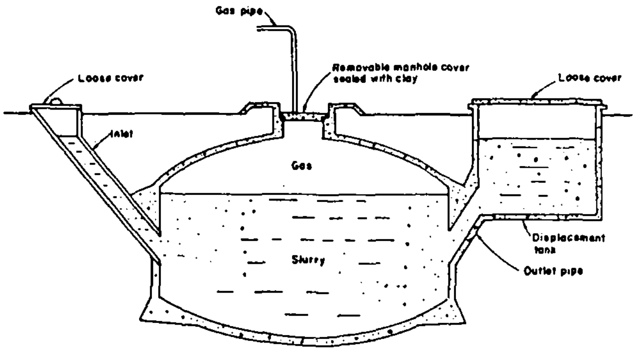


Figure 56. Improved design of the fixed dome digester. (Notice the modification in inlet pipe design to minimize gas escape through inlet and the increase in volume of displacement tank.)

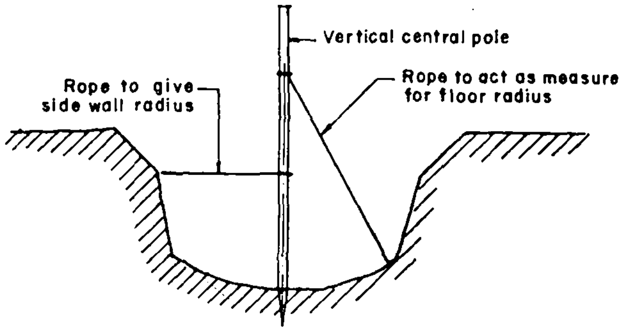


Figure 57. Central pole used in excavation work for fixed dome type digester

(e) *Other construction details*

(i) Inlet

It should be straight to feed without clogging. It may lead approximately to the middle of the digester; i.e., the opening at the lower end is about half way down the digester wall so that a certain degree of stirring can be achieved, e.g., by a bamboo stick when the digester is filled (figure 56). Normally, no mixing pit is used and the inlet pipe is about 250 mm in diameter.

(ii) Outlet pipe

This type of plant usually has human faeces put into it. As pathogens and parasites in faeces are known to stay in the lower third of the digester and die in time, the outlet pipe is about half way down the digester wall. It is usually 200 mm in diameter. The place connecting the pipe to the digester tank should be strengthened with concrete or cement plaster.

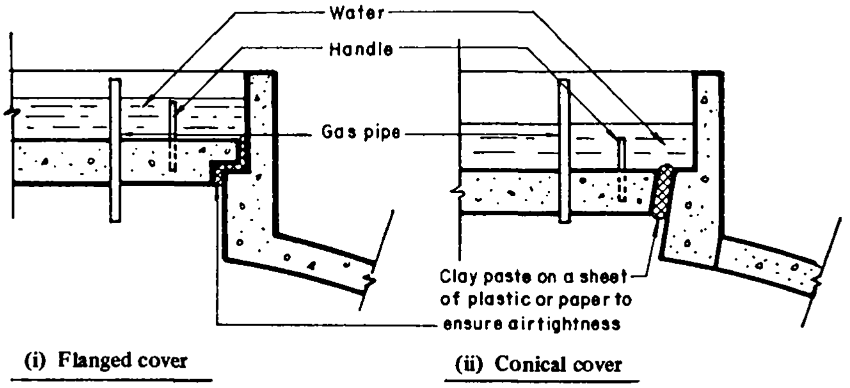


Figure 58. Construction of manhole cover

(iii) Displacement tank

This can be made of the same material as the digester. Its volume is about half the volume of the gas produced per day. A lid is fitted for safety to prevent evaporation or rain water getting in.

(iv) Digester bottom

The floor is usually curved to avoid sharp corners and minimize stress concentration, although it can also be flat. A central pole is usually erected at the very centre of the digester tank to control its curvature with a string gauge as radius (figure 57).

(v) Manhole cover

This usually of conical or flange type and is made of concrete or lime clay. It should be well sealed to ensure airtightness (figure 58).

IX. GAS HOLDER AND GAS PIPE

A. Gas holder

The volume of the gas holder depends on how much gas must be stored before it is used. For family cooking and lighting use, a figure of 60 per cent of the rated daily gas production is commonly used. It should always be remembered that in the fixed dome digester the slurry should never occupy more than 75-80 per cent of the volume of the digester tank. The rest should be kept for the gas.

1. Materials for construction of the gas holder

The principal materials for construction of the gas holder are:

(a) *Mild steel.* In most countries this is the material which costs least. Its disadvantage is that it rusts, especially on the outside, where it dips in and out of the slurry. Gas holders must be tested for leaks, before the joints are painted, by filling them with water.

Usually it is only possible to wirebrush or sandpaper the steel to remove rust prior to painting. Preferably the steel should be sand- or grit-blasted to remove all rust and millseals (the dark blue or black colour) on the steel prior to painting. If this is done properly, the life of the paint will be about three times more than the life of the same paint applied on wirebrushed steel.

The best paints seem to be:

Low cost: Red oxide primer (1 coat) followed by normal paint (2 coats);

Medium cost: Anti-saline primer (1 coat) followed by high-build black bitumen (2 coats);

High cost: Epoxy primer (1 coat) followed by epoxy paint (2 coats). This paint should only be used on sand- or grit-blasted steel.

Mild steel is often used for gas holders. Its life would be extended greatly if people would only paint it regularly or whenever rust appears.

(b) *Galvanized iron (G.I.).* This is a low-cost material in some countries.

Joints should be soldered as mastic dries out and the gas leaks. Paint does not easily stick to new galvanized iron, unless it is pretreated with a special preparation obtainable from large paint firms. If not painted it has a life expectancy of about 5 years. If properly painted and maintained it, like mild steel, should give many years of good service.

(c) *Ferrocement and bamboocement.* This is a relatively new technology.

Ferrocement is a composite material consisting of thin wire mesh impregnated with rich cement mortar. In other words, it is a reinforced mortar, but unlike reinforced concrete it has a high resistance to cracking. Ferrocement can be cast into sections as thin as 1 cm and is therefore suitable for precast products because of the resulting low weight of the components. Ferrocement gas holders are cheaper than mild steel gas holders of the same capacity, have lower thermal conductivity and a high resistance to corrosion, and they can be fabricated in the rural areas using local moderate-skill labour. For manufacturing ferrocement gas holders on a large scale, process equipment (10) can be used for casting ferrocement cylindrical units. In this case better control of the thickness and a higher degree of compactness may be achieved.

In bamboocement gas holders the wire mesh is replaced by bamboo mesh, which is cheaper, lighter and usually more available in rural areas. Suitable coatings should be applied to the inside and outside surfaces of both ferro- and bamboocement gas holders to improve their impermeability to gas. It has been reported from India (10) that bituminous surface coatings have given satisfactory results. Ferro- and bamboocement gas holders should be tested for leakage before they are used and occasionally during their operation. How to do this is explained in chapter IX.

Where there are existing ferrocement skills, this type of gas holder can be tried. Otherwise it is wise to learn the art first of all on items where wall thickness, weight and porosity are less important, e.g., water tanks.

(d) *Plastic.* Many common plastics, e.g., polyethelene, HDPE and PVC are badly damaged by the ultraviolet rays of sunlight. Various organizations have tried these materials without success. Even 3 mm black PVC, which is supposed to be the best of the three types listed above, lasted less than one year before it cracked and leaked. These plastics are not recommended when they are exposed to the sun. Plastics are also expensive.

2. Pressure of gas in gas holder

To force the gas through the gas pipe and out of the gas appliance pressure is required in the gas holder. Normally a pressure of 75 to 90 mm (3-3.5 in) water gauge is needed. This pressure is provided by the weight of the gas holder pressing on the area it covers.

Sometimes the gas holder is too light and weights need to be added to it to give the correct pressure.

The method of measuring gas pressure is given in chapter XII. When a new gas holder is designed, the pressure it will give should be calculated before manufacture. In the fixed dome digester this is not necessary as the pressure of the gas varies normally up to 400 or 500 mm water gauge.

Example: To calculate the gas pressure given by a floating gas holder 2.5 m in diameter.

The weight of the gas holder must be known. Usually it is not practical to weigh it. The weight can be quite accurately worked out by listing all the materials used. Standard engineering handbooks will give the weight per unit area or length.

Assuming that the weight is 363 kg.

$$\text{Pressure} = \frac{\text{weight}}{\text{area}} = \frac{\text{kg}}{\frac{\pi}{4} d^2} \ \text{kg/cm}^2$$

The pressure in mm water gauge is

$$1 \text{ kg/cm}^2 = 10{,}000 \text{ mm water gauge}$$

$$\text{pressure} = \frac{363 \times 10{,}000}{\frac{\pi}{4} \times 250 \times 250}$$

$$= 74 \text{ mm water gauge.}$$

This pressure is a bit on the low side. A pressure of 85 mm water gauge would be better. What weight should be added to the gas holder to increase the gas pressure to 85 mm water gauge? The increase in pressure required is 85 – 74 = 11 mm water gauge.

$$\text{Pressure} = \frac{\text{weight}}{\text{area}}$$

$$\text{therefore weight} = \text{area} \times \text{pressure}$$

$$= \frac{\pi}{4}\, 250^2 \times \frac{11}{10{,}000}$$

$$= 54 \text{ kg.}$$

If weights totalling 54 kg are added to the gas holder, then the gas pressure will be 85 mm water gauge.

3. Gas holder support

Where an internal or external (overhead) centre guide is used, the length of the guide is normally 1.5 times the height of the gas holder.

For gas plant sizes up to 5 m^3 (175 cu ft) daily gas production, it is usual to use a standard 50 mm (2 in) galvanized iron (G.I.) or black pipe. A standard 75 mm (3 in) galvanized iron or black pipe is fitted inside the gas holder. For a 10 m^3 (350 cu ft) size plant the pipe sizes are 75 mm (3 in) and 100 mm (4 in). It is important that the difference in size is not less than 25 mm (1 in), otherwise the dung dries up in the narrow gap and prevents the free movement of the gas holder.

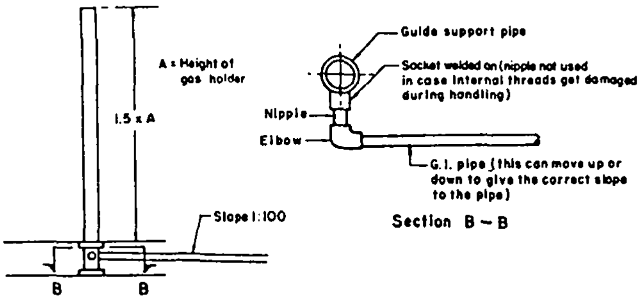


Figure 59. Details of gas holder support

When the recommended centre guide system for gas removal is used, it is usual to make the pipe fitted to the gas holder 50 mm (2 in) longer than the height of the support. The method of attaching the gas pipe to the gas holder support is illustrated in figure 59.

The slope for the roof of the gas holder should be 1:12.

B. Gas pipe and its accessories

Biogas contains moisture, which condenses and must be drained from the pipes. This can be moved to give the correct slope to the gas pipe, especially the pipes nearest the gas plant. The pipes must slope towards a drain. The recommended slope is 1:100. Failure to see that this is so is a common fault. Where fixed dome gas holders are used the gas pressure may go up to 1,000 mm (about 40 in) water gauge. For this type of plant the gas piping must be of a high standard to avoid any leaks.

1. Type of gas pipe

(a) *Plastic pipe.* This must be laid deeply and properly in sand, otherwise rodents (e.g., rats and porcupines) eat it or it can be cut during agricultural operations or damaged by heavy vehicles passing over it. Care must be taken, especially with small pipes, that the pipe is laid flat in the ground and not in waves because water collects in each hollow causing serious blockage problems. If the pipe is above ground there is the danger, unless it is protected, of damage from the ultraviolet rays of the sun, which causes cracks, and of mechanical damage, e.g., being hit. Care must be taken that the pipe does not sag between supports.

(b) *Galvanized iron pipes.* They are commonly used, although they are a little more expensive than the best quality plastic pipes. They can rust badly if the soil is very acid and they are not protected with paint or tar. Joints must be covered carefully with jute fibre and still paint or other jointing compound. If some red lead powder is added to the jointing material it will turn black if there is a leak. This is helpful when looking for leaks but is not essential.

(c) *Flexible pipe joining gas holder to main gas pipe (if used).* This is commonly the most troublesome maintenance problem in connection with floating gas holders. Where available, 5 ply rubber hose should be used.

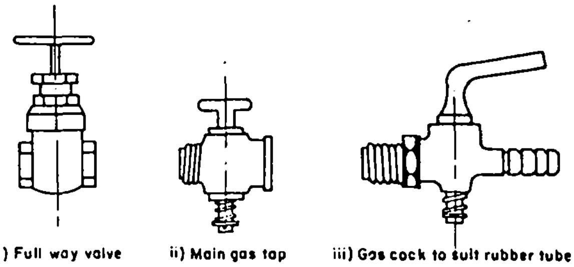
Commonly available black plastic water pipe is hopeless as it readily cracks or breaks when the gas holder is turned daily for mixing the slurry. It is also difficult to make a joint gas-tight with the steel pipe. (Normally it has to be heated until it becomes soft.) Clear plastic pipe is better than the black plastic pipe and is usually much more readily available than 5 ply rubber hose. In the course of time it becomes black, hardens and cracks longitudinally (like knife-cuts) from the effect of the ultraviolet rays in sunlight. It tends to go flat in places but this can be overcome by sliding a sleeve of a large plastic pipe over the flat section. The expected life in the tropics of this type of pipe is 8 to 12 months. The pipe needs to be cleared of condensate daily, or as often as is found necessary, by lifting one end and allowing the water to run down into the gas holder.

(d) *Bag type digesters.* The gas piping at the digester must be so arranged that it supports the gas outlet part of the bag. This is to prevent the gas outlet getting into the slurry (and blocking the pipe) under conditions of high gas usage.

2. Gas taps (figure 60)

Full way valve water taps can be used for shutting off the gas at the plant or for condensate drains. Ordinary water taps with a leather or plastic washer will not work as the gas pressure is insufficient to operate it.

Farmers who have never used a tap before tend to overtighten full way valves and break the spindle. The best solution is a proper 1/4 turn main gas valve. They are usually cheaper. Gas taps should have a spring to hold them together as this automatically takes up any wear, whereas a nut does not.



i) Full way valve ii) Main gas tap iii) Gas cock to suit rubber tube

Figure 60. Types of gas taps

Brass used for taps must not contain any lead as the hydrogen sulphide in the gas attacks the lead and quickly destroys the tap.

Stiff taps can be oiled, by pulling the gas tap handle against the spring and pouring lubricating oil around the handle and into the hole. Then pressure should be applied on the handle, then released, and the tap should be turned on and off a few times. This may be repeated as necessary until the tap turns easily. Lubricating oil is best. Animal fat, including butter, can be used. Vegetable oils (e.g., mustard seed, linseed, sunflower seed) should not be used. They become sticky in time and make things worse rather than better.

Location of main gas tap. A main gas tap should be located as near as possible to the gas holder. This will shut off the gas supply completely; this is a safety feature and is also essential when any work is to be done to the gas pipe, e.g., replacing of flexible pipe joining the gas holder to the main gas pipe.

When a flexible pipe is used it is usual to attach the main gas tap to the gas holder itself. In all other cases the tap is put as close as possible to the digester.

3. Condensate drains

There are many designs of condensate drain.

(a) *Tee drain* (figure 61)

Where the gas pipe is above ground or shallow in the ground this system works well. However, if the gas pipe is set deep in the ground, tee drains are not popular as the hole they are put in tends to fill with earth, water, etc., and can be a hiding place for snakes and scorpions. Any water lying around this device must be removed before any attempt is made to release the condensate, otherwise more water may go inside instead of coming out.

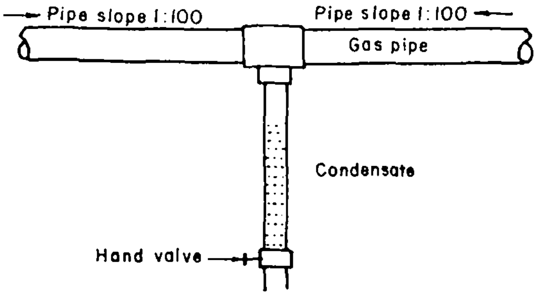


Figure 61. Tee-type condensate drain

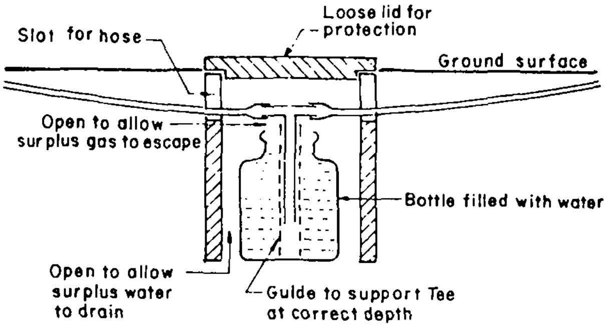


Figure 62. Bottle type condensate drain

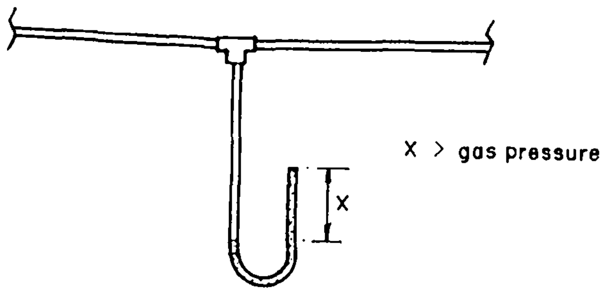


Figure 63. "U" pipe drain

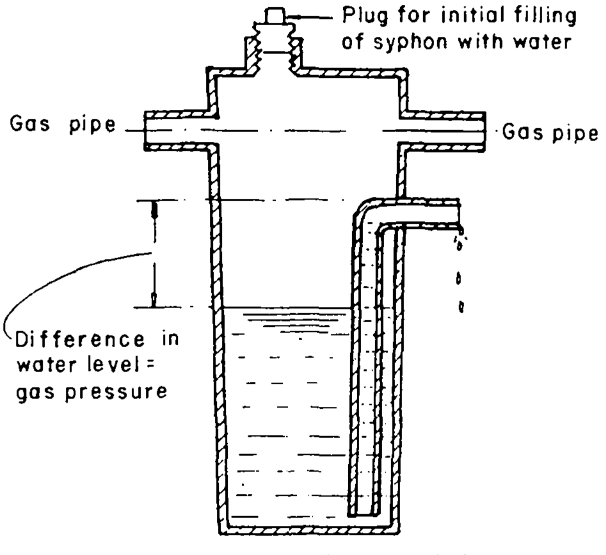


Figure 64. Syphon type drain

(b) *Bottle drain* (figure 62)

This design requires no regular attention provided it is protected from excessive evaporation or flooding.

Where it is set deep into the ground, a rainstorm may cause the water to rise above the level of the main gas pipe by more than the gas pressure and the water will flow into the gas pipe and block it.

(c) *"U" pipe drain* (figure 63)

In hot dry areas the water can evaporate faster than it is replaced by condensate and so cause gas leaks. Other points are the same as for (b) above.

(d) *Syphon* (figure 64)

Commercial syphons are available. They work on the same principle as (b) and can have the same problem caused by flooding. They are usually expensive.

(e) *Water outlet device*

This system (figure 65) avoids all the problems of the above types of condensate drain but increases the cost. It is recommended for gas plants using the hooked underside and central guide system for gas removal because the gas pipe from the gas plant in this case is usually deep in the ground.

Each new plant requires about 1.4 litres of water poured down the dipper pipe to form a water seal. Any excess water can be removed by following the instructions given below. Condensate will collect in the bottom "U" because the gas pipes slope down towards the device. To remove condensate:

> The cover of the dipper pipe should be unscrewed and the dipper should be lifted out and emptied. This should be repeated until the water container no longer fills. The dipper should be stored inside the dipper pipe. Then the cover should be screwed on. The cover does not need to be sealed as there is a water seal at the bottom of the pipe, which prevents gas leaking out.

4. Flame arrester

A flame arrester is a safety device that should be incorporated into every gas line. It is commonly placed either just after the main gas valve near the digester, or just before a gas stove or lamp. It is safer to have one in both places. Its purpose is, in case of an accidental back-fire, to prevent the flame from running down the gas pipe into the collecting drum and causing an explosion.

The arrester can be a ball or roll of fine mesh copper wire (preferably unferrous, which will not rust away)

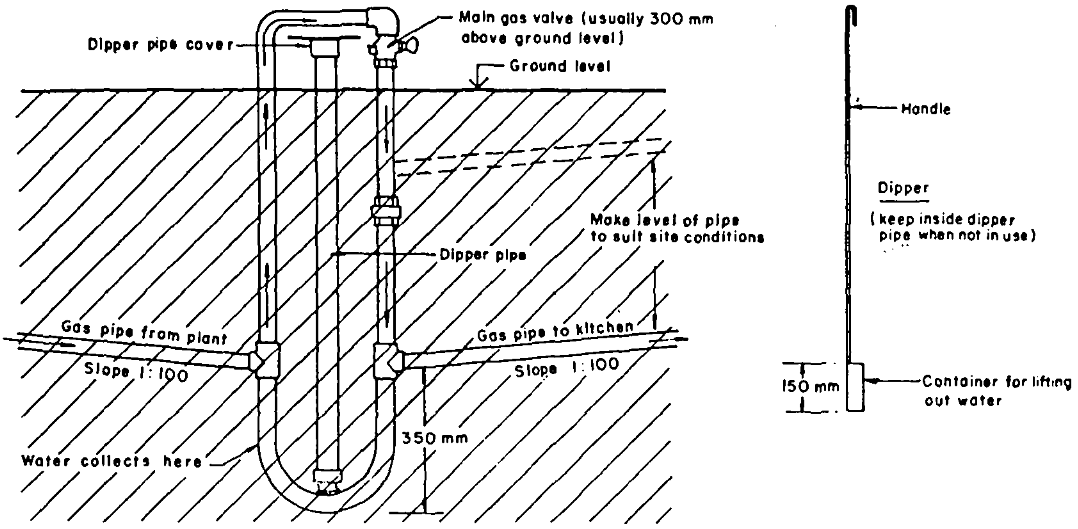
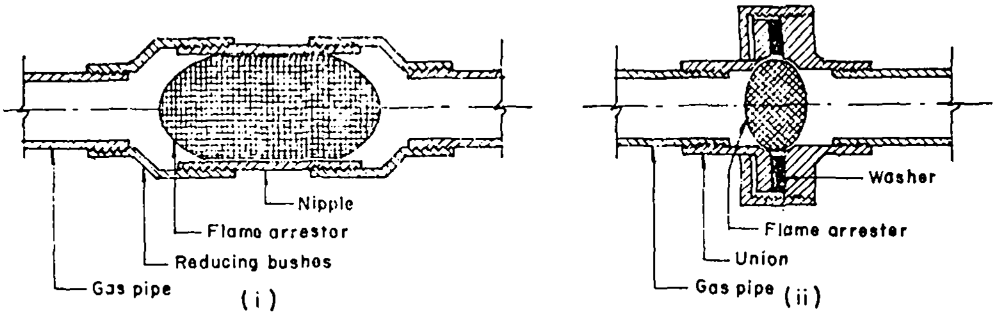


Figure 65. Diagram of water outlet device



(i) (ii)

Figure 66. Flame arresters

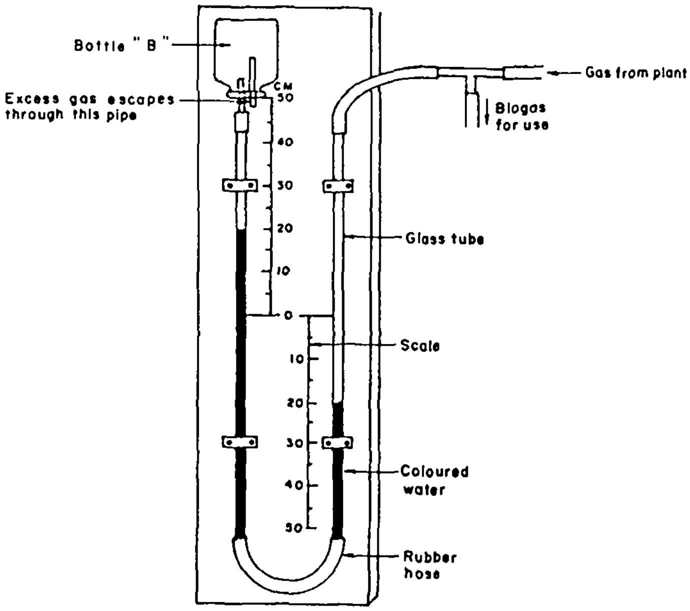


Figure 67. Manometer and safety valve combined

inserted into the gas pipe (figure 66). It is sometimes not realized that this necessarily forms an obstruction to the free and full flow of gas. It is therefore recommended that the flame arrester be placed in a length of pipe of slightly larger diameter than the gas pipe, especially if it is placed near the main valve. For a 13 mm (0.5 in) main gas pipe use a 19 mm (0.75 in) arrester, for a 25 mm (1 in) pipe a 32 mm (1.25 in) arrester.

An arrester can also be made by brazing a copper wire disc at each end of a short bit of pipe, e.g., a nipple joined into the pipe line.

5. Manometer and safety valve combined

This device is used with fixed dome type digesters and can be used with flexible bag type digesters.

The manometer (figure 67) is filled in the normal way with coloured water. It shows the gas pressure and therefore the amount of gas available as well. If the pressure increases too much, the water is forced into bottle "B". Gas can escape through the long pipe in the bottle, but the water cannot spill. When the pressure reduces, the water flows back into the manometer. This device prevents the pressure increasing too much and cracking the dome of the digester. Excess gas must be discharged outside the house for safety.

Note: In floating gas holders such a pressure safety device is not necessary. If excess gas is generated, it lifts the gas holder sufficiently high to bubble out from under the side.

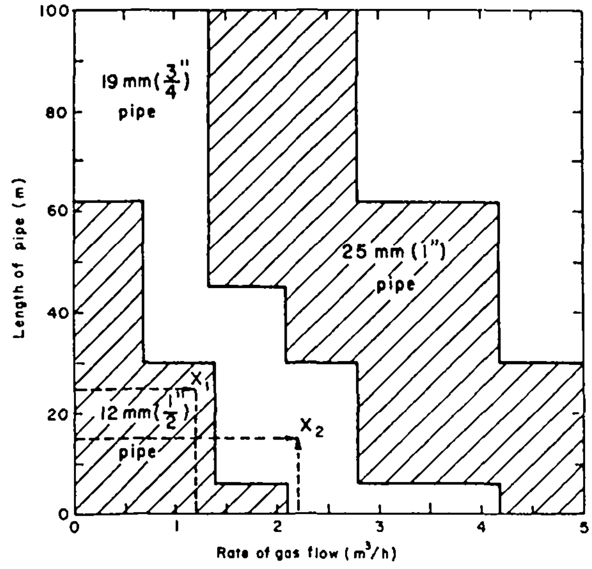


Figure 68. Diagram for quick determination of adequate gas pipe diameter

6. Gas pipe size selection

The size of gas pipe required depends on two factors: the length of pipe and the amount of gas required per hour. If a small pipe is used where a large one is needed, then the gas pressure will be reduced owing to frictional losses. Too large a pipe causes unnecessary expense. Figure 68 gives the correct size of pipe required for normal size installations.

The diagram is based on an approximate fall of 5 mm (3/16 in) water gauge per metre of ordinary low pressure gas supply.

Note: The size of pipe is the bore size.

The following examples show how the diagram should be used.

Example 1.

A house has:

2 stoves at
460 litres/hour = 920 l/hr (maximum)

3 burners at
140 litres/hour = 420 l/hr (maximum)

Maximum gas demand = 1,340 l/hr = 1.34 m^3/h

The pipe needed should be 25 m long (to cover the distance between the digester and the appliances).

Refer to the diagram and locate 1.38 m^3 gas demand per hour and 23 m feet length of pipe. The joining point is marked X_1. It will be seen that 12 mm (0.5 in) piping is adequate.

Example 2.

A house has:

3 lamps at
0.45 m^3/hour = 1.35 m^3/hour (maximum)

1 burner at
0.23 m^3/hour = 0.23 m^3/hour (maximum)

4 lamps at
0.15 m^3/hour = 0.60 m^3/hour (maximum)

Maximum gas demand = 2.18 m^3/hour

Length of pipe is 15 metres.

Refer to the diagram and locate 2.18 m^3/hour gas demand per hour and 15 m length of pipe. The joining point is marked X_2. It will be seen that 19 mm (0.75 in) is needed. This does not mean that the whole pipe must be

19 mm. It does mean that 19 mm pipe should be used to the point where the burners are located (assuming that they are grouped together). Branch pipes to individual fittings, e.g., lamps, can be 13 mm (0.5 in) pipe.

In view of the relatively high pressure of the gas in the fixed dome digester, pipes of diameter around 12 mm were found adequate and are widely used in China (7).

7. Testing for leaks

This procedure is set out for gas plants using a gas holder which takes the gas through the central guide pipe and a water outlet device as illustrated in figure 65. The procedures can be modified to suit other types of gas holder and piping.

First, it is necessary to get the correct amount of water in the water outlet device. Using the dipper provided, all possible condensate should be removed. Now a known amount of water is in the "U" section of the water outlet device. Seventy-five ml (0.5 glass) water may now be poured down the dipper pipe. The water is now at the correct level to carry out the test.

The main gas valve, all gas taps for burners and all gas cocks for lamps should be closed. A 13 mm (0.5 in) bore diameter transparent plastic pipe 1.5 metres long (5 feet) should be attached to one burner gas tap and a rubber pipe should be also attached to another burner tap (figure 69).

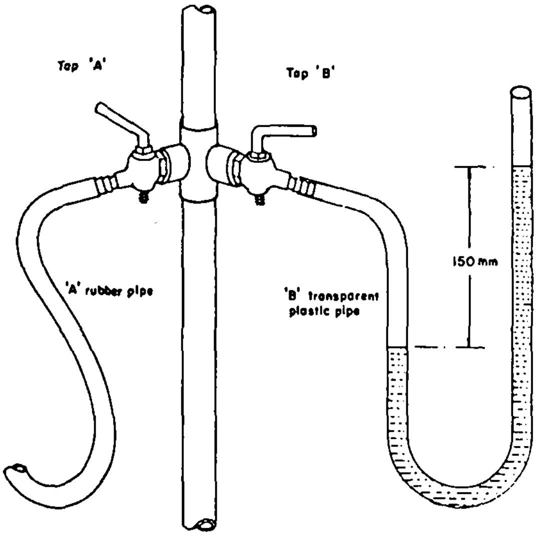


Figure 69. Attachments for leak detection test

Water should be poured into pipe "B" until it reaches about 60 cm (24 in); it should be held in the "U" position shown. The open end of the plastic pipe should not be closed. Then tap "B" should be opened. Open tap "A" too, then blow through the rubber pipe slowly until there is a 150 mm (6 in) height difference in the water level in the two legs of the "U" in the transparent plastic pipe. Tap "A" should be then closed but not tap "B".

The water levels should be watched. If they do not alter, there is no leak. If the water levels out quickly, then there is a big leak. In that case it is usually easier to close gas tap "B", open the main gas valve and use the gas pressure alone to check for a large leak (explained below). When the leak has been repaired, the above pressure test procedure should be repeated.

If the water levels out slowly, then there is one or more small leak. One person must hold the plastic pipe and keep the water level at 150 mm (6 in) apart while another inspects for leaks.

Soapy water may be put on gas taps, gas cocks, joints and fittings to check for leaks. Bubbles will form if there is a leak. If the leak is in a gas tap, cock or valve and is large, i.e., bubbles form quickly, then the defective part must be replaced. If there is a large leak at a joint, the joint should be taken apart and properly fitted again. Make sure that the leak is not coming out of the dipper pipe in the water outlet. Small leaks at joints can sometimes be repaired by thick paint pasted over the leak.

Temporary repairs can be made using soap as a paste and then binding the soap onto the pipe with a piece of cloth.

When the leaks are repaired, the water in the open end of the transparent pipe "B" should remain 150 mm (6 in) higher than the other end. If the level reduces by 35 mm (1.5 in) in 60 seconds, then the total gas escaping per day is about 30 litres, assuming an average plant with about 35 metres of 13 mm (0.5 in) galvanized iron piping. (If there is about 70 metres of 13 mm (0.5 in) galvanized iron piping, then the loss will be about 60 litres per day).

To check for leaks in the gas holder, weights should first be put on the gas holder to increase the pressure. Then soapy water should be applied to any suspected leaks and especially any spots of rust and welded joints. For ferro- and bamboocement gas holders soapy water is poured on the surface of the gas holder. All the points of leakage should be sealed using a suitable surface coating, e.g., bitumen. After the coating has dried the test should be repeated until no leakage is noticed.

To check for leaks in the water outlet device below ground level, it is first necessary to dig the soil away and then check using soapy water.

When a higher gas pressure (as in a fixed dome digester) is used, a longer transparent pipe "B" is necessary. The

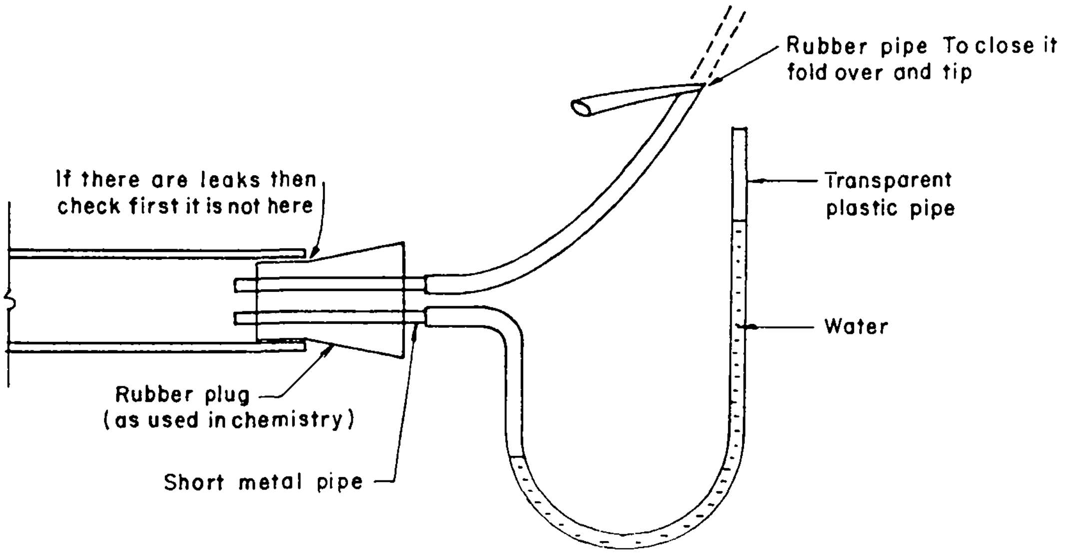


Figure 70. Method of checking for leaks

water level difference in this pipe must be greater than the maximum pressure of gas which is to pass through the pipes.

It is a big job to dismantle pipes if one joint is leaking. Therefore it is suggested that it is worth checking for leaks during installation, especially if there are many joints. Figure 70 shows how pressure can be made in the gas pipe during installation.

X. HOUSEHOLD GAS APPLIANCES AND THEIR USAGE

The principal uses of biogas are cooking and lighting. For these purposes it is not necessary to clean the gas.

A. Cooking

This is the best use for the gas. It is:

* clean: it does not make dirty cooking vessels, clothes or kitchen;

* fast: it produces immediate heat;

* healthy: it does not produce smoke to irritate eyes or lungs;

* efficient: if proper stoves are used.

About 0.28 to 0.42 m^3 (10 to 15 cu ft) of gas is required per person per day.

Biogas can be used like any other gas–mains supply, LPG (bottled) or natural. All gases have different characteristics and correctly designed stoves are needed for each type of gas so that they work efficiently and well.

1. Designing a biogas stove

It is a scientific task to design a gas stove properly. However, if a few rules are observed, satisfactory stoves can be made.

(a) Air must be thoroughly mixed with the gas before it reaches the flame ports. This air (called primary air) should flow in near the gas jet, ideally with a venturi. If sufficient air is not supplied, there will be a slight smell from the burning gas. This smell will stop immediately if the amount of primary air is increased.

(b) The total area of the flame ports should be between 80 and 200 times the area of the gas jet.

(c) The distance from the flame ports to the surface of the cooking pot should be 25 to 30 mm (1-1.25 in). This assumes a gas pressure of 75-90 mm (3-3.5 in) water gauge. (For obtaining the correct gas pressure, see chapter XII.)

(d) Supports for cooking pots must not prevent air (called secondary air) from getting at the flames.

(e) To allow cross lighting from one flame port to the next, the distance between flame ports should not be more than 20 mm (0.75 in).

(f) To prevent backfiring, the thickness of material at the flame port should be about 10 mm (3/8 in).

(g) For corrosion resistance properties cast iron is better than mild steel.

For a typical 0.45 m^3 (16 cu ft) per hour stove, which is a popular family size, the dimensions should be approximately:

Jet size: 2.25 mm diameter

Area of jet: 3.98 mm^2

Flame port size: 6.0 mm diameter

Number of ports: 20

Total area of ports: 565 mm^2

Ratio of jet area to flame port area: 1:142

Length of gas mixing pipe: 20 mm

Diameter of gas mixing pipe: 20 mm

2. Commercially made biogas stoves

Two types are available, the normal type (figure 71) and the adaptable type (figure 72).

(a) *Normal type*

(i) Both utility and deluxe stoves have exactly the same burning efficiency and life expectancy;

(ii) They give roughly the same amount of heat as a family kitchen size kerosene pressure stove;

(iii) Both can be supplied with gas taps attached to the stove, or to the main gas pipe. The latter system is recommended because if the rubber pipe leaks or is pulled off, the gas will pour into the room until it is refitted or a gas tap in the main gas pipe is closed. This tap is an extra expense;

(iv) Air adjustment is by means of a knurled nut;

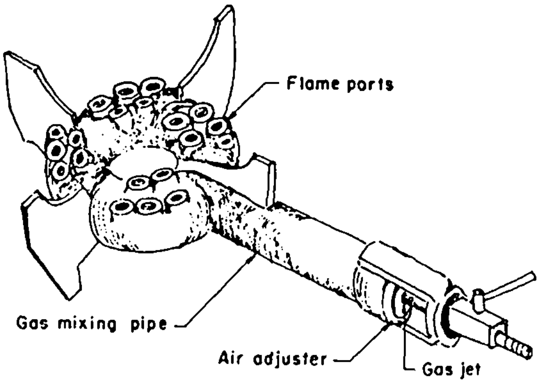
(v) Robust and efficient.

(b) *Adaptable type*

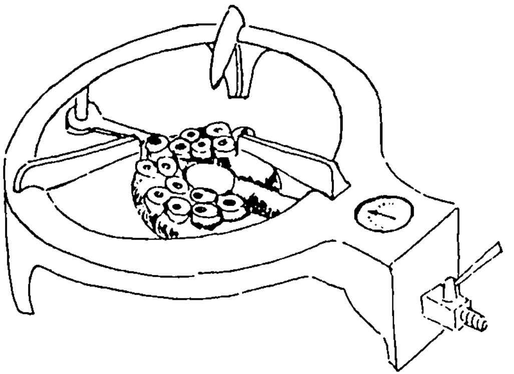
The features of this type are:

(i) The legs are spread apart for greater stability of large size cooking pots;

(ii) Cooking pot support is reversible to suit either flat-bottomed or rounded-bottom cooking pots.



(i) Utility quality



(ii) Deluxe quality

Figure 71. Normal biogas stoves "450 *l*/h" (India)

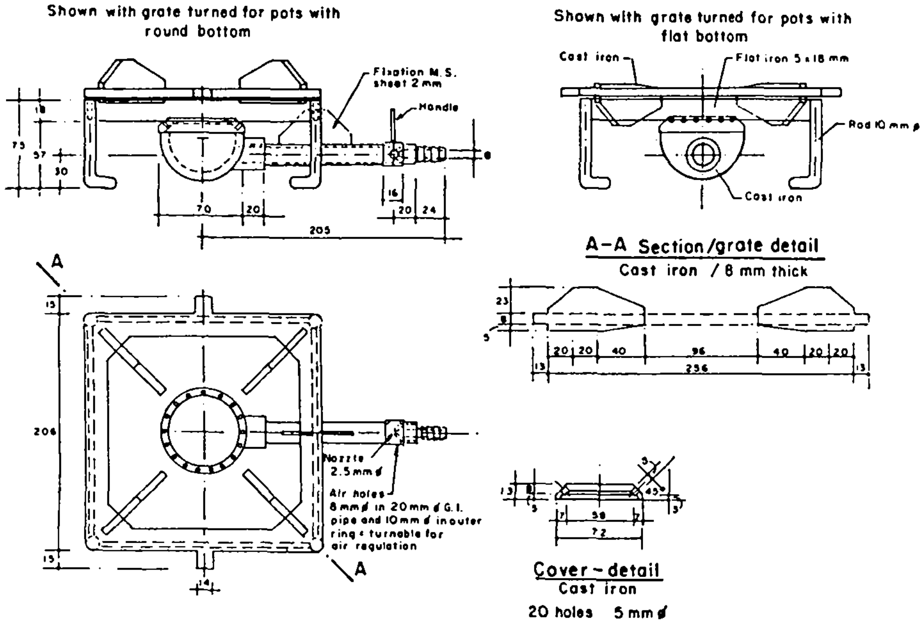


Figure 72. Biogas stove with turnable grate "450 *l*/h" (Nepal)

The distance from the flame port to the bottom of the cooking pot is correct for either type of cooking pot;

(iii) Removable flame port cap for ease of cleaning any split foods from flame ports;

(iv) Easy and quick air adjustment by means of a ¼-turn lever;

(v) Robust and efficient.

3. Village-made stoves (burners)

(a) *Tins*

Stoves have been made from tins with holes punched in the top and a gas pipe attached near the bottom. They are not so efficient and the flame temperature is not so high as properly designed burners. They tend to rust out quickly. Both the efficiency and temperature could probably be increased by making holes in the bottom of the tin to let in air and putting some stones inside to help mix the gas and air.

(b) *Wood-burning stove adaptation*

This stove is an adaptation of a common type of village wood-burning stove. A pipe is inserted and the stove is filled with stones as shown in figure 73. Air can be controlled with a piece of wood placed over the front hole.

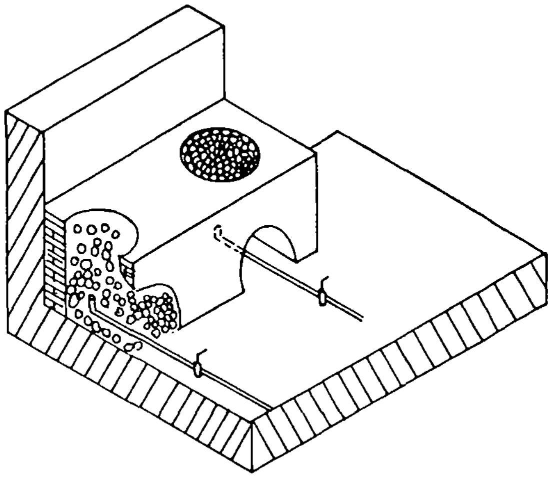


Figure 73. Adaptation of wood-burning stoves

(c) *Clay or cement*

Stoves can also be made from burnt clay or cement. These are low-cost but can break from heating, cooking and spilt liquids. Mixing some salt water and burnt rice husks or fine coal will help clay stoves to withstand heat and prevent cracking.

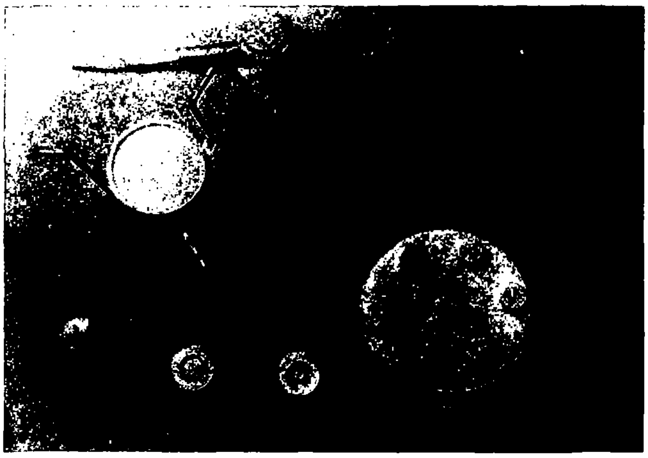
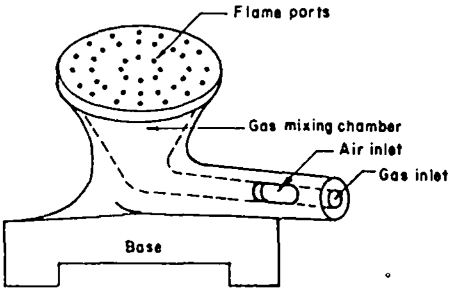


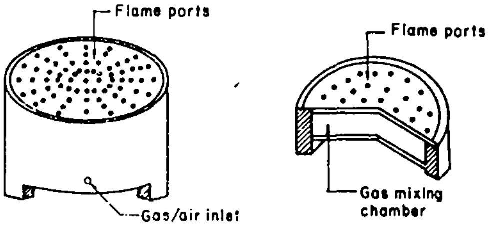
PLATE 14
Cooking burners, made of fired clay and scrap metal (China)

(i) Shower head burner (figure 74 i)

This type of burner has a concentrated flame. It is normally made of potter's clay. The diameter of the shower head varies from 4 to 8 cm. The diameter of the base is about twice that of the top. About 50 holes for flames each 1.5 to 2 mm in diameter are made in three or four rows. The air inlet is about 10 mm long and 5 mm wide. The gas/air ratio is usually changed by varying the position of the gas nozzle relative to the air inlet.



(i) Shower head burner



(ii) Drum burner

Figure 74. Clay burners (China)

(ii) Drum burner (figure 74 ii)

The drum burner is similar to the shower head burner except that it can be made from any other material easily available. It is always better to drill the holes from the inside outwards.

A metal gas pipe with nozzle is placed in the gas/air inlet. A metal cover is fitted as an air control. Combustion in this burner is efficient as the gas can be mixed well in the mixing chamber before burning.

4. Adjustment and care of stoves

After connecting the stove to the gas tap, using the rubber tube, the air adjuster should be closed fully. A lighted match should first be applied to the flame ports and then the gas tap can be opened fully. A cooking vessel may now be placed on the stove. The flames will be weak and long and rise over the sides of the vessel. This burning is bad and inefficient, and the air adjuster should be opened to admit some air to the point when the burning gas will create a noise. The adjuster may then be closed a little, but only a little, so that the noise of burning subsides and the flames are about 25 to 30 mm (1-1.25 in) high. The upper cone of the flame should touch the cooking vessel. This is very efficient burning.

Note: Burners can only be adjusted for maximum efficiency when there is a cooking vessel on the burner.

The flame ports should be cleaned out when necessary. Where a removable flame port cap is not fitted, either hold the stove upside-down to prevent any dirt falling inside or make sure any dirt which does fall inside is removed.

B. Lighting

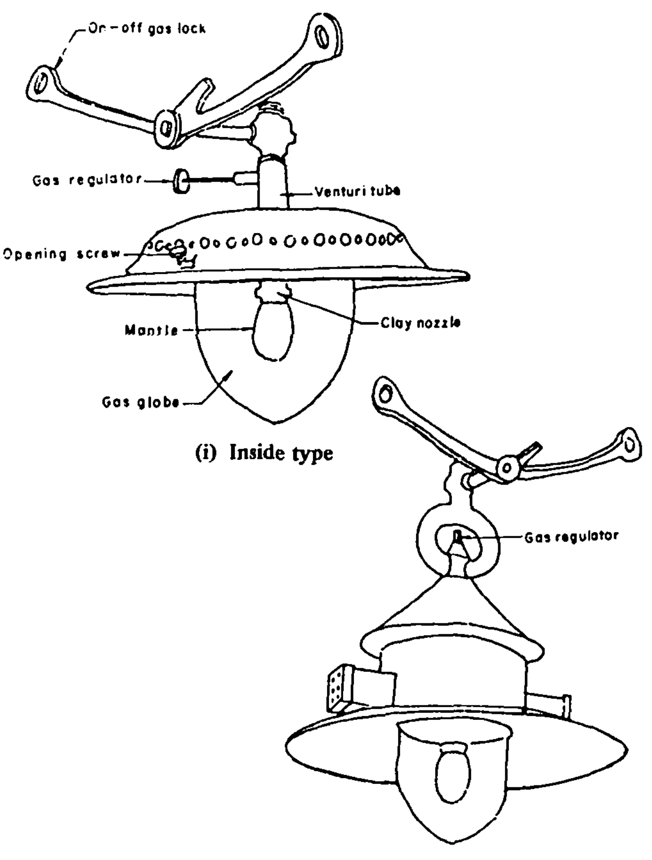
There is a big demand for biogas lamps in unelectrified rural areas. The light is not as good as an electric light. Lamps are expensive, use gas inefficiently, require regular servicing and need a good supply of mantles. Electricity, when available, is cheaper, simpler and better. Type A and B lamps illustrated below are designed for a gas pressure of 70 to 85 mm (2.75-3.25 in) water gauge. Low gas pressure gives a poor light and a high gas pressure breaks the mantles quickly. They all are about 100 candle power and use 0.11 to 0.15 m^3 (4 to 5.5 cu ft) gas per hour.

1. Commercially made biogas lamps

(a) *Single mantle lamps* (figure 75)

(i) Inside type with simple cover: 100 candle power ≅ 60 watt electric bulb.

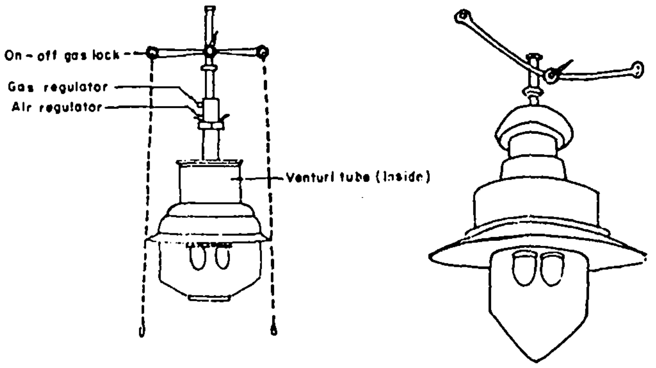
(ii) Outside type with cover to protect it from wind and rain: 100 candle power ≅ 60 watt electric bulb.



(i) Inside type

(ii) Outside type

Figure 75. Single mantle lamps (India)



(i) Inside type **(ii) Outside type**

Figure 76. Double mantle lamps (India)

These lamps work well and are well made. The mantles are the soft type (used for pressure kerosene type lamps) and do not cost much.

(b) *Double mantle lamps* (figure 76)

(i) Inside type, 2 mantles, 100 candle power with simple cover. The ranging model is illustrated in figure 76 but it is also available as a table model (see figure 77) and as a wall-mounted model.

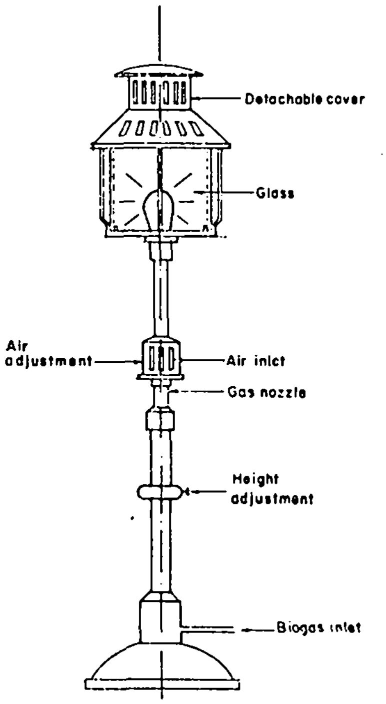


Figure 77. Biogas table lamp (Pakistan)

(ii) Outside type, 2 mantles, 100 candle power with cover to protect it from wind and rain.

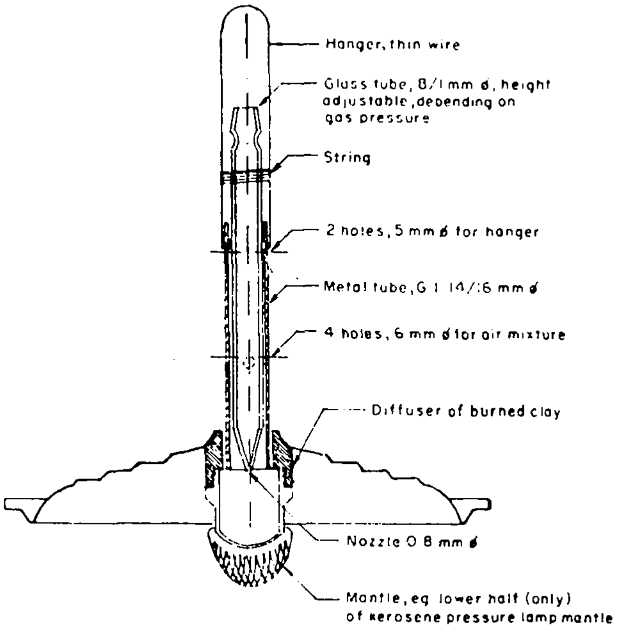
These are well made and work quite well. However, the outside type is very hard to dismantle for servicing. Mantles are preformed and expensive. An adaptor can be made to suit the soft type of mantle.

The inside type has a large hole in the base of the glass globe, which allows insects to fly inside. These insects break the mantles.

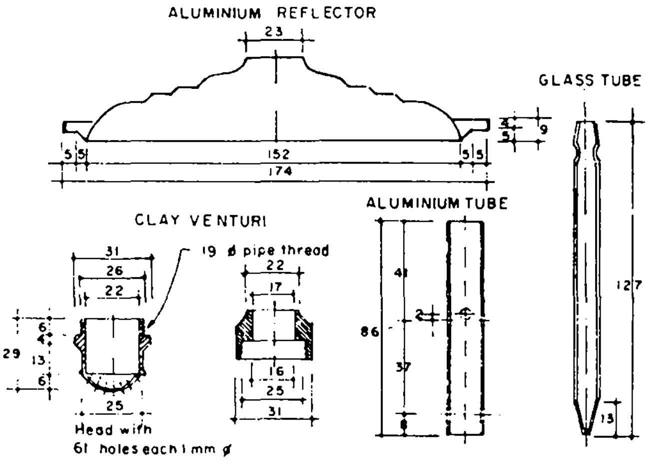
2. Village-made lamps

The design shown in figure 78 comes from China. It is rather simple. It appears to require a high gas pressure as tests at 75 mm (3 in) water gauge were not satisfactory. It consists of only four parts: an aluminium tube, a gas diffuser, to which the mantle is attached, a disc reflector with glass globe, and a slim glass or plastic tube that acts as a nozzle.

The aluminium tube is about 100 mm long and 15 mm in diameter. A little below the top of the tube there are four air holes of 3 to 4 mm. The glass (or plastic) tube is about 12 cm long and looks like a very small pipette. This tube slips into the aluminium tube. Its top end is connected through a plastic pipe to the gas mains. The top of the aluminium tube is open. Its bottom end holds the diffuser, which is very similar to the Indian diffusers in material, shape and size. The reflector fits at the bottom of the aluminium tube just above the diffuser. A more simplified construction is shown in figure 79. Here, the tube and the gas diffuser are made in one piece from clay. The reflector is also made of clay to reduce the cost. This lamp costs in China only $US 0.3 and has given entire satisfaction.



i) Section elevation of the lamp assembly



ii) Details of lamp parts

Figure 78. Simple biogas lamp (China)

3. Operation of lamps

(a) *Single mantle*

The lamp is opened and the clay nozzle fitted (sometimes called a "venturi" or "carborundum"). The mantle

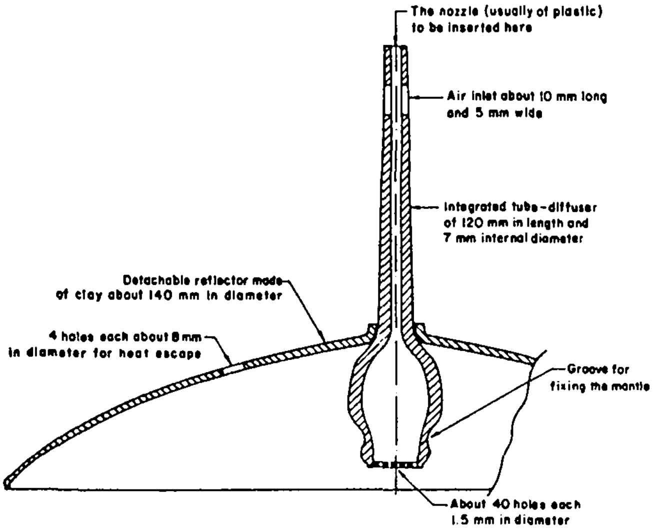


Figure 79. Clay biogas lamp (China)

Figure 80 Correct shape of needle

should be opened to form a hollow ball, then tied to the venturi. The gas cock and gas regulator may be opened fully, then the mantle should be lit and allowed to burn. Once the mantle is burning well, the lamp can be closed.

The lamp should be allowed to heat up until it makes a noise. Then the gas regulator should be adjusted so that the mantle is at its brightest. It is usually unnecessary to adjust the gas again until the mantle is changed.

To turn off the lamp, only the gas cock should be closed.

To relight the lamp, first a match should be applied close to the mantle, either through the hole in the bottom of the glass globe or by opening the reflector. Then the gas is turned on. If this sequence is reversed, there will be a minor explosion, which may break the mantle. The lamp must heat up until it makes a noise, after which it will give a good steady light.

Before a new mantle is fitted, the clay nozzle should be removed and the venturi tube thoroughly cleaned out of any insects, cobwebs, carbon or dirt. A piece of cloth wrapped around a pencil or small stick may be used. The glass globe and reflector should be washed with soap (or ash) and water, whenever necessary, and left to dry completely before the lamp is lit; otherwise the glass may crack and the surface of the reflector may go dull.

(b) *Double mantle type*

The lamp should be opened and the nozzle screwed into place. The gas cock may then be opened and the gas lit. The gas regulator should be adjusted until the flame is 65 mm (2.5 in) long from the tip of the nozzle to the end of the flame.

The air regulator should be adjusted to make the flame nonluminous, i.e., bluish. The gas cock should then be closed. The mantle may now be taken out of the box, held by a leg, without touching the fabric and fitted to the nozzle. The mantle can then be lit to burn up the coating without turning on the gas.

When lighting the lamp, a match should first be applied close to the mantle, either through the hole in the bottom of the glass globe or by opening the reflector in the case of outside lamps. Then turn the gas on. If this sequence is reversed, there will be a minor explosion, which may break the mantle.

The lamp usually takes a few minutes to heat up and will then give a good steady light.

Sometimes a lamp is found to give a better light with a perforated clay disc fitted inside the nozzle. There is no fixed rule and it is a matter of experiment.

4. Maintenance of lamps

The most common reason for properly adjusted lamps not working well is dirt, especially insects' nests, inside the venturi tube. The method of cleaning this out was described above.

The second main reason is a defective needle in the gas regulator (this device is not found usually in Chinese lamps). This must be long, thin and have a fine point (figure 80). It must come down low enough to protrude through the jet and close it off.

If the needle does not come down low enough, then file hole A and make a slot so that it can come down far enough. The gas regulator lever fits into this hole.

XI. STARTING AND OPERATING A GAS PLANT

A. Starting the plant

It is now assumed that the gas plant has been built, all the pipe-work has been completed and the appliances have been fitted. The next job is to fill the digester and fit the gas holder.

1. Digester with floating gas holder

(a) *Pre-treatment of the digester*

No pre-treatment is required where a cement mortar or a lime mortar painted with cement has been used. Where lime mortar or lime concrete have been used, it is best to treat the lime. Otherwise the pH of the slurry and thus gas production will be affected. Either of two things can be done:

(i) A weak solution of hydrochloric acid can be brushed on. Care must be taken to protect the worker's skin, and his eyes must be protected with goggles. Any acid contacting the skin must be washed off quickly using soap and water;

(ii) The digester may be filled with plain water for 2 to 3 weeks.

(b) *Slurry concentration and mixing*

For all plants, with the exception of the fixed dome type, slurry is a mixture of only dung and water.

A concentration of 7 to 9 per cent dry matter in water is generally found to work best. The moisture content of dung depends on the type of animal, health and climate. It is usually 18 to 25 per cent dry matter when fresh. It usually takes about three quarters to one and a half litres of water per kg of fresh dung to make the slurry.

When mixing the slurry care should be taken to make sure that none of the following materials get into the digester:

(i) Earth or sand (mixed with the dung). It will fill up the bottom of the digester pit and cause problems.

(ii) Straw of grass etc. If any does get in, it can be removed from the slurry by using one's fingers or a sieve, before letting the slurry go into the digester pit. If it is not removed, it will float to the surface of the digester pit and both reduce the gas production and restrict the free movement of the gas holder.

(iii) Sawdust or peat moss. These are impossible to remove once mixed with the slurry and cause very serious clogging and scum problems.

(iv) Oil, soap or detergent. These will kill the bacteria and stop all gas production.

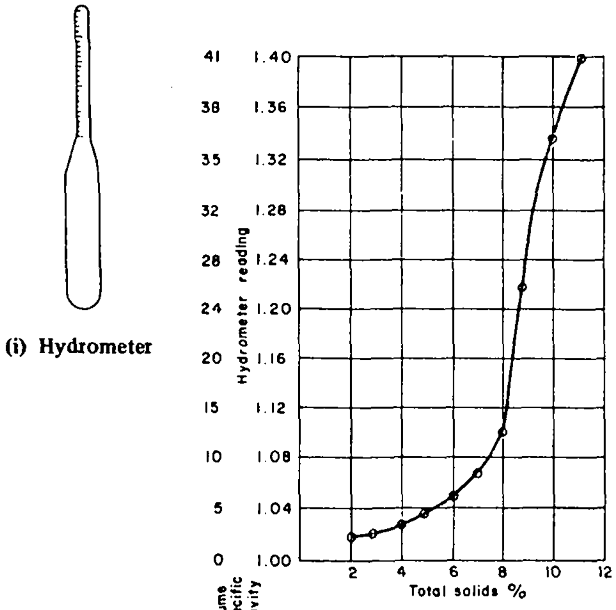
Dung and water can be mixed with hands or feet or a piece of wood, or in a mixing machine (if fitted), until there are no lumps. This is essential. If there are lumps, the gas production will be reduced.

The consistency of the mixed slurry should be like thick pea soup. Add more water or dung if necessary to get the correct consistency.

(c) *Checking of slurry consistency*

The best way to check the consistency is to use a hydrometer designed for the range 1.000 to 1.200 specific gravity (1.000 = water), or 0-30 Baume (0 = water).

As can be seen from figure 81, the relationship between the percentage of cow dung total solids and the hydrometer reading is not a straight line.



(i) Hydrometer

(ii) Percentage of cow dung total solids plotted against hydrometer reading

Figure 81. The hydrometer and its utilization

Nevertheless, if the hydrometer reading falls in the range 1.045 to 1.190 (6 – 24 Baume) it will be found that the slurry consistency is satisfactory.

After making slurry a number of times it is quite easy to see by eye if the slurry consistency is correct or not. If too thin a slurry is used, it tends to separate out into three layers inside the gas plant: heavy solids at the bottom, water in the middle and floating vegetable matter on the top. If too thick a slurry is used, the gas fails to pass through the slurry. In both cases the gas production is noticeably reduced.

(d) *Filling the digester and adding bacteria*

The filling should be done as quickly as possible. Dung can be collected for up to about 10 days prior to the start of the first filling. It must not be allowed to dry and become hard during this time because it is impossible to mix properly in that condition.

The procedure is as follows:

(i) The inlet pipe should be blocked with a piece of wood or a stone wrapped in sack cloth;

(ii) The slurry should be made up as described above;

(iii) The plug should be removed from the inlet pipe, and care should be taken that the plug does not slip down the inlet pipe! (A sieve, e.g., chicken wire, can be fitted over the inlet pipe to prevent straw, lumps of dung, stones, etc. going into the digester);

(iv) While filling a digester with a centre dividing wall for the first time, care must be taken to fill both the compartments equally, otherwise the centre dividing wall will collapse because of uneven pressure.

If there is water lying in the bottom of the digester before the pit is filled with slurry, this will not matter. The slurry should be made thicker than usual, until the mixture in the digester pit is correct. Then the remaining slurry can be made to the standard consistency.

Note: To make a slurry thick, it must be mixed with some water and all lumps broken down to a uniform consistency before it is put into the digester.

When the gas plant is full of slurry there will be no leaks of water into the digester because the pressure of the slurry in the digester is greater than the pressure of the water trying to get in.

The slurry will not leak out through any small cracks in the brickwork because the solid matter will block them up.

Slurry is put in until it starts to overflow through the outlet.

The type of bacteria added to the input material depends on the type of dung used.

(i) *Cattle dung*

Some bacteria, which form methane gas, exist in all cattle dung. Therefore no special starter is needed. In cold weather the bacteria may take several weeks to multiply enough to produce gas. This can be speeded up by adding some pig dung and mixing it with the cattle dung slurry.

(ii) *Pig dung*

The best starter for these plants is effluent from an existing plant. Up to about 6 per cent of the digester volume may be used. There are some methane-producing bacteria in pig dung. If no starter is available, then, given time, the existing bacteria will multiply and start giving gas. In some countries, concentrated starter bacteria for pig dung are available from government agencies.

(iii) *Chicken dung*

There is relatively little information available on this dung. It produces more gas per kg than any other type, but it seems to need a starter more than any other type of dung. The starter can be from another chicken dung plant or from a cattle or pig dung plant. Up to about 6 per cent of the digester volume may be used.

(iv) *Human sewerage*

Starter from an existing plant or animal dung plant is required. At least 6 per cent of the digester volume may be used.

In all biogas plants starter bacteria can be added at any time. It is recommended that they be added when the digester is about 1/4 full. This ensures that they mix well with all the slurry.

Note: Feeding should be stopped once the digester has been filled. No more slurry should be added until three full tanks of burnable gas have been produced, or after 15 days, whichever is longer.

This is essential. Failure to do this is a common cause of low or no gas production or gas which does not burn (too much CO_2). With human sewerage plants this point needs to be planned for, i.e., how to dispose of the daily sewerage during the time it cannot be put in the digester.

(e) *Fitting of the gas holder*

The digester must first be filled with slurry.

Before the gas holder is fitted, a check should be made for scratches in the paintwork. If there are any, they should be painted over. The sides, in particular, should have a final coat of paint before the gas holder is put in place. The gas holder is lifted into position and located with the central guide.

In the case of gas holders with a main gas valve attached, the main gas valve should be opened and air allowed to escape until the gas holder rests on the gas deflecting ledge (or other support provided). The main gas valve is then closed.

For gas holders taking gas from the central guide pipe, the main gas valve on the main gas pipe close to the digester and also the gas taps for the stoves should be opened to let all the air escape. (If a water outlet device is used, some water should first be poured down the dipper pipe.) After this the main gas valve and the gas taps for burners are closed.

Patience is usually needed in waiting until the gas holder is full of gas. This usually takes about 7 to 20 days.

Note: The first gas holderful of gas must not be used. The first gas can have air in it and therefore can be explosive and dangerous. (It could also be non-combustible because of too high a percentage of CO_2.) The first gas holderful of gas should all be allowed to escape as explained above.

Note: There should be no smoking or naked lights nearby while the gas is escaping. The gas holder should be completely filled a second time and even the second gas holderful of gas may not burn well.

Where used, the flexible pipe should be fitted to the gas holder as shown in Chapter VI and tightened with pipe clips. All gas taps for stoves and gas cocks for lamps and condensate taps need to be checked to see that they are closed. The main gas valve is now opened. A gas tap for a stove is opened and all the air allowed to escape until there is a definite smell of gas. It is then turned off again.

The same procedure is applied to all gas taps for stoves and gas cocks for lamps. A stove is now attached to the gas tap and the stove's air adjuster is fully closed.

A match is lit and applied to the holes in the stove and then the gas is turned on. The gas should burn with a blue flame. (It is difficult to see the flame in sunlight.)

Stoves and lamps should be adjusted as explained in chapter X.

The daily feeding of the correct amount of slurry into the gas plant should only commence after 15 days from the time when the gas holder is put on or after the gas holder has filled completely a third time, whichever is longer.

2. Bag type digester

The bag type digester is filled in the same way as a floating gas holder type digester. The bag is inflated before the slurry is put in order to get it into the correct shape. Air must therefore be released as the slurry is put in to avoid undue pressure. Air should be released gradually so that the bag does not sag too much. When the inlet and outlet pipe are covered by the slurry, air can be released through the gas pipe.

Gas pressure is given by putting sufficient weights on the top of the bag. Sand bags evenly spaced over the top are best. They should be put near the gas outlet pipe as they cause a strain on the gas pipe and its support. Other types of weights can be used but anything with sharp edges or which will give concentrated loads should be avoided. The amount of weights can be worked out by trial and error. The method of checking the gas pressure is given in the next chapter. When the bag is filled to over-flowing with slurry, all the air in the gas storage volume should be allowed to escape and this volume allowed to refill with gas.

3. Fixed-dome digester

(a) *Checking the digester tank for water tightness*

(i) The valve of the gas outlet pipe should be opened and the water digester tank filled with water to about half of the inlet and outlet compartment.

(ii) It should be left for three to five hours until the tank walls have become saturated with water, then the water level should be marked.

(iii) If there is any significant drop in water level after one day this will mean that the walls or the bottom leak.

(iv) When the water level stops dropping, a mark should be made. This shows that the leakage takes place between the initial level and the lower, final level.

(v) An attempt should be made to locate these leaks. Cracks should be chiselled wide open, the edges roughened and filled with a mixture of cement and sand (ratio 1:1). Any plaster flaking off in the digester tank should be cleaned and new plaster applied.

(vi) If no cracks can be detected it is a good idea to plaster over the walls up to and including the level at which the leakage no longer occurred.

(vii) When this plaster is almost dry, wet spots, patches or lines should be searched for. Any places needing attention should be marked and repaired.

(b) *Checking the digester for gas leakage*

(i) When the bottom and walls are watertight, a manometer may be connected to the gas pipe and the manhole closed and sealed.

(ii) More water should be added to increase the air pressure inside, or air may be blown into the digester dome.

(iii) When a pressure of about 400 mm water gauge has built up (the pressure should not be allowed to increase over 1,000 mm water gauge), no more water or air should be added. The digester should then be left for 24 hours.

(iv) If the change in the height of the water column is nil or very small, i.e., 1 to 2 cm, the digester dome is shown to be airtight. However, if the change in the height of the water column is noticeable, the dome is not airtight.

(v) A smoke test may be carried out to locate leaks. This is done by putting a bowl containing a smoke producing material, e.g., green grass sulphur powder, through the outlet opening so that the smoke rises into the dome (gas holder). The water level should then be quickly raised to seal off the inlet and outlet openings. The pressure should be brought, by adding more water, to the pressure for which the pit is to be tested. This method shows the rough position of a leak in the cover of digester dome.

(vi) Where a gas leak has not been clearly located, the gas tank should be washed clean and a coat or two of pure cement or cement and sand mix (ratio 1:1 or 1:2) should be applied.

(vii) If there is a leak at the point where the gas pipe goes through the cover of the manhole, the interface between the pipe and the cover may be chiselled open round it, and the pipe cemented in anew.

(c) *Pre-treatment of plant waste*

The fixed dome digester is the one in which plant waste can be fermented and used to produce biogas. Generally plant waste is formed of linear molecules firmly connected and wrapped round the surface with a layer of wax. For this reason it is difficult for the bacteria to destroy and digest them. A pre-treatment is therefore necessary. There are two methods for pre-treatment:

(i) In the first, the weeds, stalks and leaves are crushed or chopped into small pieces, then saccharified using a suitable enzyme, e.g., cellulase and finally fed into the digester.

(ii) The second method is called "pile composting" and is common in the rural areas of China. Here, the plant wastes are cut into small pieces, piled up in layers, each layer about 50 cm thick. A little limewater, human and animal waste or waste water is added. Then, the surface may be caked over with clay. When the average ambient temperature is about 30°C this piling and composting should last from 7 to 10 days, whereas in an average temperature of about 20°C it should last for one month.

(d) *Starting of the digester*

(i) First put in the composted plant waste (stalks, grass, weeds, etc.).

(ii) Human and animal waste may be then added through both the inlet and outlet compartments.

(iii) Cow and horse dung should first be mixed with water and then poured in through the inlet compartment.

(iv) The gas pipe should be disconnected or the safety valves, if any, opened during filling so as to avoid a build-up of pressure in the gas holder.

(v) The digester tank should not be filled more than 75-80 per cent of its volume, thus allowing volume for the storage of gas.

(vi) During the first few days the gas stored will be impure and incombustible, and should be allowed to escape a few times.

(vii) About two weeks after the initial filling of the digester tank new material may be added. Generally, in the fixed dome digester the composted plant waste is added once every six months, whereas human and animal waste is added on a continuous basis (every day or every second day). It is also possible to add a new charge of composted plant waste and human and animal materials every two weeks, after removing an equal amount of the fermented material through the outlet.

B. Operating a gas plant

Surveys show that in various countries many biogas plants do not produce as much as they should and some have gone out of use. Although they were properly constructed and sufficient feed material is available, the reason for this is faulty operation and/or poor maintenance. This section is aimed at giving information which, if followed, will prevent this happening.

1. Slurry input

The daily mixing of the correct amount of dung with the correct amount of water to obtain the correct slurry consistency is extremely important. Methane bacteria do not like changes. People with little or no schooling find it difficult to understand the importance of controlling the input. For example, a new farm labourer starts operating the plant. He makes too much or too little slurry. Perhaps he makes it too thick or too thin or makes it correctly but spoils the effect by washing out the inlet tank with an extra bucket of water and letting this run down the inlet pipe into the digester!

The following instructions need to be understood and followed. From chapter V we saw that for 1 m^3 (35 cu ft) of gas per day about 32 kg cattle dung per day, 20 kg pig dung, 12 kg poultry or human faeces or urine from 40 people is required. We also saw that about 1 litre water per kg dung is required. The amount of water is not as important as obtaining the correct specific gravity (see chapter XI).

Example: What should the daily input of slurry be for a 5 m^3 (175 cu ft) gas plant using cattle dung? (5 m^3 = daily gas production) cattle dung = 5 x 32 = 160 kg
= 160 litres (1 kg dung equals approximately 1 litre volume)

water 1:1 ratio = 160 litres

Daily slurry input = 320 litres

To calculate the volume of slurry being fed in each day proceed as follows. Measure the length and breadth of the inside of the mixing pit. Mix the slurry. Measure the depth of the slurry. All dimensions in centimetres.

$$\text{Volume} = \frac{\text{length (cm) x breadth (cm) x depth (cm)}}{1{,}000}$$

The answer gives the volume in litres.

Measuring the volume of slurry fed into a plant per day and also its specific gravity gives a very good indication of whether or not the correct amount of dung is being fed in daily.

If it is found that, during a period of time, too much, too little, too thick or too thin a slurry has been used, then it must be corrected. If it is a big change, 100 per cent correction should not be made at one time. A partial correction can be made and after about two weeks a further correction made. If a major correction is made too quickly, it will have an adverse effect on the bacteria and instead of increasing gas production, there can be a temporary reduction of gas production.

Under no circumstances should more than the recommended maximum daily amount of dung be used during the cold season. Extra dung will not increase gas production, in fact it may reduce gas production because the dung is forced out of the plant before it has given off most of its gas.

When the slurry has been mixed, the cover over the inlet pipe is removed and the slurry is allowed to flow into the plant. It flows in quickly and the slurry level in the digester rises. It will go down again as used slurry slowly comes out of the outlet.

For continuous feeding in fixed dome digesters the recommendations given above can be applied.

After the plant has been started up, any human faeces, urine, food waste, animal dung and vegetable matter, including animal bedding, can be added daily, provided that they are mixed in accordance with C/N (carbon/nitrogen) ratio, not in excess of the recommended daily input as calculated for the size of plant being used, and that the concentration of solid materials is controlled.

In the operation of the fixed dome digester one of the most important factors for normal fermentation is the C/N ratio in the material used. The optimum C/N ratio is around 20 to 25/1 (see annex I). Different materials have different ratios and even the same material may have different ratios under different conditions. It is, therefore, important at the time the slurry is put in not only to have a definite quantity of input material but also to pay due attention to the ratio of the various input material in the digester, especially with materials of high fibre content such as plant waste and materials of high nitrogen content such as human waste. The proportions and quantities of mixing various input materials as recommended by the Sichuan Provincial Office of Biogas Development (7) are given in table 5.

In the operation of the fixed dome digester it is recommended that fresh slurry should be added every 3 to 5 days to about 4 per cent of the total capacity of the digester, after removing the same amount from the outlet.

Table 5. Proportions of different materials to be put into the digester

Material	*Properties*
Fresh human waste/dry straw (wheat stalks)	1.75:1
Fresh pig waste/dry straw (wheat stalks)	4.55:1
Fresh human waste/dry rice stalks	1. 4:1
Fresh pig waste/dry rice stalks	3.65:1
Fresh human waste/corn stalks	1.13:1
Fresh pig waste/corn stalks	2.95:1
Fresh human waste/fallen leaves	0.85:1
Fresh pig waste/fallen leaves	2.22:1
Fresh human waste/soya bean stalks	0.45:1
Fresh pig waste/soya bean stalks	1.1 :1
Fresh human waste/wild green grass, including water weeds	1 :10
Fresh pig waste/wild green grass, including water weeds	1 :25
Fresh human waste/fresh pig waste/dry rice stalks	1: 1:1
Fresh human waste/fresh pig waste/dry wheat stalks	1: 2:1
Fresh human waste/fresh pig waste/dry corn stalks	3: 4:4
Fresh human waste/fresh pig waste/green grass, including weeds	1:10:180

Source: Information made available by the Chinese authorities to the members of the Interregional Biogas Study Tour in China from 1 to 21 September 1979, organized by the United Nations.

Note: The C/N ratios of sheep, cow and horse dung fall in the optimum range (20 to 25:1), hence they may be digested alone or with any of the above material mix.

2. Stirring the slurry

It is very beneficial to stir the contents of the digester as this increases the gas production. The stirring device (sometimes called a mixing device) should also break up the scum layer which tends to form on the surface and which reduces gas production. In floating type circular gas holders fitted with stirring bars proceed as follows.

Turn the gas holder 360° in one direction, then back 360° in the opposite direction. This should be done after cooking when the gas holder is low in the slurry. Do this for 3 minutes in the morning and 3 minutes in the evening.

Square type floating gas holders cannot be turned to mix the slurry but sometimes have separate mixers attached. These should be turned daily for 3 minutes in the morning and the evening.

In the fixed dome and bag type digesters it is not common to fit special mixers. Therefore the only mixing which can be done is by moving plungers up and down the inlet and outlet Unfortunately, this is not very effective.

C. Operational problems and their remedies

1. Starting problems

Defect	*Possible cause*	*Remedy*
Gas holder does not rise (floating type) or bag does not inflate (flexible bag type) or pressure does not rise (fixed dome type)	*a*) Very few bacteria	About 20 litres of slurry from an existing plant should be put down the inlet; then one lot of new slurry should be added to the digester. Gas holder should be rotated daily.
	b) Lack of time	In cold weather it could take 3 weeks to fill the gas holder for the first time. Have patience!
	c) Feeding in slurry while waiting for gas holder to fill	This is a common fault. No slurry should be fed until the third gas holder of burnable gas has been produced.
	d) No water in water outlet device	About 0.25 litre of water should be poured into the dipper pipe, and then any excess be removed by means of the water container (see chapter IX).
	e) Leak in gas holder or gas pipe	It should be located and repaired.
	f) Gas tap or cock or condensate tap open	It should be closed.
First gas produced will not burn	*a*) Wrong kind of gas	The first gas should not be burned. It may have air mixed with it and could explode. Particularly in cold weather, when the first gas is produced slowly, it frequently has a high percentage of CO_2 and so does not burn. The second gas holderful of gas should burn.
	b) Air in the gas pipe	The air should be allowed to escape until there is a definite smell of gas.

2. General problems

Gas holder or bag (or pressure in fixed dome type plant) goes down very quickly once main gas valve is opened	*a*) Condensate water outlet tap open (if fitted) *b*) Gas tap for burner open *c*) Gas cock for lamp open	Close it or them.
	d) No water in water outlet device	About 0.25 litre of water should be poured into the water outlet device and any excess removed by means of the water container.

Defect	*Possible cause*	*Remedy*
	or syphon	Water should be added until it overflows.
	e) Major leak in pipework	It should be located and repaired.
Gas holder, bag or pressure in fixed dome type plant rises very slowly	*a*) Temperature too low	Gas production is always reduced in cold weather. Ideas to improve gas production are given in chapter XIII.
	b) Thick scum on top of slurry	Gas holder (if fitted) and also the layer of scum should be removed. The drum should be agitated daily, and no straw or grass, etc. should get into gas plant.
	c) Too much slurry put in daily, or *d*) Too little slurry put in daily	Correct amount should be added daily. It will correct itself in a few weeks.
	e) Slurry mixture suddenly changed a lot	Slurry mixture should not be altered too much at one time.
	f) Putting chemicals, oil, soap or detergent into slurry	Daily feed with dung and water only to be continued. After 2 to 6 weeks it should correct itself.
	g) Gas leak	Leak should be located and repaired.
	h) Slurry mixture too thick or too thin	Slurry to be made with the right consistency.
	i) Washing out mixing tank with extra water and allowing it to go into the digester	No extra water should get into the digester.
Gas won't burn	*a*) Air in gas pipe	Air should be allowed to escape until there is a definite smell of gas.
	b) Wrong kind of gas (probably too much CO_2) *i*) Due to putting in too much slurry per day *ii*) Due to putting in too much urine per day *iii*) Due to putting in excess chemicals per day	Gas should be allowed to escape and the correct slurry fed in. It may take as long as a few weeks for the gas plant to correct itself.

3. Stoves

Flames are long and weak Flame starts far from the flame ports or does not stay alight	*a*) Incorrect air supply	Cooking vessel to be on stove and air supply to be adjusted.
	b) Gas pressure incorrect	Correct pressure of about 75 to 85 mm (3-3.5 in) water gauge should be used.

Defect	*Possible cause*	*Remedy*
Flame small	*a*) Gas jet in stove partially blocked	See "No gas at stove" below.
	b) Insufficient gas pressure	Check whether it is due to the gasholder not being turned daily to mix the slurry or whether it is due to thick scum, which needs to be removed. Soft plastic flexible pipe (if fitted) has gone flat in places. Sleeves of ordinary black plastic water pipe should be fitted over these places to bring pipe back into shape. If necessary weights may be added to gas holder.
	c) Flame ports partially blocked	They should be cleaned out.
Flame pulsates	*a*) Condensate lying in the main gas pipe	Condensate should be removed. If the flame still continues to pulsate, there is still water lying in the pipe, which cannot be drained out. The builder should relay the pipe at a slope of 1 in 100 or fit an extra water outlet tap if necessary.
	b) Condensate lying inside stove	The stove should be turned upsidedown and the condensate poured out.
No gas at stove	*a*) Main gas valve closed	The valve should be opened.
	b) Condensate completely blocking main gas pipe	
	c) Gas jet in stove blocked	The stove should be disconnected, and a check should be made to see that the gas is getting that far. The stove gas jet should be cleaned with split bamboo or a needle. The jet hole should not be damaged or enlarged.

4. Lamps

Light is poor	*a*) Gas regulator and/or air regulator (if fitted) require adjusting	Adjust.
	b) Gas pressure too low	Correct gas pressure to be used for lamps. (About 75 mm (3 in) water gauge). A check should first be made whether it is due to the gasholder not being turned daily to mix the slurry, or due to thick scum, which needs to be removed. Pressure should be increased if necessary, by adding weights to the gas holder.
	c) Obstruction in lamp between gas regulator and venturi	Venturi should be removed and cleaned out thoroughly. This is quite a common fault.

Defect		*Possible cause*	*Remedy*
Mantles break frequently	*a*)	Gas pressure too high	Correct gas pressure to be used for lamps. About 75 mm (3 in) water gauge. Jet nozzle should be set further from the diffuser in case of a Chinese plant.
	b)	Wrong type of mantle	Correct type should be used.
No gas at lamp	*a*)	Gas jet in lamp blocked	Gas regulator should be operated to clear the jet.

5. Slurry inlet/outlet

Slurry does not flow into gas plant	*a*)	Sieve (if fitted) clogged	It should be cleaned and refitted.
	b)	Inlet pipe blocked	It should be cleaned by putting a pole down the inlet and moving it up and down.
Digester pit over-flows	*a*)	Outlet pipe blocked	It should be cleaned by putting a pole down the outlet and moving it up and down.
	b)	Slurry too thick to flow easily	It should be adjusted to correct consistency.
	c)	Slope away from outlet too little causing a build-up in the slurry level at the outlet	Slope should be increased or level of outlet lowered.
	d)	Outlet too high	Level of outlet should be lowered.

XII. SERVICING AND SAFETY

A. Servicing

1. Gas holder painting

The gas holder normally needs to be painted annually, but only on the outside. There is no oxygen on the inside and rust rarely occurs there. It will be found that the lowest part of the outside of the gas holder is also generally free from rust.

The procedures for painting the gas holder are given below:

(a) Any weights should be removed from the gas holder. The main gas valve should be closed and the gas holder allowed to fill completely until gas bubbles out from under the side.

(b) All dung should be cleaned off using water.

(c) All rust should be thoroughly scraped off using a steel scrapper; then the surface should be thoroughly cleaned with a wire brush.

(d) The whole drum should be washed with clean water and allowed to dry completely.

(e) All badly rusted areas should be painted with a first coat, then the whole drum can be painted.

(f) The gas should not be used for 24 hours allowing the paint to dry.

2. Scum removal

The frequency with which this process is performed depends on how free the slurry is from straw and grass, etc. At a carelessly operated plant it could be every six months, at a well run plant it may not be necessary even after two years. The procedure is as follows.

(a) The main valve is closed and the gas holder is allowed to come up to its maximum height. There should be no smoking, no matches and no lamps in the area.

(b) The gas holder is lifted out of the slurry using the handles at its top over the centre guide and put to the side of the digester.

(c) The scum should be removed from the top of the digester pit.

(d) While the gas holder is off, its inside should be cleaned with water and a brush. A check can also be made whether the paint is in good condition. The inside usually does not need to be painted. However, if there is any rust, it should be repainted and the paint allowed to dry before the gas holder is replaced.

(e) The gas holder can now be replaced on the digester. It is essential to let all the air escape. The gas holder must settle down to the maximum possible depth in the slurry. (Gas mixed with air in certain proportions is explosive.)

(f) The pipes must also be cleared of any air. How to do this is explained in chapter XI.

3. Removing sludge from a fixed dome digester

Approximately every six months the contents of the digester tank are removed. The manhole cover is lifted out and the contents, especially the scum, are removed by buckets. The gas plant is recharged with fresh materials and the manhole cover replaced and sealed with clay. It is usual to do this shortly before the winter as maximum gas will be produced after the plant is recharged.

4. Repairing masonry work in a digester

If proper materials are used as set out in this book and the gap between the digester walls and the sides of the hole in the ground is properly backfilled and rammed, repairs are not usually necessary. However, they may be necessary on occasion. If the damage is serious, the wall has to be rebuilt. Where it is less serious it can be repaired by cleaning the wall around the crack and attaching 2 to 3 layers of chicken wire to the wall at least 30 cm (1 ft) either side of the crack using many nails (figure 82). Plaster (cement sand ratio 1:3) at least 13 mm (0.5 in) thick should be applied.

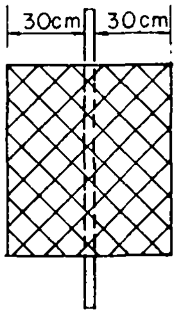


Figure 82. Chicken wire reinforcing for repairing cracks in masonry work

5. Condensate removal

Where a flexible pipe joins the gas holder to the main gas pipe, the flexible pipe should be lifted near the main gas pipe so that any condensate (water) flows to the gas holder end and down through the open main gas valve into the gas holder. This job usually needs to be done every one to seven days.

For removing condensate from traps, see the instructions given in chapter IX.

6. Stiff taps

Lubricate any stiff gas taps. See chapter IX.

7. Stoves

Clean out flame ports. See chapter X.

8. Lamps

Maintenance is described in chapter X.

9. Removal of dried slurry

Any cakes of dried slurry should be removed from the sides of the mixing pit, outlet and top of the digester pit between the wall and the gas holder.

10. Water seal

The water level should be maintained to avoid gas leakage. An oil film should be maintained on the surface to prevent mosquitos from breeding.

11. Flexible pipe

The flexible pipe, if fitted, joining the gas holder to the main gas pipe needs to be checked for any cracks or leaks and replaced if necessary. When a new flexible pipe is fitted, care should be taken to ensure that gas does not leak from either end. Soapy water should be used.

12. Rubber gas pipes

The rubber pipes joining gas taps to stoves need to be checked for any leaks or cracks. Bad ends should be cut off or the complete pipe replaced if necessary.

13. Leak test of main gas pipe

All pipe work should be tested for leaks. How to do this is explained in chapter IX.

14. Repairing steel gas holders

This is only necessary if the steel is not painted regularly. Where it is badly rusted and there are many holes, the whole gas holder has to be replaced.

Pieces can be cut out and new bits welded on. For small holes, clean thoroughly and repair using epoxy resin, e.g., "Araldite".

15. Check of gas pressure

For lamps a gas pressure of 70-85 mm (2.75-3.25 in) water gauge is usually required. For stoves the recommended pressure is 75-90 mm (3-3.25 in) water gauge, although there can be a greater variation.

Gas pressure is influenced by two things:

(a) Pressure in the gas holder;

(b) Pressure losses due to friction in the pipe.

Pressure losses in the gas pipe have to be considered when a gas plant is being installed. That is why some pipes are 0.75 in or even 1 in instead of the normal 0.5 in pipe.

Gas pressure in the gas holder can be increased by putting weights (e.g., bricks) on top of the gas holder. Weights should be placed symmetrically on the gas holder and not all on one side. Weights should be raised from the surface of the paint (i.e., placed on small strips of wood); otherwise the gas holder tends to rust underneath them. It should never be necessary to decrease the pressure more than by removing any weights from the top of the gas holder.

If too high a gas pressure is used, the gas will escape from condensate outlets, which use water to provide a gas seal, and mantles for lamps will break frequently.

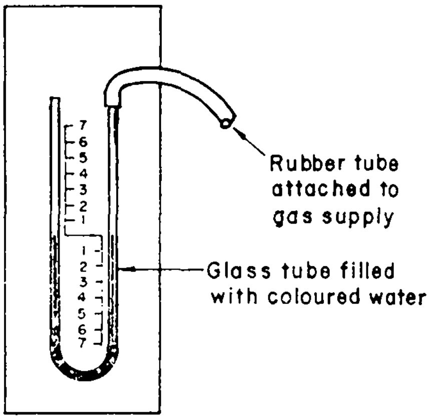


Figure 83. Manometer

The gas pressure can be measured by means of a manometer (figure 83). It is attached to a gas tap using a rubber tube. It is not always necessary or usual to have a manometer permanently attached to the gas plant (see chapter IX). If a manometer is not available, the gas pressure can be checked in the following way.

A rubber tube is attached to a gas tap and put straight down into a container of water to a depth of at least 150 mm (6 in). The gas tap is turned fully on and the pipe is lifted out of the water until bubbles just start to come out of the rubber pipe. The water level on the rubber pipe can be marked with your finger. (To do this accurately, the pipe must be just in far enough to stop any bubbles coming out.) The gas should then be turned off. The pipe is withdrawn and the distance from your finger to the end of the pipe is measured. This gives the pressure in mm or inches of water gauge.

16. Measurement of gas production

Gas is usually measured by a flow meter. However, the moisture and hydrogen sulphide in biogas corrode and quickly put out of action all normal types of meter. Special scientific wet type meters can be used but these are extremely expensive.

Gas production can easily be measured when a gas holder floating in the slurry is used (figure 84).

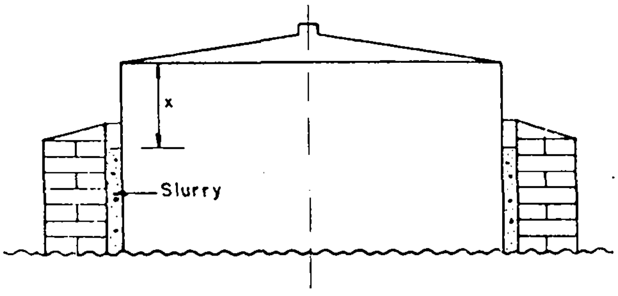


Figure 84. Measurement of gas production

Any scum should be removed from the surface of the slurry between the wall and the gas holder. This is important. Care should be taken to ensure that the gas holder is low in the slurry; otherwise there will not be room for the gas which is to be measured. The height from the slurry surface (not the masonry) to the top corner of the gas holder (X) is measured. After at least 8 hours, X should be measured again. If any gas escapes from under the side of the gas holder, the result will not be accurate. This rarely happens in 8 hours.

Example: Diameter of gas holder $d = 150$ cm

At start of test $X_1 = 8$ cm

At end of test $X_2 = 65$ cm

Time period 8 hours

$$\text{Volume of gas} = V = \frac{\pi d^2}{4} h$$

$$h = X_2 - X_1 = 65 - 8 = 57 \text{ cm}$$

$$V = \frac{\pi}{4} 150^2 \times 57 \text{ cm}^3$$

$$= \frac{\pi}{4} \times \frac{150^2 \times 57}{1{,}000} \text{ litres}$$

$$\text{Volume} = 1{,}010 \text{ litres} \cong 1 \text{ m}^3$$

in 8 hours
1,010 litres ($\cong 1$ m^3) $\cong$ 36 cu ft gas is produced

then in 1 hour
126 litres = 4.5 cu ft gas is produced

and in 1 day
3 m^3 = 108 cu ft gas is produced

Tests carried out over a period of less than 8 hours are inaccurate. The graph in figure 85 gives the figures obtained during an actual test to illustrate the possible hourly variation in gas production. The highest point was at the time when fresh slurry was fed into the plant and the gas holder was revolved to mix the slurry.

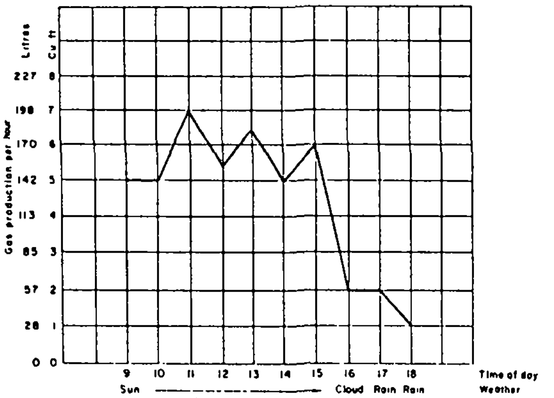


Figure 85. Graph of gas production/hour against time of day, air temperature and cloudiness

Gas expands with increased temperature and vice versa. This is at least part of the reason for the apparent reduction in gas production when it started raining.

There will always be a peak of gas production during the first three months of operation of a new gas plant while the large amount of dung put in initially produces gas and until the bacteria in the plant are stabilized. Therefore it is better to carry out gas production tests after this time.

B. Safety

1. General considerations

Biogas, when used as instructed, is safer than other gases used in houses. It can only explode when there is 6 to 25 per cent biogas mixed with air. If all the air is removed from the gas holder and pipes before use, as explained in chapter XI, the gas plant cannot explode.

After the gas holder has been removed (or opened) and then replaced (or closed), it is essential to let all the air in the gas holder escape, by ensuring that the gas holder settles down to the maximum possible depth in the slurry, or the bag is deflated or the first gas is allowed to escape from a fixed dome type digester.

Once the gas holder has filled with gas again, the pipes must be cleared of air. The procedure for doing this is given in chapter XI. After repairing pipes or even checking for leaks, care must be taken to remove any air from the pipes before the gas is used again.

Care must also be taken if there is a gas leak. If there is a leak, the following procedure may be followed. If there is a serious leak, there will be a smell of unburnt gas. The doors and windows should be opened to let the gas dissipate and fresh air come in.

There should be no smoking, no candles, no fires, no matches, no lamps or other open flame until the smell of gas has gone.

The main gas valve should be closed. If you are looking for the leak in daylight, care should be taken to ensure that all gas taps for burners and all gas cocks for lamps are closed. The main gas valve is then opened and attempts are made to find the leak by trying to smell where the gas is coming from. Leaks can be detected by putting soapy water over suspected leaks (often at joints). If bubbles appear, then it is certain that there is a leak.

The full procedure for finding gas leaks and repairing them is given in chapter IX.

2. Fixed-dome type digester

Care must be taken if this type of digester is opened up for any reason. While there is any slurry in the digester, gas will continue to be produced. It could easily burn, but it is not likely to explode because there is a large entrance for any flame (which would be huge) to come out. The flame in itself is dangerous and can cause serious burns to anyone standing in the way. The gas is not poisonous, but if a person breathes only gas he gets no oxygen and cannot live. If any worker needs to enter the plant before it is empty, the following procedures should be followed.

Once the gas plant is completely empty there is likely to be CO_2 gas lying at the bottom of the digester. It should be lifted out by buckets and poured away from the plant so that it cannot re-enter via the inlet or outlet or manhole. If possible, blow air into the plant to ventilate it. The gas hose should first be detached from the gas outlet pipe and the manhole cover should be left open for several days. Bellows, a winnowing machine or some machine to raise wind should be used to force air into the digester tank. If none of these is available, buckets may be used to lift the gases, particularly CO_2, lying at the bottom of the digester.

Before anyone enters the digester tank it is best to make a check with an animal. A frog, chicken or rabbit should be lowered into the digester tank and brought up again after a few minutes. If the animal seems to behave normally, this indicates that there is enough air in the digester tank, and one may enter it to work. If anything unusual happens to the animal, if it faints or loses consciousness, this indicates a lack of air. In this case air circulation should be continued.

A worker going into the pit should breathe through a long piece of pipe or hose with one end attached somewhere outside the digester tank. There should be a second person to pull him out if he is accidently overcome with the gas.

If a worker feels dizzy while working inside the digester tank or finds it hard to breathe or in any way uncomfortable, be should leave the tank immediately and rest in a place where there is good air circulation.

XIII. IMPROVING GAS PLANT PERFORMANCE

In village situations there are some things which can be done to increase gas production. Only a few are economically justifiable. The most important thing is to operate the plant properly. Daily feeding of the correct amount of slurry of the correct specific gravity and daily mixing of the slurry are extremely important.

A. Thermal methods

There is no doubt that gas production is significantly increased when the temperature of the slurry is raised. The optimum temperature for the type of plant discussed in this book is about 35°C. In most places this will never be reached without heating and insulation. Temperatures need to be kept constant ± 1°C (± 2°F) for the sake of the bacteria (see annex II). The effect of the means of heating and insulating the digester listed below is still to be proved.

1. Insulation

The whole plant is insulated, including the gas holder. This means that all the walls must be strong enough to withstand the hydraulic pressure (assuming the insulation has no compressive strength) and must be waterproof. The insulating materials, such as straw, must be kept dry. The gas holder roof is insulated with straw or similar material (figure 86). The thickness of the insulation is usually about 5 to 8 cm.

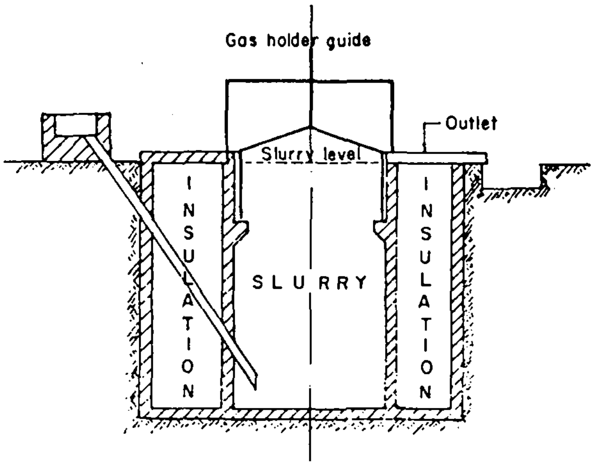


Figure 86. Insulated digester

2. Heating of input slurry

Solar energy may be used to heat the input slurry. As the daily input of slurry is only about 2 to 4 per cent of the total volume, it will have to take effect on the total mass, which can lose heat to the surrounding ground. If care is taken in heating the input slurry gradually and avoiding excessive temperature, which will kill the bacteria in the slurry, the solar heating of the fresh slurry may help to bring its temperature, which is usually low in view of the fact that the dung is mixed with cold water, to that of the slurry in the digester.

3. "Glass" house

A tent made of plastic sheets can be erected over the gas plant. This gives a glass house effect, provided the joints are made airtight. In case any gas has collected inside the tent, care must be taken to avoid an explosion (i.e., no smoking or direct lights should be allowed in the tent, and means should be provided for any accumulated gas to escape). Ultraviolet rays in sunlight destroy the sheets in time. The longest-lasting sheets are PVC. Clear material is most efficient but black sheets will last longer. The sheets should be removed after winter and stored for the next winter. It has been reported that this scheme increases gas production by 50 per cent.

4. Solar heating of digester

Attempts to incorporate a solar water heater and heating coil in the digester have been made. This is expensive because the coil is lower than the heating panel and therefore the water must be pumped through the coil. It is neither practical nor economic for general use in villages.

Research is progressing and appears to offer considerable potential, provided there is plenty of sunshine during the colder time of the year.

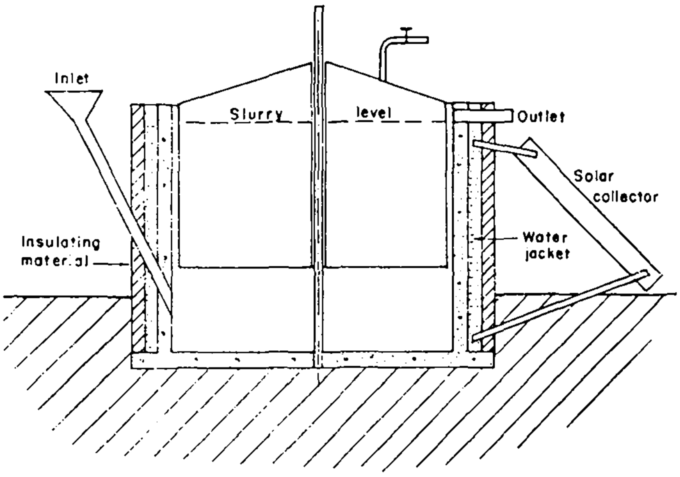


Figure 87. Solar-heated digester

The water jacket is more efficient than a coil as it gives better uniformity of temperature throughout the plant (figure 87). It is claimed that more gas per kg of dung is produced in a shorter time because the plant operates at an elevated temperature.

The specific gravity of the slurry can be increased by 10 per cent. Thus a smaller digester is needed and this saving of cost compensates for the cost of the solar heater. This design is currently made entirely from steel, but it is possible that in future other materials, including ferrocement, could be used. The development in this direction is important as it may be economically justifiable and operationally suitable for village use in the course of time.

5. Thatched roof for gas holder

The idea is to prevent heat loss through the gas holder. It should not cost much and it can be tried.

6. Reflecting surfaces

A curved wall located and painted to reflect the sun onto the still digester has been used. Enough information on this method is still not available.

7. Composting around the digester wall

Aerobic composting generates a lot of heat. The idea is to make several composting pits around and against the side of the digester and to use and empty them in turn so that continuous heat is given to the gas plant. This has not been fully tested yet, but there appears to be no reason why this should not work well. The main thing is the discipline to empty and refill the compost pits regularly in rotation, so as to maintain a constant temperature in the slurry in the digester. If this is not done, the temperature of the slurry will fluctuate and the gas production may be less than without composting.

B. Chemical and microbiological methods

1. C/N ratio and pH

If the gas plant using cow dung is operated as instructed, especially regarding stopping feeding once the digester is filled and until proper gas production starts, these factors will find their own satisfactory levels.

2. Feeding bacteria

The bacteria can be stimulated to give better gas production, by supplying readily accessible food. If too much is added, it may produce a toxin (poison), which in time will kill all the bacteria.

(a) *Nitrogen*

(*i*) Urine. This will increase gas production provided not too much is added per day. One litre per 1.4 m^3 digester volume can be added per day, e.g., if the digester volume is 7 m^3, then 5 litres per day can be added.

(*ii*) Urea fertilizer. This also stimulates gas production but not enough work has been done to recommend a fixed amount to be added per day. It could be as low one level teaspoon per day per 3 m^3 digester volume.

(b) *Carbon*

Molasses or sugar waste products, powdered straw or bajra leaves. When the material has to be bought or it takes a lot of time to powder, it is doubtful whether it is economically justifiable. Insufficient research has been done with these materials, but it appears that about 70 grams per m^3 of digester volume can be added per day.

Note: If straw or bajra leaves are used and are not powdered properly, they will float to the surface and cause scum problems.

(c) *Enzymes*

In the West enzymes have been used to reactivate septic tanks. They have been tested on biogas plants and found to increase gas production, notably methane. The only known sources of supply are in Switzerland and the United States of America. This method is extremely expensive and still not economic unfortunately.

(d) *Water hyacinths*

This water weed produces gas well. It cannot easily be used in a continuous type gas plant because it readily floats to the top and causes scum problems. See chapter V.

(e) *Algae*

Water containing algae has been found to give a significant increase in gas production in plants using pig manure. Tests using algae have not been reported for gas plants using other types of manure.

C. Mechanical methods

There are two different types of bacteria. "Active" bacteria move to food and away from their poisonous residue toxins and "passive" bacteria depend on food coming to them and their residue toxins being removed.

1. Mixing (stirring)

It is well known that mixing is an effective way of increasing gas production. A few minutes of mixing several times a day is best, although most villagers only do it once or twice per day.

All commonly used circular gas holders floating in the slurry are fitted with mixing bars at various radii so that by turning the gas holder a limited amount of mixing is accomplished. Square gas holders have to have a separate mixing device fitted at the top or alternatively a frame is attached to the gas holder, and this mixes the slurry a little as it moves up and down with the gas holder. It is not possible to mix the contents of the fixed dome and bag type digesters effectively, unless a special mixing device is incorporated. A little mixing is caused when the gas plant is fed. For this reason some people feed their digester (with a proportion of the daily input) more than once per day.

Mixing also helps to break up any scum and to dissipate a bit of it. It also releases trapped gas bubbles. Scum causes reduced gas production. When scum forms a thick layer, the only thing to do is to lift off the gas holder or gain access by other means and remove the scum.

For cylindrical gas holders some people suggest attaching mixing rods inside, which reach down to the bottom of the digester. If the internal guide system is used, these rods will prevent the gas holder rotating more than 90°. Where the external guide system is used and a central wall is incorporated, the movement will be 180°. Modifications to overcome these limitations have been suggested, e.g., old motor cycle chains or ropes with a weight on the end. Care must be taken to ensure that these do not get wrapped around the internal centre guide or that the rope does not fray.

2. Recycling of slurry

The principle is to add a little of the old slurry to the fresh slurry in order to seed it with bacteria. Not enough research has been done on this, but it appears that for every 100 litres of fresh slurry about 2 litres of old slurry can be added. This will speed up and increase gas production.

XIV. COMMERCIAL USES OF GAS

About 95 per cent of all the gas plants in Asia are of 10 m^3 (350 cu ft) size. It is reasonable to assume that at the most only 5 per cent of Asian gas plants are used for any other purpose than cooking or lighting. Some commercial uses of gas are given below.

A. Refrigerators

Absorption type refrigerators can be run on biogas. The flame needs to give the correct amount of heat, not too much, not too little. Commercially made biogas burners for refrigerators are not available. However, a Telcu or Bunsen burner can be modified and used. The Telcu burner is easier to adjust and is preferable. The following modifications may be required:

(a) A piece of metal gauze (preferably non-ferrous) should be put over the flame port to prevent the flame lifting off;

(b) The jet size should be altered to get the right amount of heat (done by trial and error);

(c) The air port should be altered to get an efficient flame and not a long "lazy" flame;

(d) The barrel size should be altered. This may need to be increased in diameter to reduce the flame speed and thus avoid flame lift off.

The amount of gas required for a refrigerator will depend on its size, room temperature, refrigerator temperature and the condition of the refrigerator. For estimating purposes, a figure of 0.6-1.2 m^3 per hour per m^3 refrigerator capacity (0.6-1.2 cu ft per cu ft) can be used.

Example. How much gas will be required per day for a small refrigerator of 125 litres (0.125 m^3) capacity?

Gas required per hour = 1.2 x 0.125 m^3

Gas required per day =
1.2 x 0.125 x 24 = 3.6 m^3 (127 cu ft).

For this application a large gas holder is not required as the gas is used uniformly throughout the day.

B. Incubators

Incubators which are designed for operation with kerosene or commercially available gas can be modified to suit biogas. Modified Telcu or Bunsen burners can be used (see section 1 above).

For estimating purposes allow 0.5 to 0.7 m^3 gas per hour per m^3 incubator capacity (0.5 to 0.7 cu ft per cu ft).

Example. How much gas will be required per day for an incubator which measures 50 cm x 50 cm x 30 cm inside?

$$\text{Volume} = \frac{50 \times 50 \times 30}{1{,}000} \text{ litres} =$$

$$= 75 \text{ litres} = 0.075 \text{ m}^3$$

Gas required per day = 0.075 x 0.7 x 24 = 1.26 m^3

C. Welding

The temperature of an oxy-methane flame is about 3,000°C, i.e., 250°C lower than an oxy-acetylene flame. An oxy-biogas flame temperature would be lower still, the actual temperature depending on the percentage of CH_4 in the gas. The lower temperature means that oxy-biogas is unsuitable for ferrous welding but could be used for brazing (hard soldering). If uncleaned gas is used, a manometer should be used instead of a normal pressure gauge. The H_2S and moisture in the gas could damage a sensitive gauge.

D. Treatment to eliminate undesired gas components

Some users of biogas in engines claim that it is necessary to clean the hydrogen sulphide (H_2S) out of the gas before using it. It is essential to clean it of H_2S and carbon dioxide (CO_2) if the gas is to be bottled. Biogas used for cooking or lighting does not need to be cleaned.

(a) *Removing* H_2S

Iron filings may be used to absorb H_2S. It is not easy to calculate the absorption capacity of iron filings as they get a sticky sludge on the surface from the action of the H_2S, which prevents the gas getting at the filings on the inside. Once this sludge has formed on the whole surface it is time to replace the filings. In one experiment in running a petrol engine the gas passes through a 200 litre drum full of iron filings, which is replaced every six months. Iron filings or ferric oxide (rust) of about 2.5 kg will absorb 1 m^3 of H_2S, i.e., will clean 100 m^3 of biogas assuming it contains no more than 1 per cent H_2S.

(b) *Removing* CO_2

CO_2 is usually removed by bubbling the gas through lime water. Lime water is a mixture of 1.8 kg burnt lime in 1,000 litres of water. One thousand litres of lime water will remove 560 litres of CO_2. Therefore assuming there is 35 per cent CO_2 in the biogas, 625 litres of lime water will be needed to purify 1 m^3 biogas. Lime water becomes a milky colour as it absorbs CO_2 and then it starts clearing a little again as it becomes saturated. This shows when it needs to be replaced.

These figures illustrate the fact that large amounts of lime water are required for removing CO_2. The lime sludge which comes out of the solution can be removed, if it is given time to settle. The water can then be re-used with fresh burnt lime. The dried lime sludge sometimes has a commercial value to chemical industries. Sodium hydroxide (NaOH) mixed in water also absorbs CO_2. It requires much less water but is not so easily available and is more expensive. Eleven and a half kg NaOH is mixed with 1,000 litres water and this will absorb 3,200 litres of CO_2.

Assuming there is 35 per cent CO_2 in the biogas 1 m^3 biogas requires only 11 litres of solution for purification.

Sodium hydroxide is caustic and can cause burns to the skin. Great care must be taken when handling it.

E. Storage and bottling of biogas

In general, biogas produced from the digesters is stored only temporarily in the gas holder attached to or integrated with the digester. However, apart from cooking and lighting, biogas can also be used for running engines, irrigation pumps, tractors and transport vehicles. For these purposes it becomes necessary to store the gas in a portable container and carry it to the place of application. Liquification of biogas in cylinders is not considered feasible for technical and economic reasons and therefore attention has also to be given to flexible inflatable bags as portable containers.

Storage of biogas at producation sites requires either technically efficient floating gas holders which are expensive, unsightly and space taking or the underground, less expensive, fixed-dome holders, considered as less efficient and prone to leakage. Flexible bag systems are generally expensive, difficult to construct and unsatisfactory for many reasons.

Carbon dioxide, which forms about one third of biogas needs additional storage space. If it is feasible economically to remove carbon dioxide, it will be a good proposition to remove the gas through purification measures.

(a) *Compression in metal cylinders*

Methane gas is unlike commercially available bottled butane or propane gas, which liquifies at about 1.75 MN/m^2 (18 kg f/cm^2). A pressure of about 34.5 MN/m^2 (350 kgf/cm^2) is required to liquify methane. Biogas must be cleaned of all H_2S as this would corrode the storage bottles. It should also be cleaned of CO_2 as there is no advantage in compressing this. About 20 per cent of the energy available in the methane is required to compress the gas.

A typical steel storage bottle would be about 1.6m long x 0.27 m in diameter; capacity 54 litres, weight 63 kg. It would hold 12 m^3 (420 cu ft) of cleaned methane gas, which is the equivalent to 18.5 m^3 (650 cu ft) biogas, assuming the biogas is 65 per cent methane. The gas pressure used is about 20 MN/m^2 (210 kgf/cm^2). This is equivalent to about 16 litres of petrol or 14.5 litres of kerosene.

(b) *Principles for compression of biogas in metal cylinders*

The following basic points should be kept into consideration, while compressing the gas into cylinders:

(a) Complete removal of air from the cylinder;

(b) In initial stages compressor should be fed at atmospheric pressure;

(c) The cylinder should be placed in cold water while filling and the temperature should be properly controlled;

(d) The compression should be done in three stages:
  (i) From atmospheric to about 1 MN m^{-2} (150 psi);
  (ii) From 1 MN m^{-2} to about 3 MN m^{-2} (450 psi);
  (iii) From 3 MN m^{-2} to about 14-20 MN m^{-2} (2000-3000 psi);

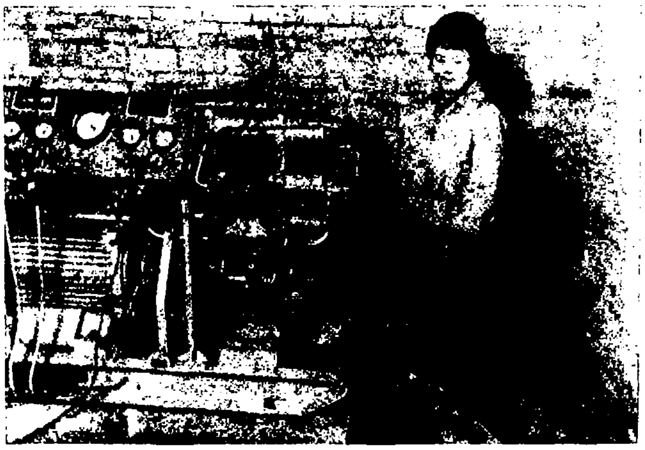


PLATE 15

Biogas compressing unit

(e) Allow cooling between each stage;

(f) It is possible to compress the biogas at 25 m^3 per hour under a compression of 20 MN m^{-2} (200 atm);

(g) Biogas can be stored at pressures of 20-35 MN m^{-2} (200-350 atm);

(h) At this pressure biogas occupies about 5 times less volume than when under medium pressure;

(i) A medium compression of 4 MN m^{-2} (40 atm) is sufficient for purposes like running a tractor and at the same time is less costly.

(c) *Storage in flexible bags*

Flexible bags can be made of a variety of materials such as rubber, PVC and polythene. A simple compressor can be used to fill the bags.

Rubber tubings of vehicle have also been used as biogas storage containers. The inner tubes can be inter-connected with T pieces and the desired pressure can be obtained by placing weight on the top of the tubes.

Balloons have been used in China for storage of biogas. Such balloons are made of 0.28 mm PVC film. Cost of two such balloons is Yuan 900 ($US540) each with a capacity of 120 m^3.

Flexible biogas storage bags made of rubberized fabric material are marketed in India by a commercial firm, Kirloskar. The bags are made available in two sizes viz. 1.8 m^3 and 3.6 m^3 costing about $ 55 and $ 75 respectively.

(d) *Storage of biogas at production sites*

Biogas at production sites is stored in three ways: (a) in floating dome gas holders, (b) in fixed-dome gas holders, and (c) in separate gas holders attached to fixed dome digesters. Recently use has also been made of flexible bags for storing gas at production sites. While the first three methods have been dealt with earlier, storage in flexible gas holders is described below.

PLATE 16

Biogas stored in plastic bags

Digesters made from plastics

Small-scale digesters made with vinyl chloride plastic are used in Republic of Korea. Plastic containers are placed in concrete boxes and are lagged with small stones or straw to reduce heat loss; the entire unit is then covered with a plastic tent.

In Bangladesh, a flexible biogas digester made from PVC plastic sheet has been designed. A trench, 1 meter deep, is dug in the soil and lined with a sheet of PVC plastic. The fermentation material is placed in the trench and is covered with a PVC plastic sheet with its sides dipping below the slurry and attached to the trench walls by tying to pegs. A piece of PVC tubing is inserted in the top to serve as gas outlet. The plastic cover inflates with the production of biogas. However, the system has not proved durable as the PVC deteriorates in sun light.

Use of red-mud plastic

The residual material obtained from extraction of aluminium oxide from bauxite, using sodium hydro-oxide as an extractant, is known as red-mud. Typical analysis of the mud is SiO_2 14.6 per cent, Al_2O_3 22.6 per cent Fe_2O_3 35.6 per cent, TiO_2 7.2 per cent and Na_2O 9.1 per cent on a dry weight basis. The PVC is blended with old waste engine oil and red-mud at a temperature of about 453 K (180°C). The final product which is obtained is known as red-mud plastic and resembles rubber in appearance and texture. The material is said to be highly resistant to ultraviolet light, salts, acids and alkalies. Bags made of red-mud plastic are used in Taiwan province and can withstand internal pressures upto 4 KN m^{-2} (40 cm water/column).

F. Engines for motive power

Biogas is an excellent fuel for both petrol and diesel engines. The power obtained will be less than that obtained when using liquid fuel alone. Engines using biogas run hotter than on liquid fuel. Therefore the cooling system needs to be in good repair.

Petrol engines can run on 100 per cent methane gas. It is common, however, to use a little petrol for starting up.

In diesel engines the temperature at the end of the compression stroke is usually not over 700° C, whereas the ignition temperature of methane/air mixture is 814°C. Hence the injection of a little diesel fuel just before the end of the compression stroke, to ignite the gas mixture, can ensure the normal running of the engine.

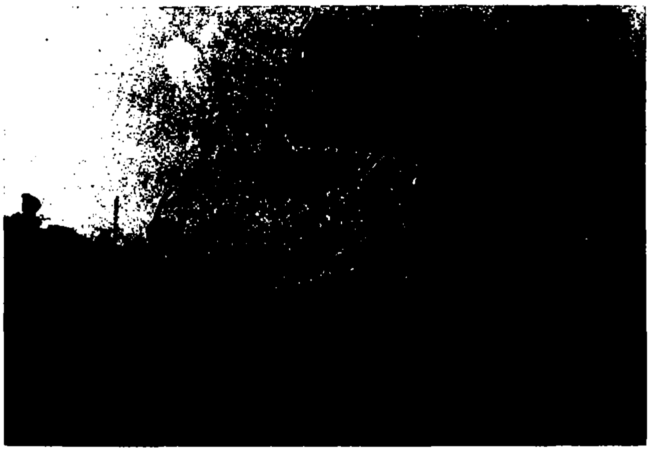


PLATE 17

Plastic bag biogas container for running engines mounted on vehicle top

PLATE 18

Truck run on biogas

Engines require about

$$0.45 \text{ to } 0.54 \text{ m}^3\text{/h (16 to 19 cu ft) per hp}$$
$$= 0.60 \text{ to } 0.70 \text{ m}^3\text{/h (21 to 25 cu ft) per kW}$$

Gas pressure used = 25 to 100 (1-4 in) water gauge

Example 1. How much gas is required to run a 5kW generator for three hours each evening?

$$(0.65 \text{ m}^3\text{/kW/h}) \times 3 \text{ hours} \times 5 \text{ kW}$$
$$= 10 \text{ m}^3 \text{ (350 cu ft)}$$

Note 1: All this gas is required in a three-hour period. The gas holder must be able to store this amount, which might be the gas plant's total gas production per day. (Normally gas holders are designed to hold only about 60 per cent of the daily gas production as the gas is used at different times throughout the day.)

Note 2: The engine is rated at 5 kW. However, if a lesser amount than the maximum power is being used, the amount of fuel will also be reduced, e.g., if only 3 kW power is being used the fuel required will be about $10 \times \frac{3}{5} = 6 \text{ m}^3$ (210 cu ft)

Below about 50 per cent of the nominal power output rating there will be no significant further fuel savings. This is a characteristic of internal combustion engines irrespective of what fuel is used.

Example 2. How much gas is required to run a 5 hp engine for nine hours per day?

$$(0.50 \text{ m}^3\text{/hp/hr}) \times 9 \text{ hours} \times 7 \text{ hp}$$
$$= 31.5 \text{ m}^3 \text{ (1,112 cu ft)}$$

Note: The gas plant to produce this gas must produce $\frac{31.5}{24} = 1.31$ per hour. In nine hours it will produce 11.80 m^3. Therefore the gas holder must have a minimum capacity of $31.5 - 11.80 = 19.7 \text{ m}^3$. It would be wiser to make it a bit larger, anything up to 25 m^3 (900 cu ft). This would be an extremely large gas holder, both bulky and heavy.

Stationary engines located near a gas plant can be an economical and practical proposition. If the engine is water-cooled, the waste heat can be used to heat a water jacket around the gas plant. This should not be done, however, if the periods during which the engine runs would cause the water jacket temperature (and hence the slurry temperature) to fluctuate a lot as this would affect the bacteria and might reduce gas production instead of increasing it.

Engines running on gas require a large volume of gas and hence a large gas plant. In general, it is recommended that people gain experience with smaller plants using the gas for such things as cooking and lighting before taking on a large project such as this.

(a) *Diesel engines*

Engines designed to run on dual fuel (biogas/diesel oil) or diesel fuel only (should the biogas run out) are now manufactured in India.

Existing diesel engines can be modified to run on dual fuel while still retaining the ability to use diesel fuel only. By supplying only the correct amount of gas and making no modifications to the engine it is possible to save at least 60 per cent diesel oil.

When modifying a diesel engine the following points need to be carefully considered:

(i) *Compression ratio*

Some users have noticed that diesel engines run more smoothly on dual fuel when the compression ratio is

PLATE 19

Fuel mixer adapted to run on biogas and diesel oil

lowered. As the compression ratio is lowered, the rated power will fall too. Starting will be also difficult in view of the drop in the temperature of the compressed gases. On the other hand, biogas has good anti-detonation properties. Detonation caused by pre-ignition of biogas does not usually take place, except if the engine is overheated because it is sucking too rich a biogas mixture with the air. Besides, all types of diesel engines are normally set with an advance injection angle. This will ensure the normal running of the engine both on dual fuel and on diesel oil alone.

For these reasons, it is recommended that the original compression ratio should be kept and that the advance injection angle should not be changed. Retaining the original features of the engine will also facilitate its maintenance and repair.

(ii) *Modification of the intake*

The main idea in the modification of the intake is to provide the biogas after the air filter in the inlet pipe (figure 88). Some of the designs suggested for the introduction of biogas into the intake are shown in figure 89.

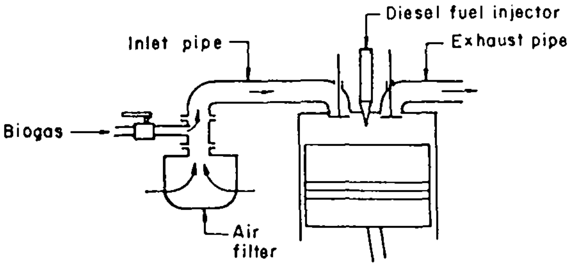


Figure 88. Diesel engine running on dual fuel

Gas inlet devices are designed to suit different engine designs land inlet pipes and in order to give the proper biogas/air mixture.

(iii) *Starting*

Diesel fuel only is used for starting. The starting procedure is the same with the engine unconverted.

(iv) *Operation*

After the engine has been running with diesel fuel for a while, the biogas valve may be opened slowly. This will automatically reduce the diesel fuel supply in view of the action of the speed governor. It is important to let the engine just warm up, then open the biogas valve gradually, otherwise the engine may fail to take on load, emit smoke or even stop altogether. As the engine is operating, the biogas valve should be opened or closed in response to the change in engine speed or load, in order to ensure smooth running and better fuel consumption. For this reason it is more economic and convenient to operate the engine on as steady a speed as possible when it runs on biogas.

When there is an ample supply of biogas, the load is steady and the engine is operating properly the percentage of saving of diesel fuel is 75 to 95 per cent.

In order to stop the engine the biogas valve should be closed first and then the throttle valve.

(v) *Maintenance*

There is no significant difference in maintenance when the engine is run on biogas.

(b) *Petrol engines*

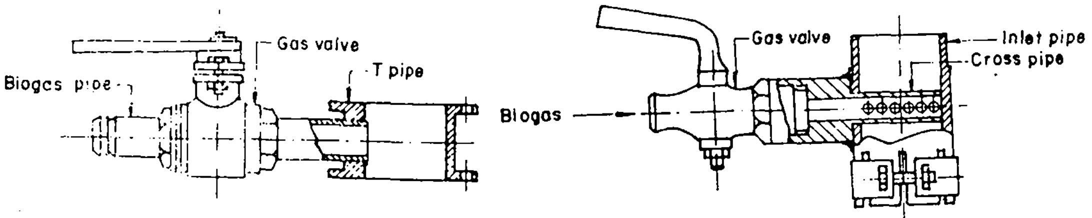
These are not so commonly used as stationary engines as the fuel is more expensive than diesel. They can run on 100 per cent biogas.

The air intake can be the same as that used for diesel engines. One alternative design is given in figure 90.

On low engines (less than 10 hp) it is sometimes found advantageous to provide a plastic bag near the gas inlet so that the engine can suck in gas more easily.

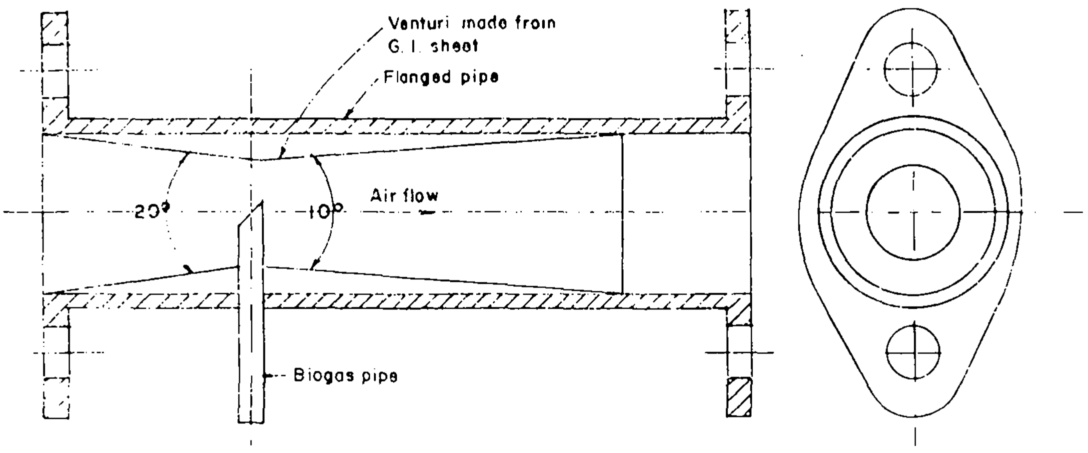
For starting purposes it is important that the amount of gas that can be supplied is greater than that required for normal running. After starting and warming up, the flow of gas is reduced and controlled by means of a gas tap. It is often easier to start the engine with petrol and then change over to biogas.

Maintenance tends to be lower when gas is used as a fuel. Valves, plugs, etc. remain clean and the sump oil needs



(i) Direct connection of biogas pipe to inlet pipe (China)

(ii) Cross flow connection (China)



(iii) Gas venturi (Pakistan)

Figure 89. Different devices for connecting the biogas pipe to the intake

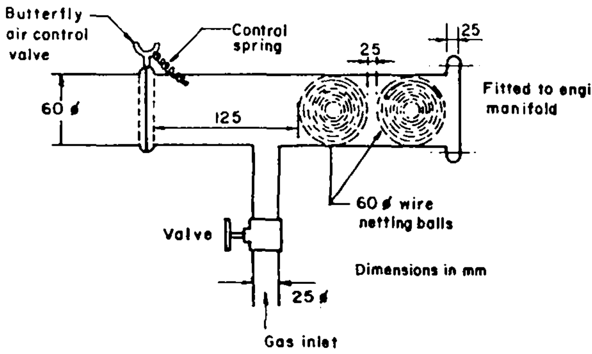


Figure 90. Carburettor for 10 bhp petrol engine running on biogas

less frequent changing. The engines tend to run a bit hotter and the cooling system must be in good condition. One user of a petrol engine running on biogas states that after 9 months of using uncleaned gas the pistons burnt out. Since then the engine has been running trouble-free on cleaned biogas.

(c) *Kerosene engines*

Kerosene engines can be run on biogas in the same way as petrol engines. They are started up in the normal manner and when warmed up they can be switched over to biogas.

(d) *Gas engines*

If the engine is designed to work on biogas, everything is straight-forward and is explained by the manufacturer. When a gas engine is designed for any other type of gas, it is necessary to adjust the carburettor. The quantity of gas needs to be adjusted so that it has the same heating value as the original flow and type of gas for which the engine was designed. After adjustment, the carburettor air intake needs to be adjusted accordingly. The gas to air ratio is 1:8.

G. Electricity generation

Generating electricity is a much more efficient use of gas than using gas lights. To generate 1 kWh of electricity 0.70 m^3 gas is required; this would be sufficient for 16 or 17 electric bulbs, each 60 watt, for one hour.

The same 0.70 m^3 of gas would only be sufficient for 5 gas lamps, each of 100 candle power (about 60 W) for one hour. A 100 candle power gas light is supposed to give about the same amount of light as a 60 watt electric bulb. For the user, electric light fittings cost less and are cheaper to maintain than gas lights.

The disadvantage is the high cost of the engine and generator, and also the distribution wires, if the houses are not close together.

Asynchronous generators of say 3, 5.5 or 7.5 kW are recommended, in view of their simple structure operation and maintenance, for coupling with small internal combustion engines running on biogas.

XV. EFFLUENT AND ITS USES

A. Effluent value

The value of the effluent can be of even greater benefit than the value of the gas. This is not usually emphasized enough. A biogas plant does not, however, produce more fertilizer nutrients than are put in initially.

What is true is:

(a) The phosphorus and potash put into a gas plant come out with very little if any reduction.

(b) There is a small loss of nitrogen into the gas. Some of the nitrogen (various sources say 20 per cent at least) which enters the plant as organic nitrogen is changed into an ammoniacal form, which is more readily absorbed by plants. Much of this ammoniacal nitrogen is lost if the slurry is dried.

(c) Some of the dung put into the plant is broken down by the bacteria into gas and water. The digested slurry solids coming out of the plant are usually about 70 per cent of the input. Therefore the specific gravity (i.e., percentage solids) at the outlet will always be lower than the input.

(d) The volume of manure after processing will be greater than if the same dung had been put in a farmyard manure pit, assuming it is measured at the same moisture content.

(e) The gas plant effluent will have more nutrients than farmyard manure because there is less leaching. Much nitrogen is lost in farmyard manure owing to volatilization (evaporation), which is increased when it is exposed to and heated by the sun.

B. Nitrogen effectiveness

Tests done on the nitrogen effectiveness of cattle dung following different field practices gave the following results.

Table 6. Amount of nitrogen in cow dung

Field practice	*Nitrogen effectiveness Index (per cent)*
Dung spread and ploughed in immediately.	100
Dung piled for 2 days before spreading and ploughing	80
Dung piled for 14 days before spreading and ploughing	55
Dung piled for 30 days before spreading and ploughing	50
Effluent from gas plant introduced immediately into irrigation water	100
Dried biogas plant effluent spread and ploughed	85

C. Other effluent features

Like all compost materials biogas adds humus and supports the microbiological activity in the ground: it increases the soils porosity and water-holding properties, all of which add up to increased crops. Unlike chemical fertilizer, it is effective over a period of about 3 years. This is known as the residual effect. Effluent also has minute quantities of different elements all essential for healthy soils and plants. Chemical fertilizers do not have these.

D. Crop response to effluent

Different crops are more or less responsive to applications of farmyard manure. The same response can be expected from the effluent from the gas plant.

Responsive	**Less responsive**
Vegetable crops especially:	Cereal crops:
Potatos	Jowar
Tomatos	Bajra
Sweet potatos	Wheat
Water melons	Ragi
Radishes	Barley
Carrots	Oats
Cauliflowers	Oilseed crops:
Turnips	Groundnuts
Onions	Linseed
Garlic etc.	Sesame
Fruit trees and vines such as	Castor beans
Orange	Coconut
Grape	Other crops including:
Apple	Cotton
Guava	
Mango etc.	
Other crops including:	
Sugarcane	
Rice	
Jute	

E. Effluent uses

Much has been written about "total integrated systems". In this system, the slurry is used to feed algae ponds and fish ponds and to fertilize fields. The food thus produced is used to feed humans and animals and their waste is used to produce more gas and so the cycle continues. This has been done. It is not easy. It requires a good technical knowledge in a large number of disciplines, careful control of all parts of the system and capital. Where any of these have been lacking, the scheme has not been successful.

Although attractive, it is not a practical scheme for an average village. However, it is practical to use elements of the system. The elements chosen will depend on local farming skills.

(a) Algae production: This is difficult; it needs good technical knowledge, very careful control and substantial capital. The algae produced can be used as a pig feed supplement. Specialized advice should be obtained before attempting to produce algae on a big scale.

(b) Animal feed: Slurry dried and processed to free it from all parasites and pathogens. Used to replace a proportion of standard feed for pigs. Needs capital and control. Probably only suitable for big installations.

(c) Fish ponds: Easy, no processing, small capital required. Control simple. Only requires a small amount of slurry. Advice can be obtained from national fishery departments. (Nitrogen in the slurry encourages algae to grow. This in turn absorbs oxygen from the atmosphere. Oxygen is essential for the fish.)

(d) *Fertilizer: Straightforward.*

(i) Liquid form. This can be taken in buckets and put on vegetable gardens and around fruit trees. To convince people of its benefit it is well worth doing different parts of the same crop with and without slurry. The difference can be quite noticeable.

(ii) Diluted form. This is carried by irrigation water to the fields. It is important that it is spread over all the fields and not on one field only. One field could be overfertilized and cause a poor crop.

(iii) Composted. This is a commonly used method. The slurry is an excellent composting material as it is full of bacteria, which break down vegetable matter very well. Two or three pits are dug about 80 cm deep (2 ft 8 in). This allows the slurry to dry a bit and is not hazardous to animals, which might walk into it.

First a layer of straw, animal bedding, leaves or other vegetable matter is put in and then a layer of slurry is poured on top. Another layer of vegetable matter is added, followed by more slurry. Alternative layers are added until the pit is full. In the fixed-dome digester the slurry is used directly in the field. The sludge obtained twice a year when the digester is emptied is usually composted as described above, as it is the most polluted layer in the digester.

The compost is put on the fields in the normal manner. It should be ploughed in quickly.

The pits must be large enough to hold all the compost until it can be put on the fields.

Assuming that:

a. the compost is put on the fields twice a year;

b. the water which was added evaporates, thus reducing the volume by at least 50 per cent;

c. the reduction in the volume of dung (25 to 30 per cent of the solids in the dung are broken down into gas and water), due to the digestion process in the gas plant, is made up by the addition of compost materials;

then the volume of the pits must equal the volume of dung added per day multiplied by the collecting time.

Example:

A biogas plant has 120 kg (= 120 litres approximately) of pig dung added per day. The compost pit is emptied after 7 months (maximum time). What area of compost pits is needed assuming they are 80 cm deep?

The volume of compost collected in 7 month =

$$\frac{120 \text{ litres} \times 7 \text{ months} \times 31 \text{ days per month}}{1{,}000 \text{ litres/m}^3} = 26 \text{ m}^3$$

If the depth is 80 cm, then the area required

$$= \frac{26}{0.8} = 33 \text{ m}^2 \text{ (350 sq ft)}$$

Therefore three pits 2.5 m x 4.5 m should be sufficient. The pits do not have to be bricklined but it is better if they are as this keeps the weeds from growing into the compost.

Where there is a very high water-table it is occasionally necessary to lift the compost out of the pits and put it on the ground to dry sufficiently to make it convenient to transport to the fields.

(iv) Semi-dried. This is similar to composting but no additional composting materials are added. The slurry is run into shallow pits and allowed to dry partially in the sun. It is then dug out and stored in piles until it is time to spread it on the fields. It can be fully dried in the sun if so desired.

F. Health aspects of effluent

Concern is sometimes expressed regarding (a) the heavy metal content (b) disease-carrying organisms in the effluent. The former is not a problem in village plants using animal or human waste or vegetable matter. (It could be a problem if industrial waste is used.)

It is impossible to give exact figures of the reduction of disease-carrying organisms (especially those in human waste) because it depends on several factors.

(a) Input material: type and amount of disease-carrying organisms in the waste used;

(b) Temperature: a high temperature gives a greater kill rate;

(c) Residency time: a longer time gives a greater kill rate.

One thing that is certain is that the effluent is much freer from disease-carrying organisms than the input material. Further improvements take place if the effluent is subsequently composted. The biogas process is much more hygienic than commonly practised village methods of human faeces disposal. In view of the absence of oxygen, the presence of ammonia, the subjection to high temperature, and other factors in the digester, the pathogenic organisms and parasitic ova cannot normally survive for long, or develop and multiply. For this reason alone certain governments are actively encouraging the construction and use of biogas plants as a means of promoting better village health. It is not the ultimate hygienic standard, but it is a realistic and greatly improved standard, which can be paid for and maintained by a village. It is only suitable where people are willing to keep the toilet clean.

XVI. GAS PLANT DEVELOPMENT PROGRAMMES

A. Publicity

There is no question that the best publicity is to see a full-size gas plant working. This could be at a community institution such as a school, health centre or agricultural centre. Even better is a village house used by an "average" (rather than an "exceptionally rich") farmer. People can see how the plant is operated and the benefits of gas, fertilizer and improved hygiene. A demonstration plant at a private farm is demanding on the farmer, who will probably have lots of visitors. Such a farmer must have full technical support. If the plant breaks down and he cannot get it repaired quickly adverse publicity will ensue.

Good publicity can also be given by well informed village workers and also over the radio. Newspapers and television are not generally available in villages and are therefore not effective.

Portable demonstration units can be used at public gatherings such as fairs.

Progressive schools can be encouraged to include biogas technology in their syllabuses. The chemistry of fermentation, the fertilizer benefits for crops, the fuel and fertilizer needs of the community, etc., can all be investigated. This helps to bring confidence to farmers if their children are being taught about the new technology and are working with it at school.

It is very important that women are well informed about biogas. It affects them directly. They usually do the cooking and provide the fuel. They may have to operate the gas plant themselves or supervise servants doing it.

B. Promotion

1. General

A biogas scheme can only be promoted once the following are known:

(a) The advantages and disadvantages to the nation;

(b) The advantages and disadvantages to the community;

(c) The advantages and disadvantages to the individual family.

Possible benefits are listed in chapter I. These benefits have to be measured against the alternative uses of the resources available. Where careful preparatory work has been carried out, along with good promotion and technical support, biogas schemes have been successful.

In some countries large numbers of plants were installed but failed because of various reasons such as:

(i) Inappropriate design;

(ii) Too strong a campaign to install plants at subsidized prices before people were genuinely interested and had a realized need for them. People did not operate or maintain their plants properly;

(iii) Lack of technical support.

2. Financial aid

It is clear from experience that direct subsidies, while causing many plants to be built quickly, usually result in many of these plants going out of use within a few years. This is especially true if technical support is lacking, which is unfortunately all too often the case. Another alternative is to take things more slowly, to let the farmer pay the full price of the gas plant and to subsidize the cost indirectly by giving low interest loans. This subsidy can be compared to the financial assistance given to other rural services such as electricity or drinking water supplies.

If a government decides to give financial aid, which is usually limited, it is normally given to people living in areas of most need. Typically these areas have one or more of the following problems:

- High cost of fuel;
- High cost of fertilizer;
- Dung burnt as fuel;
- Bad sanitation;
- Undesirable deforestation due to use of firewood as fuel.

Before starting a programme to help these people they must have three facilities, otherwise biogas is unsuitable:

- Sufficient suitable input materials;
- Sufficient water;
- Reasonably high temperatures throughout the year.

3. Promotion campaign

(a) *Examples*

In China promotion work is carried out in different areas in series. Usually a model suitable to the geological and climatic conditions is constructed using local materials. The inhabitants have to copy the model using the technical and financial assistance provided by the government or the commune.

An example of how biogas was promoted in Nepal over a period of four years is given below. It may seem a slow and demanding programme but it is proving to be very successful. Not only is there a good demand for new gas plants, but most existing plants are continuing to run successfully.

Year One

a. A study was made of existing available designs. The best one was selected to suit local needs and was modified as necessary.

b. A small portable demonstration plant was shown at fairs, etc.

c. A few plants were built at a fixed price on the basis that if it did not work there would be no charge. A one-year guarantee was given together with regular, good technical support.

Year two

d. Low-interest loans were made available from the national agricultural development bank. Publicity and information were given over the radio.

e. Twenty to fifty plants are built in a restricted area (for case of control). A guarantee and technical support are also given.

f. Plants were revisited at intervals to see that plants were operated properly and that there were no technical problems. The guarantee was honoured. A technical questionnaire was filled in every six months.

Year three

g. In the light of information gained in f above, designs and specifications for materials were modified as necessary and the building and servicing of plants continued.

Year four

h. With the confidence gained from the work already done, a private non-profit-making company was formed. The shareholders were the national agricultural development bank, one appropriate government agency and a building organization. This company was to work in the whole country (or in one state, province or island as appropriate).

i. Appropriate good quality plants were built. A one-year guarantee was given on everything. The digester and gas holder were guaranteed for a period not less than the payback period for the loans (probably 5 to 10 years). These two items accounted for about 70 per cent of the total cost of the gas plant. To do this the development organization had to collect sufficient money to pay for its own staff to visit the gas plant and paint the gas holder at regular intervals throughout the guarantee period. All plants were visited three times in the first year and a technical report was made. After the first year an annual visit and report on every gas plant were made for a period of 20 years. At the time of this visit free technical advice was given and an on-the-spot estimate for any repairs or modifications needed.

j. Financial help was given in the form of reduced interest or interest-free loans. No direct subsidies were given at all.

k. Research and development is continuing. Any new ideas are thoroughly tested before general use. Standards are established for gas plants, gas holder designs and protective coatings, fittings and appliances.

This programme is continuing as detailed for year four.

(b) *Technical after-sales service*

The difficulty lies in giving good technical aftersales service. Rural development officers and extension workers often have other pressures of work and perhaps other things in which they are more interested. For this reason, there are considerable advantages in having a private biogas company, and also the lending bank as a business partner. Company staff have only one objective to concentrate their efforts on. If existing plants do not work well, word will get around and staff will not be able to secure new orders. In this way management can see what is happening and can take action.

The bank, being a shareholder, is interested in giving loans. If any farmer, at the time of repaying his gas plant loan or at any other time, lodges a complaint about his plant, the bank can pass this on to the company directly. The bank can make sure action is taken. This is effective as the management knows that the bank will not give new loans if the service to existing plants is not satisfactory.

(c) *Measuring campaign effectiveness*

Building plants in this way with no subsidies either for materials or service means a higher cost. The significant thing is that orders continue to come in and existing plants continue in use. The programme is only four years old but over 350 plants have already been built.

A recent survey of 95 plants carried out in Thailand, where organized biogas activity does not exist, showed that less than 50 per cent of the gas plants built were still in operation.

A survey of 167 plants carried out in India, where a long established organized biogas activity exists, showed that 76 per cent of the plants were working. Of these, 10 per cent were temporarily nonoperating and required minor repairs and only 14 per cent were completely nonoperating.

It cannot be stressed too much that successful promotion means both building new gas plants of the right size and in the right places and giving good technical service so that these gas plants keep working.

C. Training

If a gas plant programme is to be successful, it is essential that staff are properly trained. Biogas technology is not a difficult subject to grasp sufficiently well to ensure the successful building of plants. However, people in different positions need different types of training.

1. Senior rural development officers, scientific officers, agricultural engineers etc.

The main need of these staff is classroom instruction. Visits to see plants working, being built and serviced are also essential. One week's training is normally sufficient. A manual or set of papers on biogas technology should be supplied.

2. Government extension workers, biogas company supervisors etc.

These people usually do not have as high an academic schooling as group (a) above. When a plant is being built or it gives trouble, these people are usually called. Therefore they need both a good theoretical and practical knowledge. The classroom work needs to be illustrated by practical work, i.e., seeing a gas plant in all stages of construction and the full servicing of the plant. The basic training can be given in a week to 10 days. These people need to be supplied with a technical manual. After this, each person who is to work full time with biogas will benefit greatly by supervising the installation of three plants under the guidance of an instructor. Also he should service a number of plants himself under the guidance of an instructor. By the time he has done this he should be quite competent for all normal work and only need assistance in exceptional circumstances. In India, such people can be registered as qualified biogas supervisors after doing this course. They are then paid a fee for each new installation built, working effectively as a private entrepreneur. The difficulty with this is that an incentive is necessary for servicing existing gas plants.

3. Manufacturers of gas holders, pipe fitters and masons

These people basically only need "on-the-job" training, i.e., to do the job under an instructor a few times, and they will grasp it quickly. A little classroom instruction to explain a little about biogas is good, but not essential.

Training courses are organized in China for technicians from several villages. During the two-week course the teacher constructs several digesters with the trainers, then each trainer constructs alone at least one digester under the supervision of the teacher. After that the trainers return to their villages to teach others.

D. National biogas centre

Biogas development in a country tends to be started by various organizations and individuals. It is helpful to have a national biogas reference centre in a country. This centre is usually run by a government or semi-governmental organization. It coordinates rather than controls all aspects of biogas including:

- Information collection and dissemination;
- Research and development;
- Designs and standards for fittings and appliances;
- List of approved manufacturers of biogas equipment;
- List of approved biogas builders and service engineers;
- Procurement service for specialized items (e.g., stoves, lamps, gas taps and spare parts), if necessary.

A committee drawn from people working in all aspects of biogas gives guidance to this centre.

In China, research institutes for biogas development have been established in several provinces. They carry out technical, biological, environmental, social and economic studies in biogas technology. National conferences and seminars on biogas are organized every two years.

XVII. COMMUNITY PLANTS

A. Background

A great number of articles and papers have been written over the years saying that community plants should be used in villages. They are more economic than individual plants and could be of help for those people with too few livestock or too little space for their own plant. The fact is that very few community plants have been built outside China and, of those which have, only some are still working.

Although there are some minor technical difficulties, this is mainly due to the following sociological and managerial problems.

B. Sociological considerations

(i) The priority the community gives to a biogas plant over other projects (e.g., school or health post);

(ii) Community co-operation or lack of it;

(iii) The main reason the community wants the biogas plant (cooking – is there plenty of forest nearby? Lights – is there electricity in the village?):

(iv) Whether the gas plant can be incorporated into an integrated rural development programme with other benefits, e.g., fish farming or power for a rural industry.

C. Management considerations

(i) The way the farmers will get credit for the dung they supply;

(ii) The way of distributing the gas. Turning the gas on and off at certain times of the day is dangerous as a tap could be left open and remain open after the supply was resumed. There are no known low-cost meters which are suitable for biogas (normal gas meters corrode and seize up in a short time because of the moisture and hydrogen sulphide in the gas). If each farmer had his own gas holder, this could be the answer, but it would be expensive. Gas can be charged for on the basis of the number, type and size of appliances in the household;

(iii) The way of fairly distributing the gas plant effluent. The volume will change depending on the amount of water added during mixing, decomposition (digestion) of the waste material in the gas plant and later on to water evaporation;

(iv) The person who will operate the plant. The village administration may build the plant and lease it to a resident;

(v) The person who will carry out repairs and pay for them;

(vi) The priority of distributing the available gas if there is not enough of it;

(vii) Availability of sufficient dung for the plant of the type or types which are socially acceptable by the whole community;

(viii) Availability of sufficient water in the dry season;

(ix) Availability of sufficient money to build a plant.

D. Technical considerations

(i) The distances between the houses

If houses are far apart, long pipes with a large diameter will be required. This is very expensive and could easily add 30 per cent or more to the cost of the plant. In this case it might be more economic to have several plants in different parts of the village. The plants could be interlinked using small pipes to provide some gas should one plant be closed down for any reason or give poor gas production temporarily, thus giving a better security of supply.

(ii) The practical size of the plant in the village.

Standard designs are available up to about 28 m^3 (1,000 cu ft) gas production per day size. Plants above this size are a major undertaking.

Note: A 28 m^3 gas plant will require about 900 kg of cattle dung and 1,000 litres of water per day. Assuming a gas holder of 4,115 mm (13 ft 6 in) diameter, the weight of it will be about one ton. It will require lifting equipment both when it is first put in place and again when it has to be removed for servicing the plant (e.g., scum removal). This size of plant will provide gas for the cooking and lighting needs of a maximum of 70 people.

It has been suggested that gas pipes be used as water pipes for part of the day. This is not recommended. The gas would flavour the water and all water would have to be drained from the pipes before the gas service was resumed.

If solutions can be found to the above listed problems (and any other local problems), there is no reason why a successful community plant should not be installed.

It is obviously essential that yearly schemes are tried in progressive, co-operating villages with a good local administration. There will probably be a better chance of success if the biogas plant is an essential part of an integrated rural development programme (i.e., a programme which includes other things such as better animals, composting, fish farming, local agricultural-based industry, electric light, etc.)

XVIII. ECONOMICS

A. Evaluating a project

Generally the investor is an individual, corporation, community or State. In each case a separate economic analysis affected by a different group of factors may be considered. Some of the factors that may be considered are listed below:

(a) *Economic factors*

- (i) Interest on loan for biogas plant;
- (ii) Current/future cost of alternative fuel;
- (iii) Current/future cost of chemical fertilizer;
- (iv) Current/future cost of materials needed for biogas plant construction;
- (v) Savings of foreign currency in view of biogas utilization;
- (vi) Current/future labour cost;
- (vii) Inflation rate.

(b) *Social factors*

- (i) The effect on the health of the farmers and on their health bills;
- (ii) The advantage of having cleaner villages, especially if toilets are attached;
- (iii) Employment created in biogas construction and related industries;
- (iv) Better lighting;
- (v) Less time consumed on food-making (no collection of firewood or cow dung cakes is needed);
- (vi) Improving facilities in villages, thus encouraging bright young people to stay in the community.

(c) *Technical factors*

- (i) Construction, maintenance and repairs of biogas plant;
- (ii) Availability of materials required;
- (iii) Suitability of local materials.

(d) *Environmental factors*

- (i) The utilization of a cleaner source of energy (in comparison with firewood and dung cakes for example);
- (ii) Conservation of forests, thus preventing soil erosion, flash floods, etc.

It is clear that a comprehensive economic study taking all these factors into account is beyond the scope of this guidebook. The analyses for the different investor levels of individual, corporation, community and State cannot be discussed here. Instead, the way in which a farmer may evaluate a biogas plant will be discussed in some detail, together with an illustrative example.

However, it may be mentioned that economists will find ways to include all the economic factors listed in (a) for carrying out analyses for governments, communities or States (b). It will be more difficult to evaluate the environmental and social factors mentioned in (b) and (c). Few methods were introduced to accommodate these factors. To take an example, the environmental factors were accommodated by adding to the capital costs the costs of the devices, etc. needed in the case of conventional plants in order to obtain the same environmental conditions prevailing for the use of biogas plants.

Table 7. Calorific values of fuels

Fuel	*Unit*	*Calorific value MJ (kcal)*	*Stove*	*Efficiency of stove (per cent)*	*Effective heat MJ (kcal)*	*Effiective equivalent heat to $1 m^3$ biogas*
Biogas	m^a	20 (4700)	biogas stove	60	11.8 (2830)	1 m^3
Electricity	kWh	5.6 (860)	hot plate	70	2.5 (600)	4.70 kWh
Kerosene	litre	38 (9100)	pressure stove	50	19 (4560)	0.62 litre
Charcoal	kg	29 (6900)	open fire	28	8.1 (1940)	1.46 kg
Firewood[a]	kg	20 (4700)	open fire	17	3.4 (810)	3.47 kg
Butane	kg	46 (10900)	butane stove	60	27.3 (6530)	0.43 kg
Cattle dung cakes	kg	8.8 (2100)	open fire	11	0.96 (230)	12.30 kg

[a] The figures for firewood are taken as examples. They do vary, e.g., depending on the type and dryness of the firewood.

B. Value of gas

Biogas has no commercial value. It is compared here with fuels which do.

It is worth noting that 12.3 kg dried cattle dung cakes is equivalent to 61.5 kg wet dung, assuming 20 per cent solids in the wet dung. If this dung were processed in a gas plant, it would be expected to produce 2 m^3 of gas, which is double the amount of heat obtained from the dung cakes and there is the further direct advantage of the subsequent fertilizer value.

C. Value of fertilizer

This depends on the initial fertilizer value of fresh dung and how it is used (see chapter XV).

We will assume that (a) all elements except nitrogen (N) remain constant no matter how they are used; (b) the fresh dung (cattle) has initially 0.12 per cent N; (c) for each m^3 of biogas produced 32 kg of cattle dung is used per day, i.e., 11,700 kg per year.

To put a value on the fertilizer, it is a case of seeing how much nitrogen is in the original dung and how much effective nitrogen is gained by the soil. This depends on field practice. In 11,700 kg cattle dung at 0.12 per cent N there is 14.1 kg N. This is equivalent to about 31 kg of urea fertilizer, which is normally about 46 per cent N. If the current practice is to pile dung for 30 days before use, then the amount of nitrogen = 14.1 X 50 per cent = 7 kg. If the new practice is to dry the effluent, then the amount of nitrogen = 14.1 kg X 85 per cent = 12 kg.

For percentages, see table 6, chapter XV.

D. Example of biogas evaluation – farmer's view

A farmer considers installing a 3 m^3 per day biogas plant using cattle dung. This is the correct size of gas plant for his needs 70 per cent of the gas will be used instead of wood for cooking and 30 per cent instead of kerosene for lighting. He has sufficient cattle dung. Water is easily available and does not represent a cost to him. He currently piles the dung for more than a month and then uses it. He plans to dry the slurry and use this in the future.

Will the farmer benefit financially from installing the plant?

(a) *Total capital cost (including interest)*

The inclusive cost of the gas plant with all fittings, etc. is assumed to be $US 540.00 (in Nepal). The farmer obtains a government loan at 6 per cent interest to be repaid over seven years (at a special low interest rate offered by the Government to encourage the building of biogas plants).

The loan is to be paid off in equal amounts. The annual payment may be calculated from the formula: where C_c is the capital cost and a is the annuity factor, which depends on the interest rate and the repayment period and can be determined with the help of the formula or the figures given in table 10.

For 6 per cent rate of interest and seven years repayment period, the annuity factor is:

$$a = 5.58$$

$$\text{Annual payment} = \frac{540}{5.58} = \$97$$

The total cost of the loan, including interest, is

$$97 \times 7 \cong \$680$$

(b) *Annual cost*

Assuming that the life of the gas plant is 20 years and the gas holder is painted yearly the following items may be estimated as follows:

(i) Capital and interest on loan

The average cost per year of the loan spread over

$$20 \text{ years} = \frac{680}{20} = \$34.$$

(ii) Repairs and maintenance. These are minimal except for the yearly repainting of the gas holder. Two per cent of the capital cost should be sufficient to allow the annual repair and maintenance. This is about $10 per year.

(iii) Time required to operate gas plant. Many people do not consider this because it can be compared with the time saved in not having to collect firewood or buy kerosene. Also cooking takes a shorter time. In cases where the farmer decides to include it, a usual rate is 7 to 10 minutes per day per m^3 of digester volume. For a 3 m^3 size plant 30 minutes may be allowed per day = ½ hour x 365 days = 183 hours per year. Labour cost (in the developing countries of the region) = $0.05 per hour. Therefore the labour cost ≅ $9 per year. The total annual cost = 34 + 10 + 9 = $53. $53 per year = 14.5 cents per day. Therefore the value of 3 m^3 of gas = 14.5 cents and 1 m^3 of gas = 4.85 cents.

(c) *Comparison of energy costs*

Expanding on table 7 and assuming the given costs of fuel, it is possible to obtain the cost of equivalent effective heat as in table 8. Table 8 shows that biogas in this example is a fuel costing less than any other, ignoring all side effects such as taxes or subsidies.

Table 8. Cost of equivalent effective heat

Fuel	*Market cost per unit (cents)*	*Effective equivalent energy using 1 m³ biogas*	*Cost of equivalent effective heat using 1 m³ biogas (cents)*
Biogas	4.75/m³	1 m³	4.75
Electricity	4.17/kWh	4.70 kWh	19.6
Kerosene	20.8 /litre	0.62 litre	12.9
Charcoal	6.67/kg	1.46 kg	9.74
Firewood	1.83/kg	3.47 kg	6.35
Butane	40.0 /kg	0.43 kg	17.37
Cattle dung cakes . .	0.42/kg	12.30 kg	5.17

(d) *Comparison of N costs*

The following is a comparison of N costs in manure following different field practices and urea.

If urea costs about 20 cents per kg and is 46 per cent N then 1 kg N = 44 cents. From the above it follows that:

The value of N in fresh cattle dung for the
3 m³ size plant = 14.1 kg x 3 x 0.44
= $18.6 per year.

Using the current method of making farmyard manure the value of N = 18.6 x 50 per cent
= $9.3 per year.

Table 9. Costs and benefits of using biogas

	Annually (dollar)	*Daily (cents)*
Total costs	53.0	14.5
Benefits:		
70 per cent equivalent wood for cooking 3 m³ x 6.33 cents x 70 per cent	48.5	13.3
30 per cent equivalent kerosene for lights 3 m³ x 12.92 cents x 30 per cent	42.5	11.6
Increased N fertilizer value	6.5	1.8
Total benefits	97.5	26.7

Note: Benefit cost ratio $= \frac{\text{benefits}}{\text{cost}} = \frac{97.5}{53} = 1.84/1.00$

Using the proposed method of making manure the value of N = 18.6 x 85 per cent:
= $15.8 per year.

The improved N value of manure = 15.8 – 9.3
= $6.5 per year.

(e) *Costs and benefits*

In the example below the direct benefits are attractive. However, all indirect advantages and disadvantages must be considered before a final decision is reached.

Table 10. The values of the annuity factor a

$$a = \frac{1 - (1 + i)^{-n}}{i}$$

Payment period in years n	*Rate of interest i (per cent)* 3	4	5	6 ↓	7	8	9	10	11	12	13	14
5	4.58	4.45	4.33	4.21	4.10	3.99	3.89	3.79	3.70	3.60	3.52	3.43
6	5.42	5.24	5.08	4.92	4.77	4.62	4.49	4.36	4.23	4.11	4.00	3.89
7 →	6.23	6.00	5.79	5.58	5.39	5.21	5.03	4.87	4.71	4.56	4.42	4.29
8	7.02	6.73	6.46	6.21	5.97	5.75	5.53	5.33	5.15	4.97	4.80	4.64
9	7.79	7.44	7.11	6.80	6.52	6.25	6.00	5.76	5.54	5.33	5.13	4.95
10	8.53	8.11	7.72	7.36	7.02	6.71	6.42	6.14	5.89	5.65	5.43	5.22
11	9.25	8.76	8.31	7.89	7.50	7.14	6.81	6.50	6.21	5.94	5.69	5.45
12	9.95	9.39	8.86	8.38	7.94	7.54	7.16	6.81	6.49	6.19	5.92	5.66
13	10.63	9.99	9.39	8.85	8.36	7.90	7.49	7.10	6.75	6.42	6.12	5.84
14	11.30	10.56	9.90	9.29	8.75	8.24	7.79	7.37	6.98	6.63	6.30	6.00
15	11.94	11.12	10.38	9.71	9.11	8.56	8.06	7.61	7.19	6.81	6.46	6.14
16	12.56	11.65	10.84	10.11	9.45	8.85	8.31	7.82	7.38	6.97	6.60	6.27
17	13.17	12.17	11.27	10.48	9.76	9.12	8.54	8.02	7.55	7.12	6.73	6.37
18	13.75	12.66	11.69	10.83	10.06	9.37	8.76	8.20	7.75	7.25	6.84	6.47
19	14.32	13.13	12.09	11.16	10.34	9.60	8.95	8.36	7.84	7.37	6.94	6.55
20	14.88	13.59	12.46	11.47	10.59	9.82	9.13	8.51	7.96	7.47	7.02	6.62
25	17.41	15.62	14.09	12.78	11.65	10.67	9.82	9.08	8.42	7.84	7.33	6.87

Note: Arrows refer to the example given on page 101.

ANNEXES

Annex I

PROPERTIES OF BIOGAS

Biogas is a mixture of gases. The principal ones affecting gas plants are:

Methane (CH_4):
usually 60-70 per cent

Carbon dioxide (CO_2):
usually 30-40 per cent

Hydrogen sulphide (H_2S):
usually less than 1 per cent.

Other gases present in very small amounts and which are normally ignored include:

Nitrogen (N_2)

Hydrogen (H_2)

Carbon monoxide (CO)

Oxygen (O_2)

Methane is the gas which is wanted. The percentage of methane is affected by the biological process and the type of dung or vegetable matter used in the gas plant. Most people have no means of checking the percentage of methane content but this does not matter. If the plant is working well then the gas will burn well. If the plant is overfed with fresh slurry (particularly during starting up – see chapter XI), the carbon dioxide content increases and the gas may not burn.

Hydrogen sulphide (sometimes called "rotten egg gas" because of its unpleasant smell) has both advantages and disadvantages. Its smell warns people if there is a leak. It forms an acid when mixed with water and this is mildly corrosive (it is very diluted and therefore weak).

Biogas is a wet gas because it picks up water vapour from the slurry. This vapour condenses in the pipes and has to be removed.

Because the composition of biogas varies, so do its various properties. Therefore the following figures (13) can only be taken as approximations.

Calorific value:	20-25 MJ/m³ (4,700-6,000 kcal/m³)
Specific gravity:	0.86 (air = 1.00)
Wobbe No:	732
Flame speed factor:	11.1. This is a low figure and therefore the flame will tend to "lift off" burners which are not properly designed.
Inflammability in air:	Six to 25 per cent biogas mixed in air will burn. More or less biogas will not burn. (This is a relatively narrow range and therefore biogas is safer than other commonly used household gases.)

The amount of air required for complete combustion depends on the percentage of methane in biogas.

For 60 per cent CH_4 per 1 m³ biogas, use 8 m³ air.
Usually burners use a ratio of 1:9 or 1:10.

Annex II

FACTORS AFFECTING THE BIOGAS PROCESS

There are many factors which affect the biogas process. Those which can easily be controlled in a village (e.g. mixing the slurry correctly) are covered in the main part of this book. Those which need to be understood in the designing and planning of a gas plant are included here. Often there is very little one can do about these factors in a village but they should at least be understood.

(a) *Temperature.* Methane-producing bacteria are greatly affected by temperature. The ideal temperature is about 35°C, just about blood temperature. When the slurry temperature is low the gas production is greatly reduced. At 10°C it more or less stops. The common range of slurry temperature in Asia is 18 to 32°C. A 35°C temperature is not usually possible in an unheated plant.

The bacteria cannot tolerate fluctuating temperatures, i.e., hot during the day, cold at night. This will reduce gas production. Plants built in the ground tend to have stable temperatures and keep within the daily allowable fluctuation of ± 1°C.

(b) *Retention time.* Retention time is temperature dependent. The higher the temperature the faster the bacteria use the food in the slurry and the sooner it needs replacing. It is in winter, when the temperatures are lowest, that most gas is usually wanted. The theoretical retention time is the volume of the digester divided by the daily input. In practice the effective volume is reduced by a build-up of solids at the bottom of the digester or by scum and therefore the effective retention time is shorter.

(c) *Air.* Methane-producing bacteria are anaerobic. Therefore air should be excluded.

(d) *Bacteria.* Bacteriology is a highly specialized science. Normally bacteria multiply and the type depends on the sort of dung and the temperature level. A few strains of methane-producing bacteria have been isolated in laboratories and put into gas plants which are at the same temperature as the sample. However, there are some methane-producing bacteria in all dung. If the temperature of the gas plant changes just a little (say more than 2°C). One strain of bacteria is superceded by another and any benefit from the strain supplied by the laboratory is lost.

It is thought that all gas plants contain several different strains of methane-producing bacteria. In a village situation there is no practical control of the bacteria.

(e) *Carbon nitrogen ratio (C/N).* To guarantee the normal biogas production, it is very important to mix the raw materials in accordance with the C/N ratio.

The carbon to nitrogen ratio of biogas digestion raw materials represents the proportion of the two elements. The elements of carbon (in the form of carbohydrates) and nitrogen (as protein, nitrates, ammonia, etc.) are the chief nutrients of anaerobic bacteria. Carbon is utilized for energy and nitrogen for the building of the cell structures. These bacteria use up carbon about 25 to 30 times faster than they use nitrogen. Experiments have shown that a C/N ratio of 25 to 30:1 will permit digestion to proceed at an optimum rate, if other conditions are favourable. If there is too much carbon in the raw materials, nitrogen will be used first, with carbon left over; this will slow down the digestion.

Annex table 1. The C/N ratio of different raw materials (approximate value)

Raw materials	*Carbon (percentage by weight)*	*Nitrogen (percentage by weight)*	*C/N ratio*
Plant:			
Wheat straw	46	0.53	87:1
Rice straw	42	0.63	67:1
Corn stalks	40	0.75	53:1
Fallen leaves	41	1.00	41:1
Soybean stalks	41	1.30	32:1
Weeds	14	0.54	27:1
Peanut stalks and leaves	11	0.59	19:1
Dung:			
Sheep	16	0.55	29:1
Cattle	7.3	0.29	25:1
Horse	10	0.42	24:1
Pig	7.8	0.65	13:1
Human faeces	2.5	0.85	2.9:1

Annex table 1 shows that the contents of C and N and the C/N ratio of each raw material are quite different. The C/N ratio can be ignored only in villages which use cattle, sheep or horse dung as raw material as the C/N ratio of these materials is rather near the optimum ratio.

(f) *pH.* Given time bacteria will find their own pH level. This is usually 7.0 to 8.0 but can go up or down a further 0.5; pH is not likely to present any problems provided the plant is started up properly (see chapter XI) and not overfed with fresh slurry.

The gas plant operator should notice a fall-off in gas production before he notices a change in the pH. A change in the pH says what has happened but too late.

The pH can be simply checked using narrow band indicator paper.

(g) *Volatile acids.* These are more important than pH as they give the actual situation inside a plant. They are not easily measured and this has to be left to researchers.

(h) *Solid contents.* The suitable solid contents (dry matter concentration) of raw materials is 7 to 9 per cent. In actual rural situations, the dry matter concentration of raw materials is changed with the change of season. It is lowered in summer. When the gas production is high, and increased in winter.

(i) *Toxic substances.* Industrial effluent can contain toxic substances, which will kill methane-producing bacteria. This does not apply to village situations. Some animals are given special feeds and medicines. For practical purposes these can be ignored as they will not (or only very slightly) affect gas production.

Annex III

EFFECT OF SELECTED PARAMETERS ON GAS PRODUCTION

Although much has been written about all aspects of biogas by many people, much still remains to be learned. There is relatively little well researched and documented information about how much gas can be expected from various types of dung under conditions found in villages.

Three of the most important variables appear to be temperature, retention time and the percentage of solids (specific gravity). The graphs in figures 92 to 94 illustrate these variables. These graphs were produced by various research bodies in different countries. Some conditions are not normal for village conditions (e.g., in figures 92 and 93 the temperature is 35°C). However, until better information becomes available, they serve the purpose of showing the trends caused by changes in different varibles.

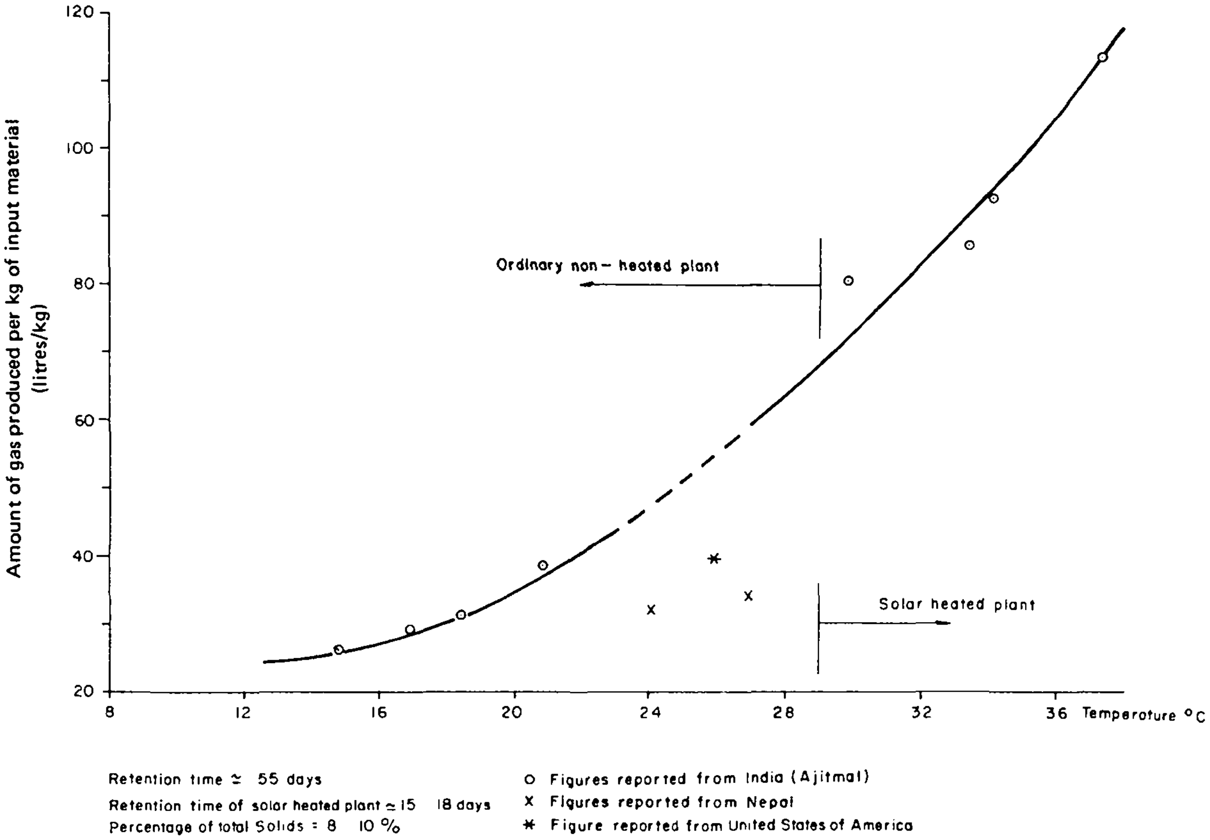


Figure 91. Gas production as a function of slurry temperature

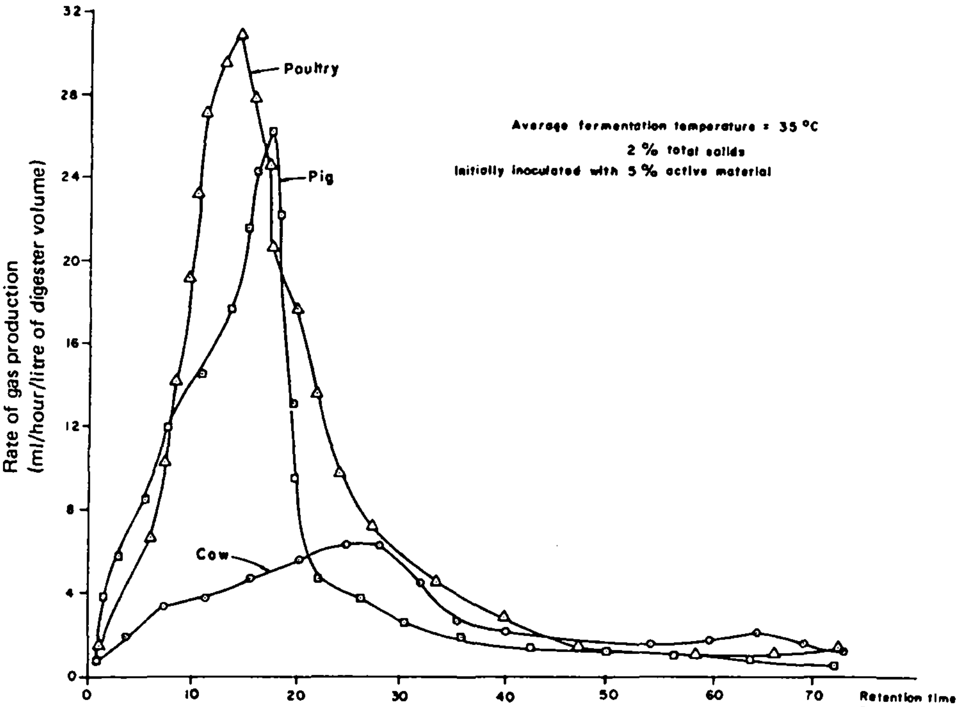
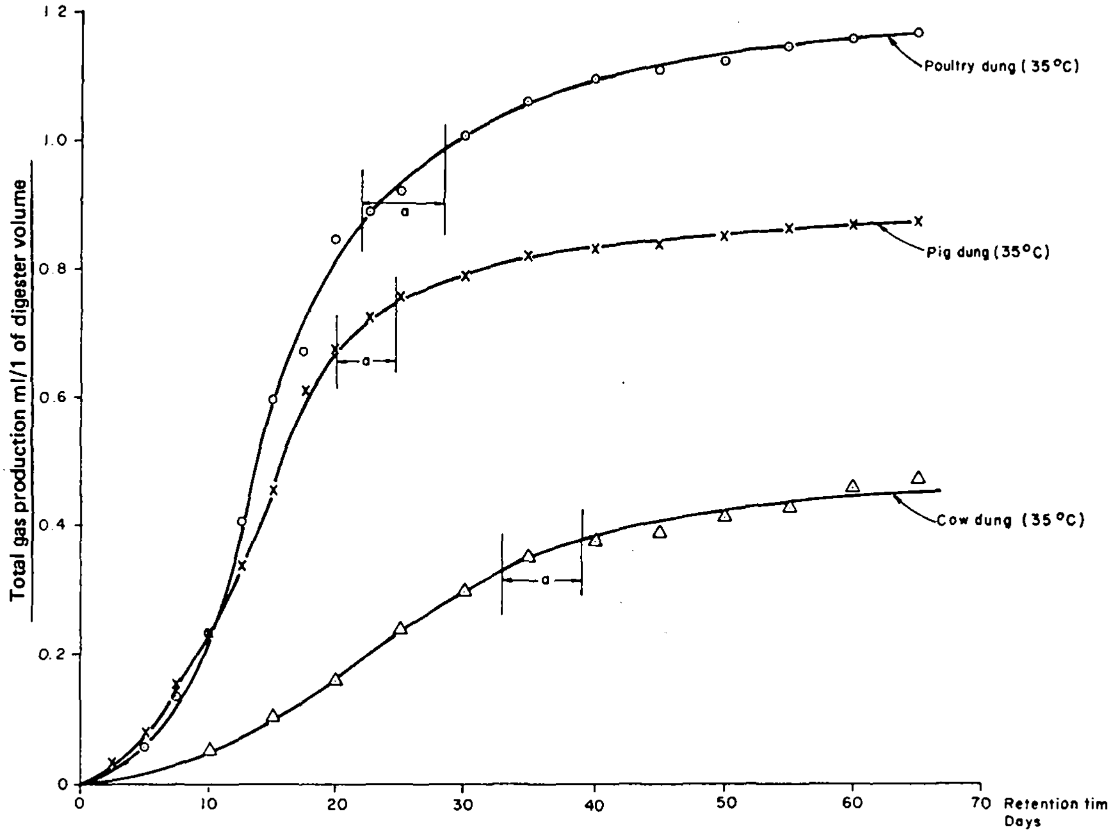


Figure 92. Rate of gas production as a function of retention time (Republic of Korea)



For gas production equaling 75 85 % of the maximum value, the corresponding retention times are as follows (region 'a' on the curves) :—
22 ... 29 days for poultry dung
20 ... 25 days for pig dung
33 ... 39 days for cow dung

Figure 93. Total gas production as a function of retention time (Republic of Korea)

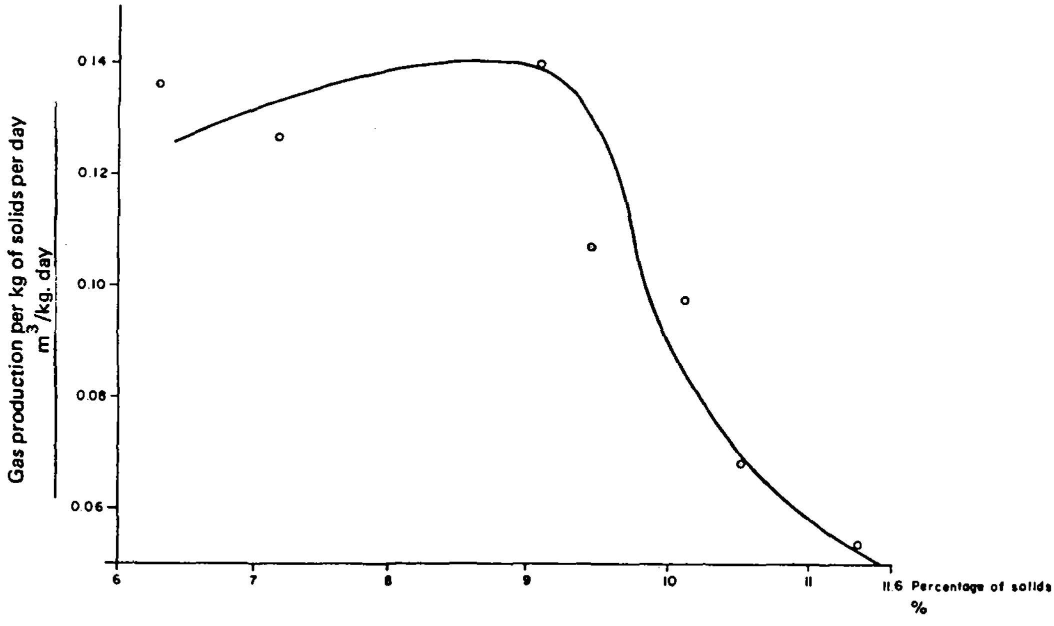


Figure 94. Gas production from cow dung as a function of the percentage of solids (India)

Annex IV

FIXED – DOME TYPE BIOGAS PLANTS

The designs given are made from bricks, #30 concrete (compression strength in a test sample = 30 kg/cm^2 #100 = 100 kg/cm^2) lime concrete and lime clay. The materials and mixing ratios for the latter two are given in chapter VIII. Different materials can be used for different parts of the same digester. The thickness must be appropriate for the material used.

In all designs shown the inlet opening and displacement part are made from lime clay. The constructional details of five sizes, 6, 8, 10, 12 and 50 m^3 are given in figures 95, 96, 97 and 98. The variable dimensions of these sizes using different construction materials are given in annex tables 2, 3 and 4.

These designs were provided by the Sichuan Provincial Institute of Industrial Buildings Design, China (16) and recommended by the South West Engineering Institute in Beijing (15).

Annex table 2. Variable dimensions of brick digester of 6,8,10 and 12 m^3 capacity
(in millimetres)

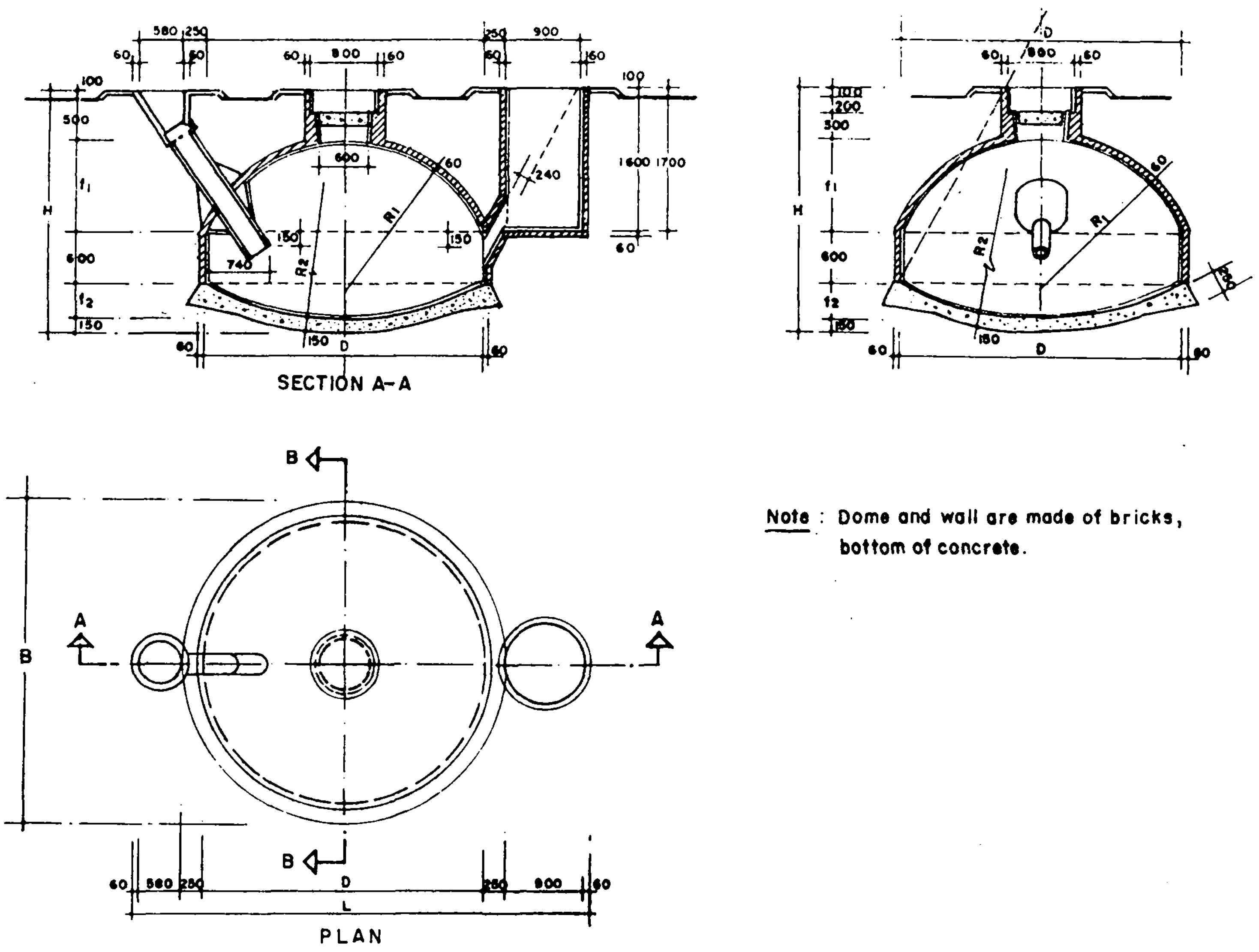
Size m^3	*L*	*B*	*H*	*D*	R_1	f_1	R_2	f_2
6	4700	3080	2550	2600	1410	870	2760	330
8	4900	3280	2630	2800	1510	930	2980	350
10	5200	3580	2760	3100	1680	1030	3300	380
12	5400	3780	2870	3300	1790	1100	3510	410

Annex table 3. Variable dimensions of digester of 6, 8, 10 and 12 m^3 capacity constructed from concrete, lime concrete and lime day
(in millimetres)

Material	*Size m^3*	*L*	*B*	*H*	*D*	R_1	f_1	R_2	f_2	t_1	t_2	t_2	*t4*
Concrete No. 30 . . .	6	4580	2880	2440	2400	1740	480	2550	300	60	60	30	60
	8	4880	3180	2540	2700	1960	540	2860	340	60	60	30	60
	10	5180	3480	2640	3000	2180	600	3180	380	60	60	30	60
	12	5380	3780	2700	3200	2320	640	3400	400	60	60	30	60
Lime concrete	6	4580	2960	2480	2400	1740	480	2550	300	100	100	50	100
	8	4880	3260	2580	2700	1960	540	2860	340	100	100	50	100
	10	5180	3560	2680	3000	2180	600	3180	380	100	100	50	100
	12	5380	3760	2740	3200	2320	640	3400	400	100	100	50	100
Lime clay	6	4580	3060	2530	2400	1740	480	2550	300	150	250	70	125
	8	4880	3360	2630	2700	1960	540	2860	340	150	250	70	125
	10	5180	3660	2730	3000	2180	600	3180	380	150	250	70	125
	12	5380	3860	3790	3200	2320	640	3400	400	150	250	70	125

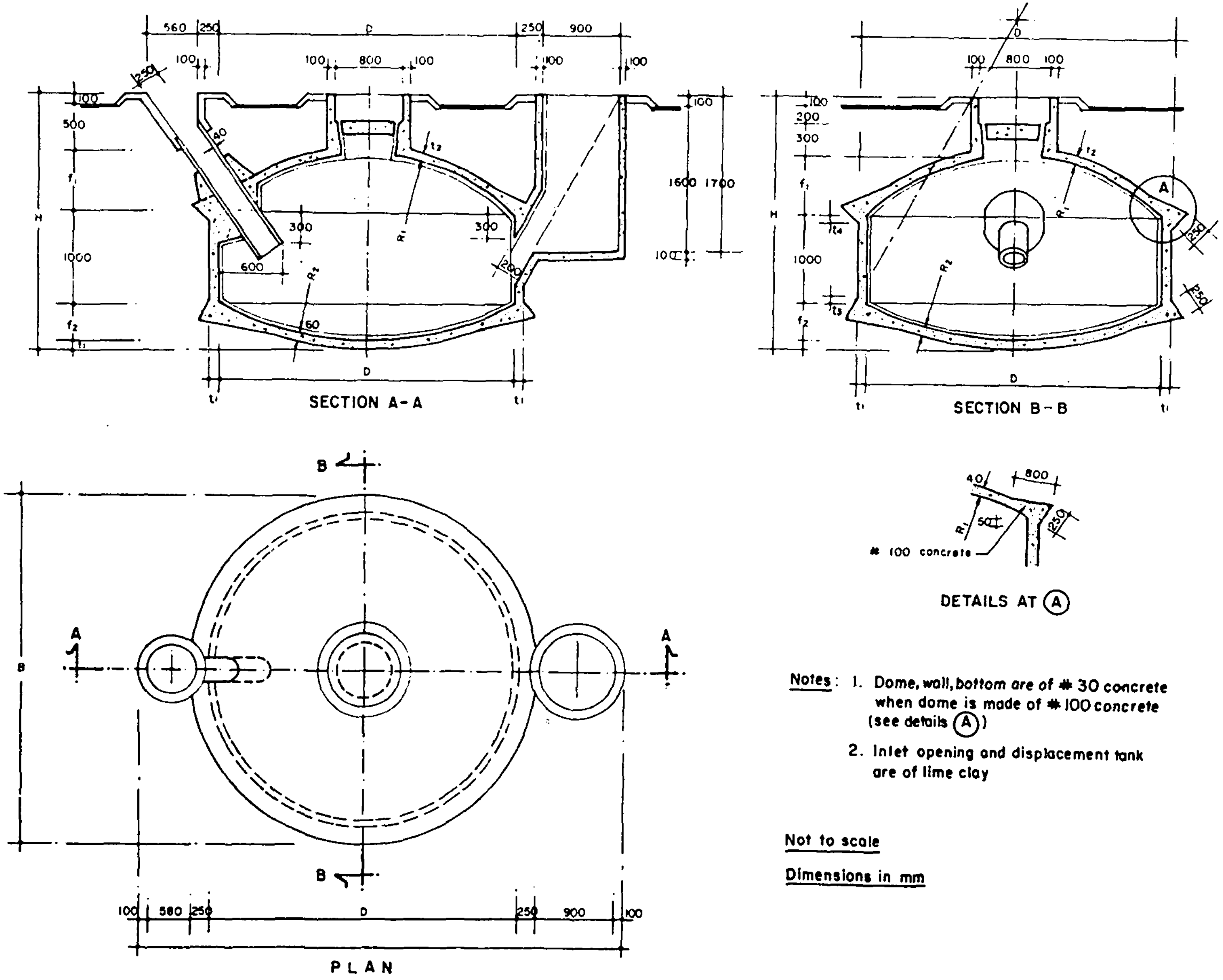
Annex table 4. Variable dimensions of digesters of 50 m^3 capacity constructed from concrete, lime concrete and lime clay
(in millimetres)

Material	*Size m^3*	R_1	R_2	t_1	t_2	t_3	t_4
Concrete No. 30	50	3620	5380	100	120	55	110
Lime concrete bottom made from No. 30 concrete	50	3620	5380	180	180	96	100
Lime clay bottom made from No. 30 concrete	50	3620	5380	300	300	176	320



Note : Dome and wall are made of bricks, bottom of concrete.

Figure 95. Fixed dome digester of 6, 8, 10 and 12 m^3 capacity constructed mainly of brick (China) (see annex table 2)



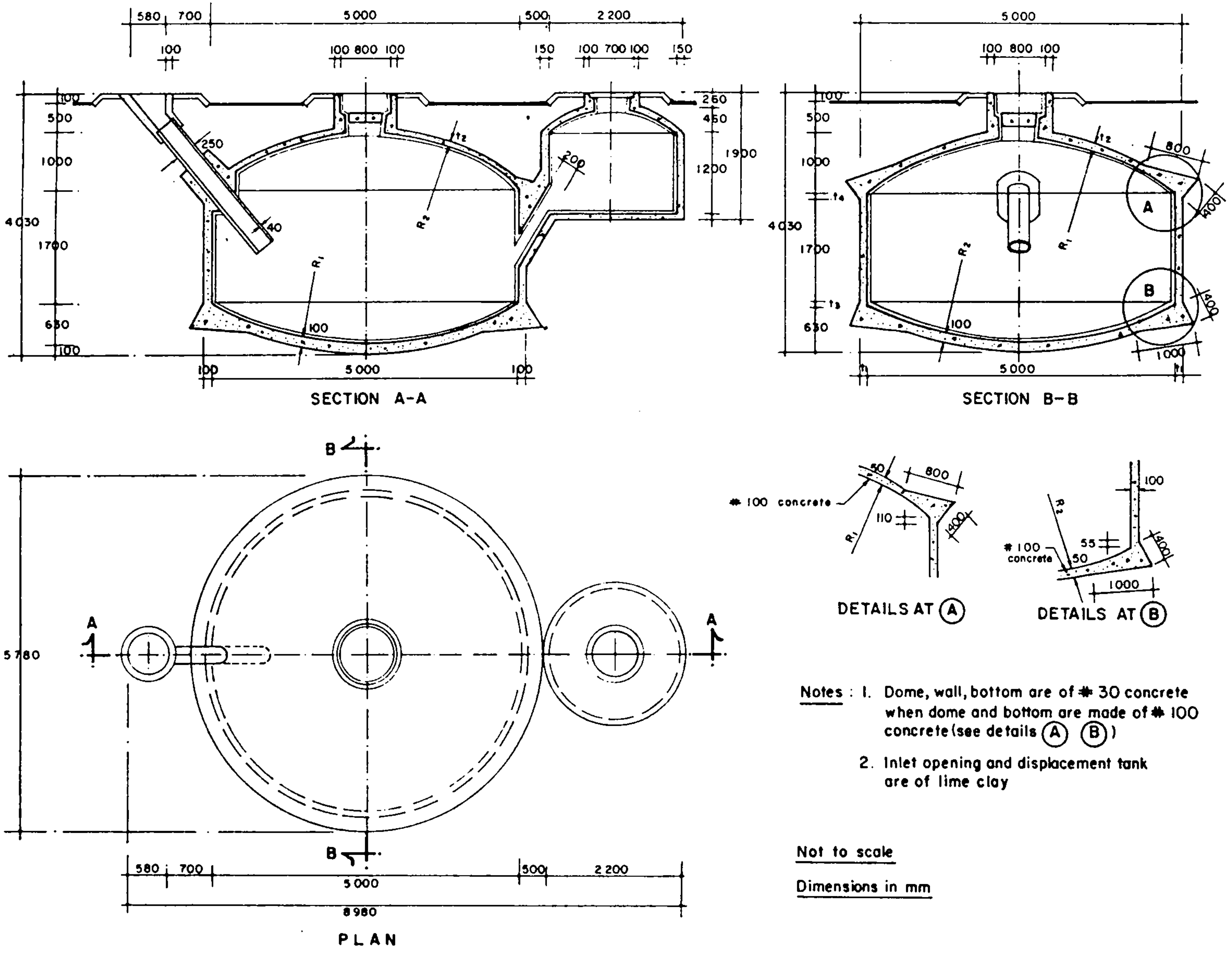
Notes: 1. Dome, wall, bottom are of # 30 concrete when dome is made of # 100 concrete (see details Ⓐ)

2. Inlet opening and displacement tank are of lime clay

Not to scale

Dimensions in mm

Figure 96. Fixed dome digester of 6, 8, 10 and 12 m^3 capacity constructed of concrete, lime concrete and lime clay (China) (see annex table 3)



Notes : 1. Dome, wall, bottom are of # 30 concrete when dome and bottom are made of # 100 concrete (see details Ⓐ Ⓑ)

2. Inlet opening and displacement tank are of lime clay

Not to scale

Dimensions in mm

Figure 97. Fixed dome digester of 50 m^3 capacity constructed of concrete, lime concrete and lime clay (China) (see annex table 4)

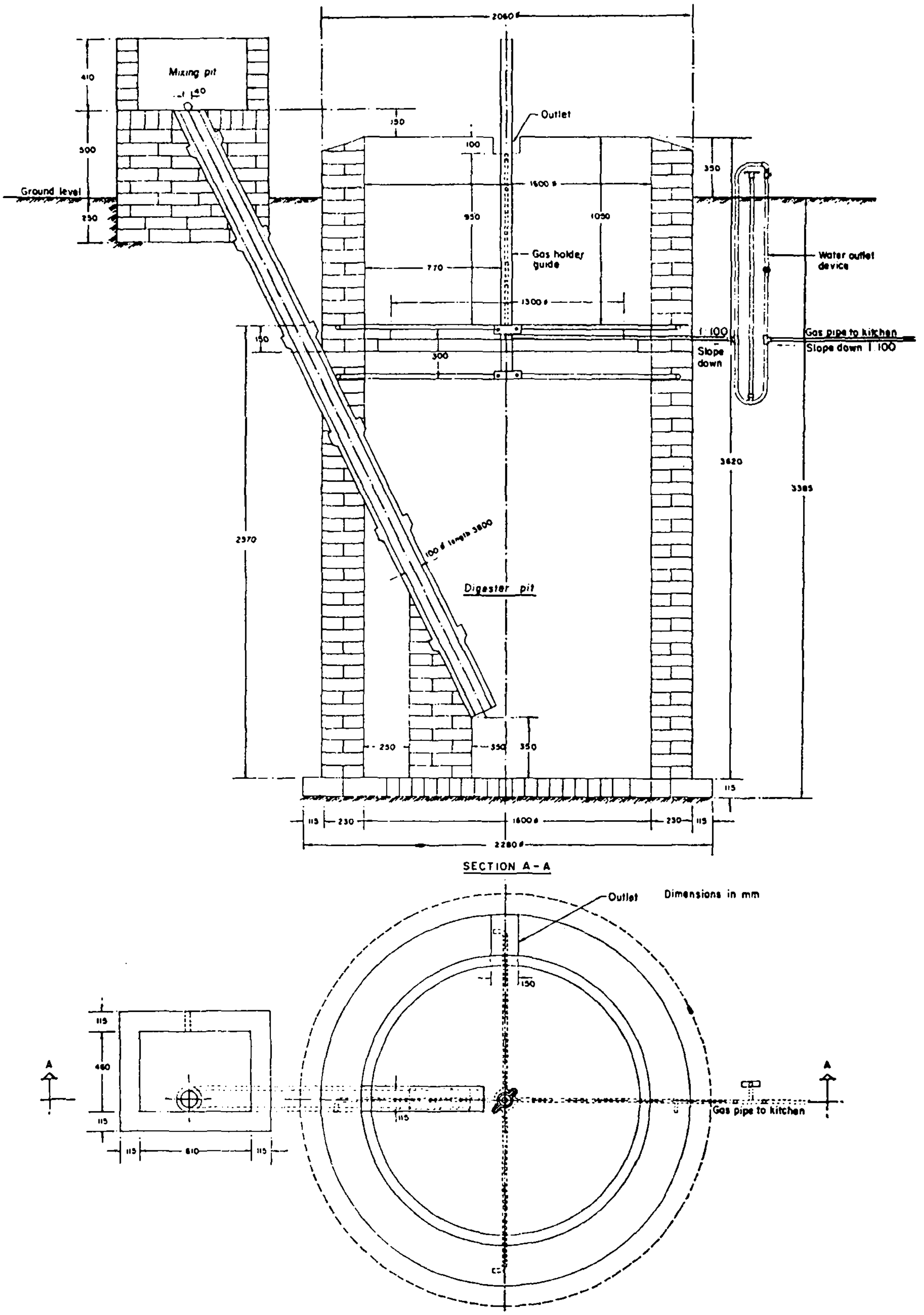
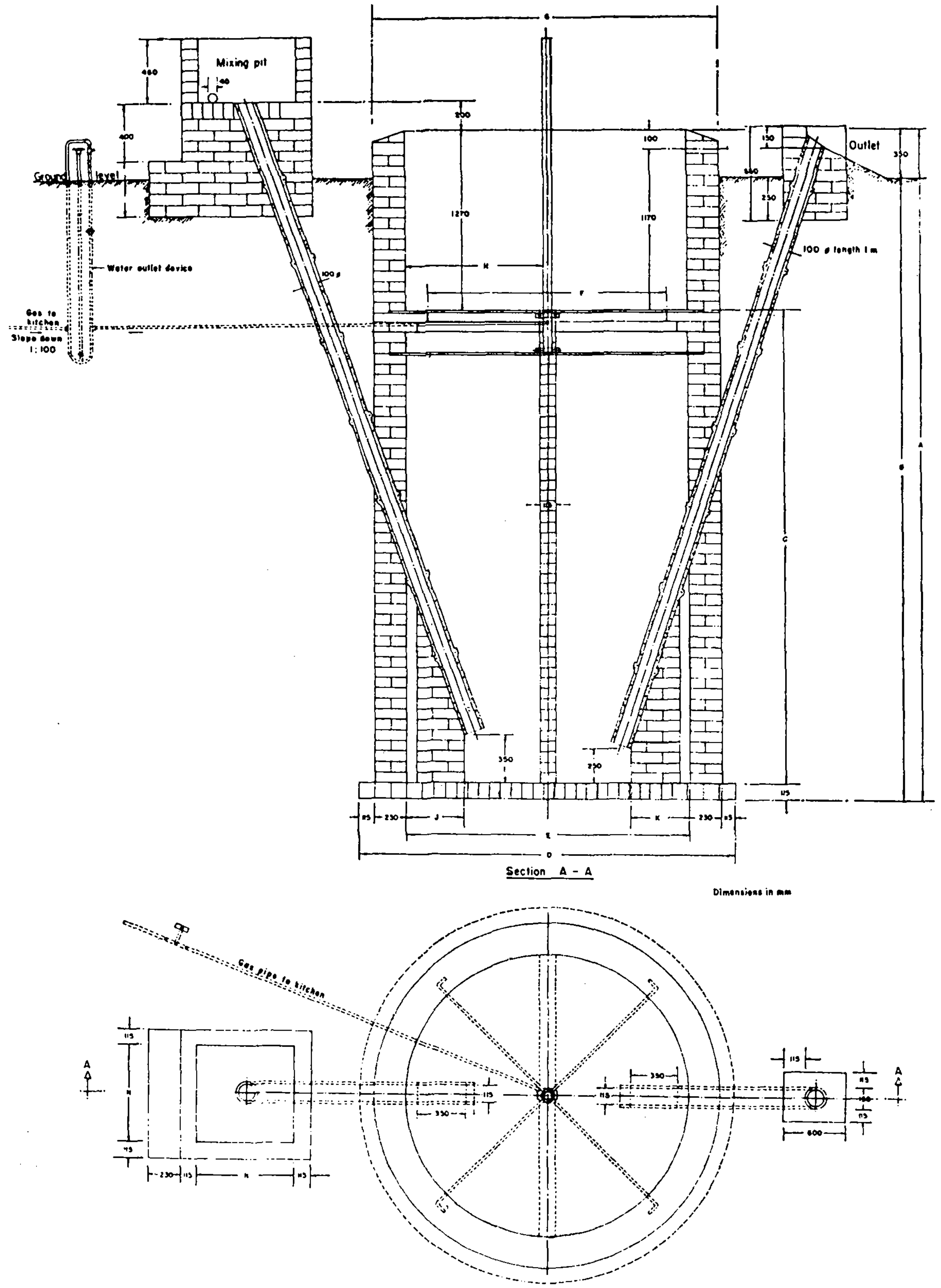


Figure 100. Floating gas holder digester of 2.8 m^3 gas per day, DCS design (Nepal)



Plant size	A	B	C	Dø	Eø	Fø	G	H	J	K	L	M	N
5.7 m^3 (200 cu ft)	4750	4400	3360	2690	2000	1700	2460	970	410	410	4800	4600	700
10 m^3 (350 cu ft)	5045	4695	3860	3290	2600	2300	3060	1255	350	350	5000	4900	1000

Figure 101. Floating gas holder digester of 5.7 and 10 m^3 gas per day, DCS design (Nepal)

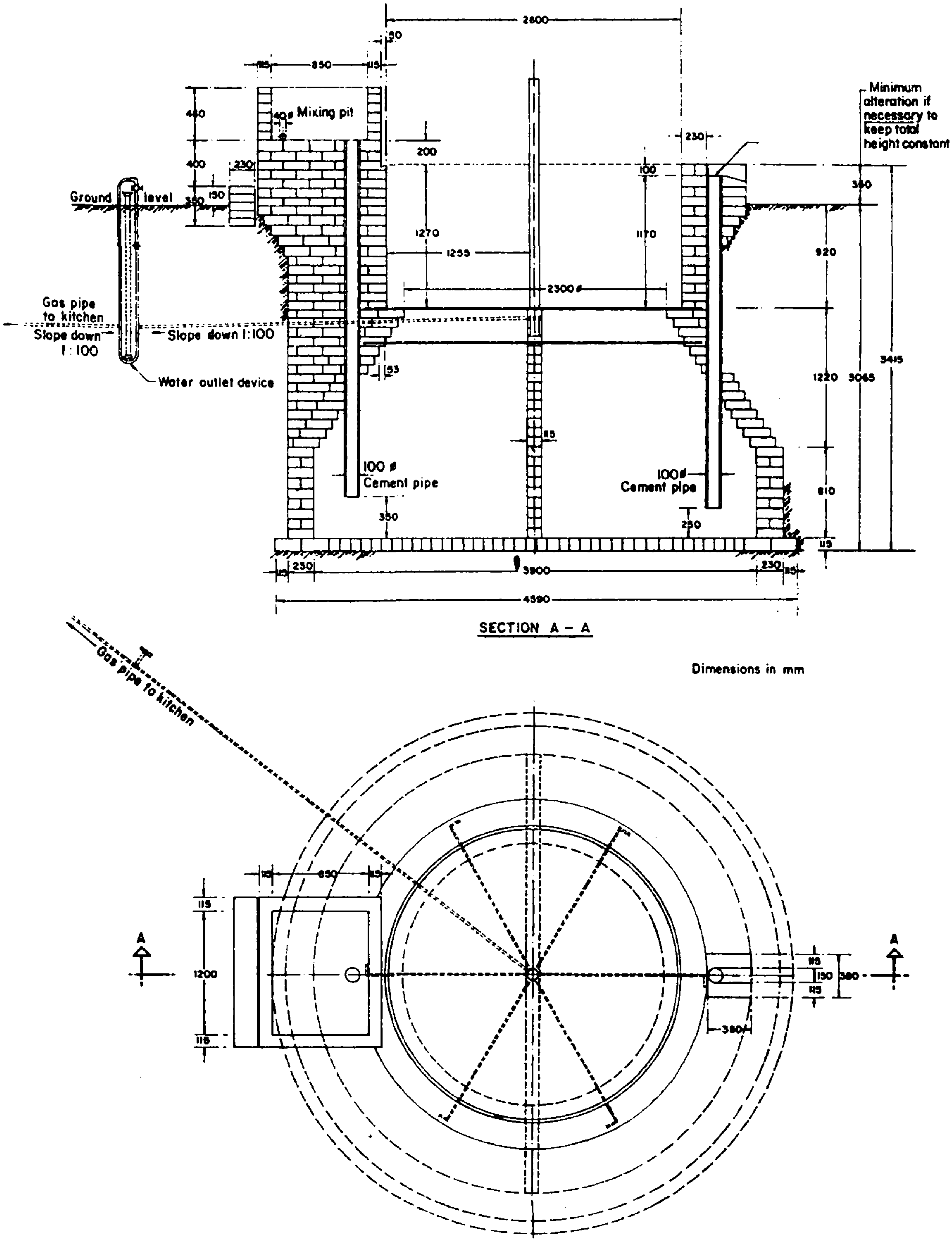
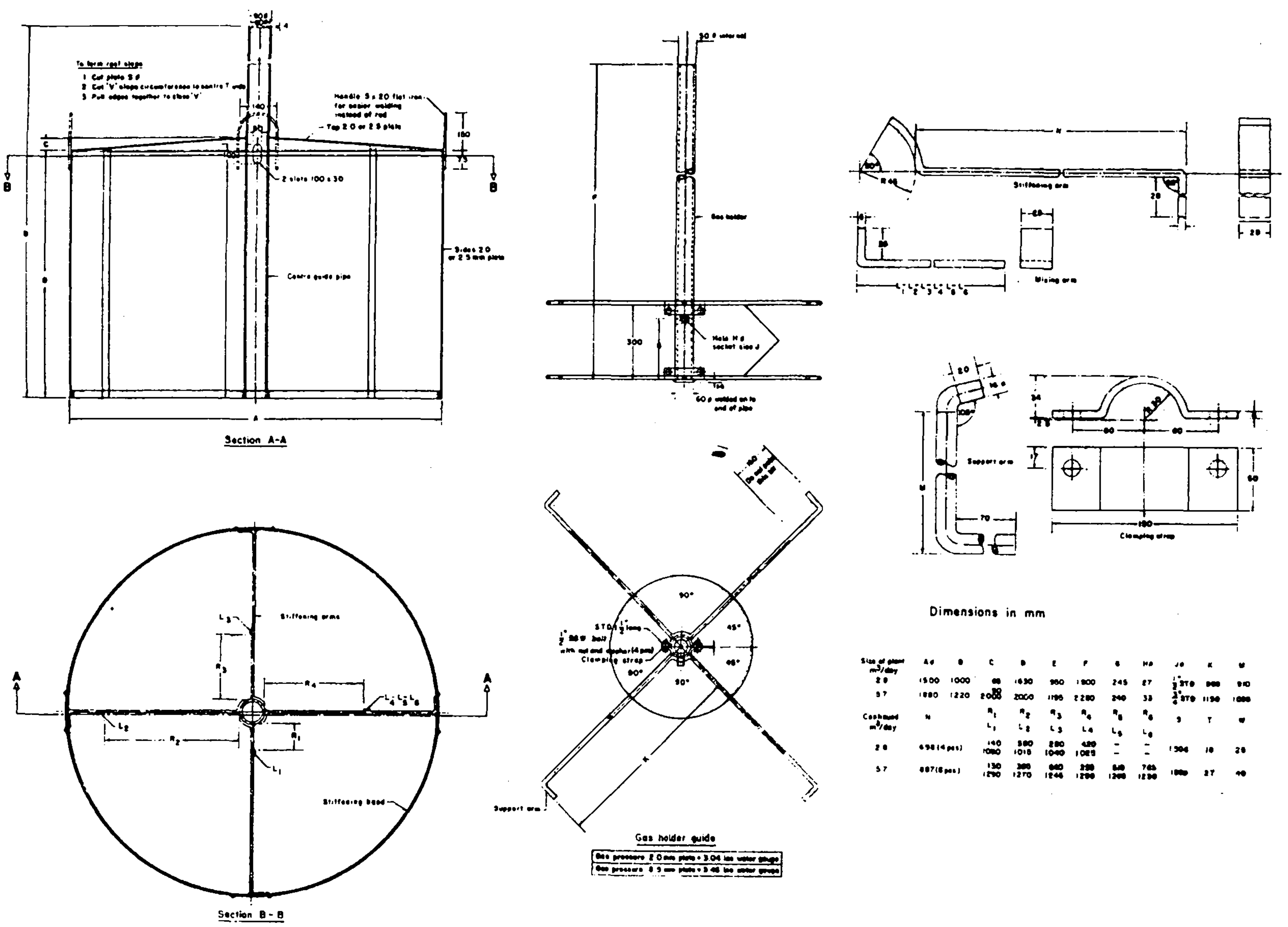


Figure 102. Floating gas holder of the taper type of 10 m^3 gas per day, DCS design (Nepal)



Dimensions in mm

Size of plant m³/day	Ad	B	C	D	E	F	G	Hø	Jø	K	M
2.8	1500	1000	68	1630	960	1800	245	27	½" STD	960	910
5.7	1880	1220	80 2000	2060	1195	2280	240	33	¾" STD	1150	1080

[illegible] m³/day	N	R₁ L₁	R₂ L₂	R₃ L₃	R₄ L₄	R₅ L₅	R₆ L₆	S	T	W
2.8	698 (4 pcs)	140 1080	380 1018	280 1040	420 1025	– –	– –	1304	18	28
5.7	887 (6 pcs)	130 1290	380 1270	640 1246	230 1200	640 1260	765 1230	[illegible]	27	40

Figure 103. Gas holder for DCS digesters of 2.8 and 5.7 m³ gas per day (Nepal)

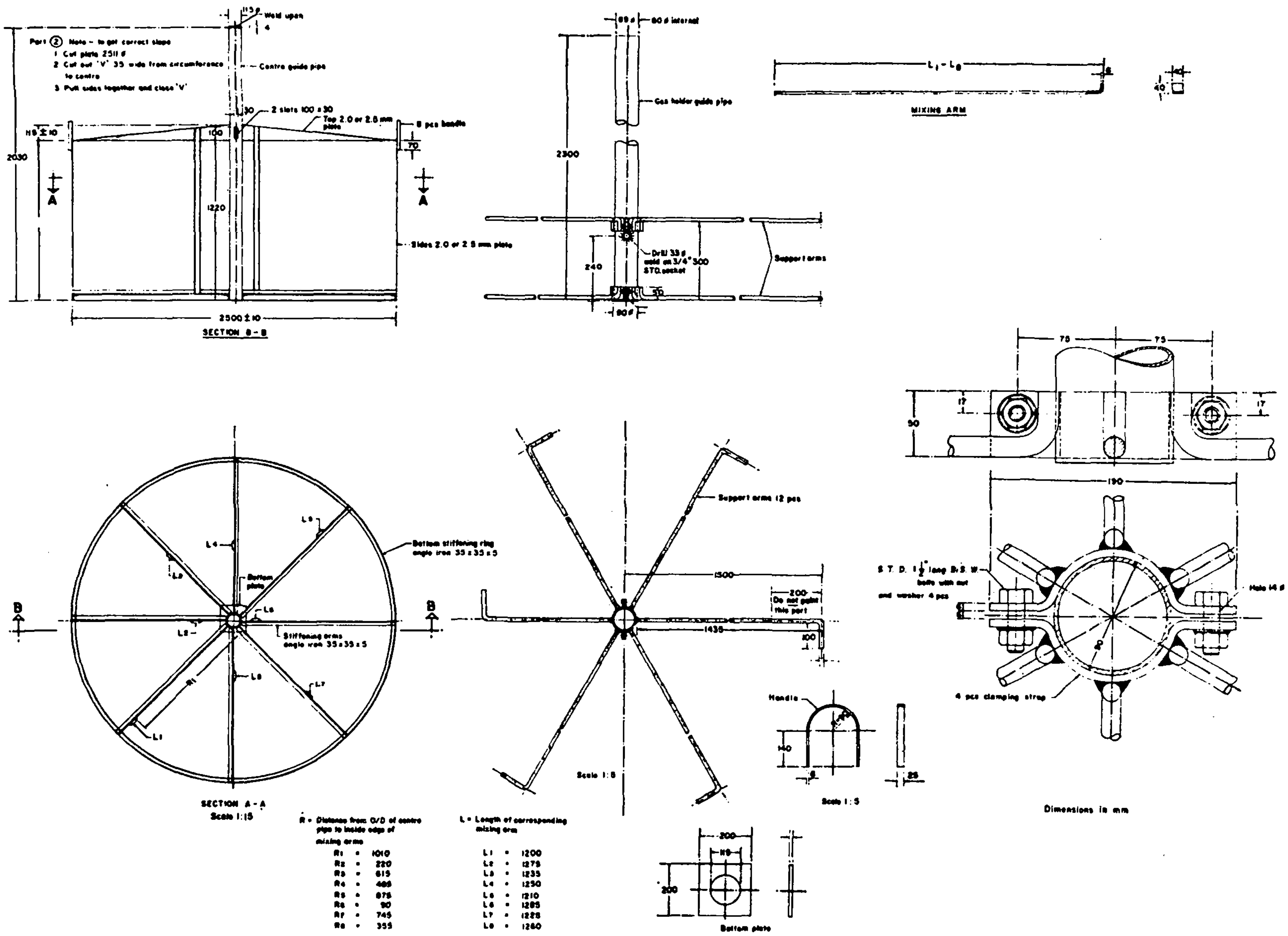


Figure 104. Gas holder for DCS digester of 10 m^3 gas per day (Nepal)

The specifications of the DCS plants are given below:

Expected gas production using cattle dung:	2.8 m^3/day (100 cu ft)	5.7 m^3/day (100 cu ft)	10 m^3/day (350 cu ft) straignt and taper designs
Digester volume:	7.1 m^3	13 m^3	24.3 m^3
Gas holder volume:	1.7 m^3	3.4 m^3	6 m^3
Bricks 9 x 4½ x 3:	3,000	5,000	7,500
Cement (50 kg bags) :	12	17	21
Sand (old cement bags) (holding 1.25 cu ft) :	70	110	130
Motar mix 1:6 for brick work			
1:4 for plaster work. Plaster exposed brickwork (only for decoration)			
100 mm diameter pipe:	3.8 m	9.4 m	9.9 m straight 6.1 m taper

(b) The Khadi and Village Industries Commission (KVIC) plants**

The drawings attached include the following designs:

(i) Digester, gas holder and gas holder guide for a plant of 2 and 3 m^3 gas per day (figure 105);

(ii) Digester, gas holder and gas holder guide for a plant of 5 m^3 gas per day (figure 106);

(iii) Digester, gas holder and gas holder guide for straight and horizontal plants of 10 m^3 gas per day (figure 107).

Volume of spherical segment = (cf. figure 108b)

$$= 3.1416h\left(\frac{c^2}{8} + \frac{h^2}{6}\right)$$

(used for design of dome roofs and floors)

**These designs were provided by the Khadi and Village Industries Commission, Irla Road, Vile Parle (West), Bombay 400 056, India

Size m^3/day	D	L	a	b	c	d	e	f	g	h	i	j	k
2	1350	2500	1750	500	230	4000	380	100	355	405	430	380	400
3	1600	3000	1900	750	300	4500	450	150	380	525	380	750	600

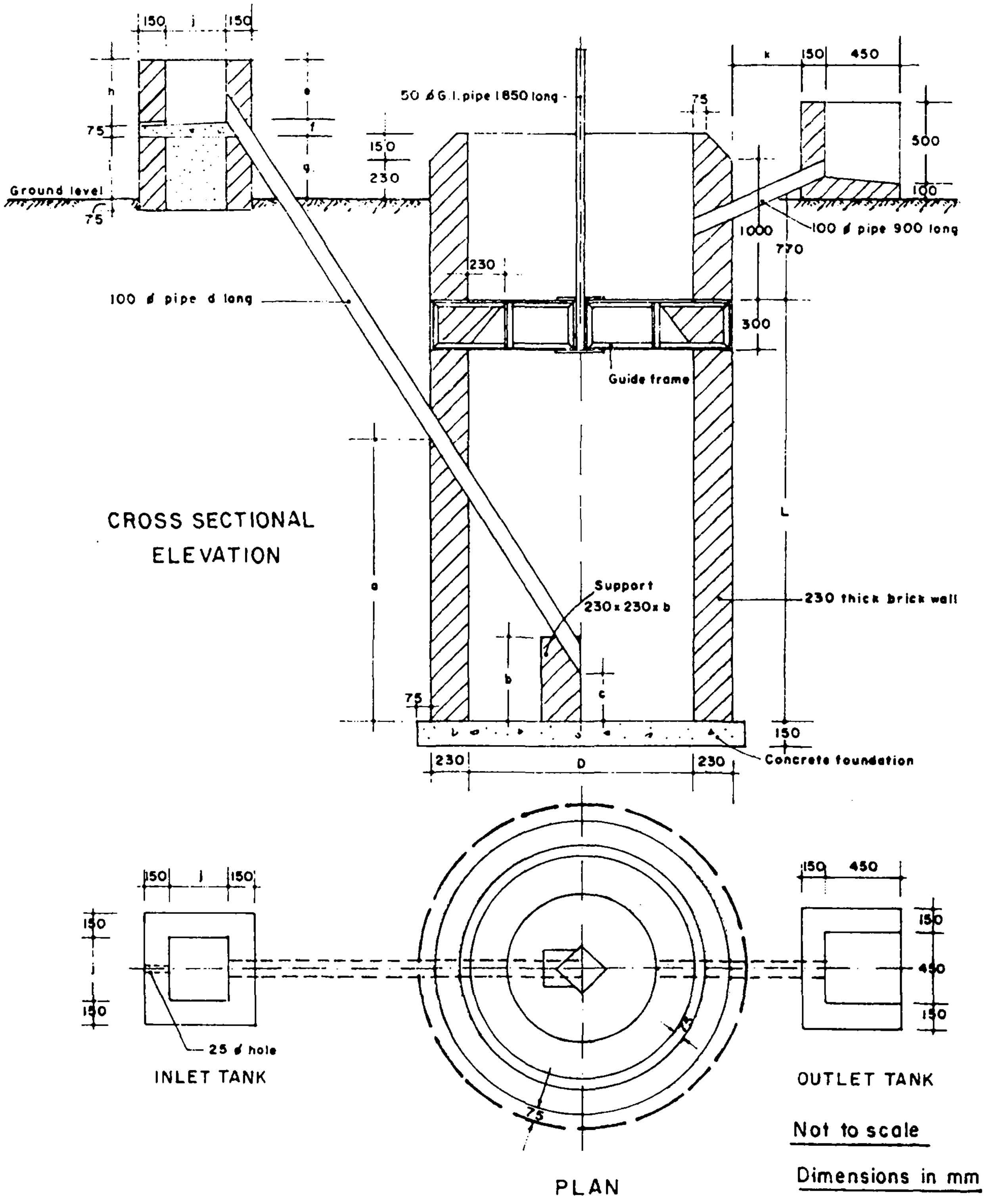
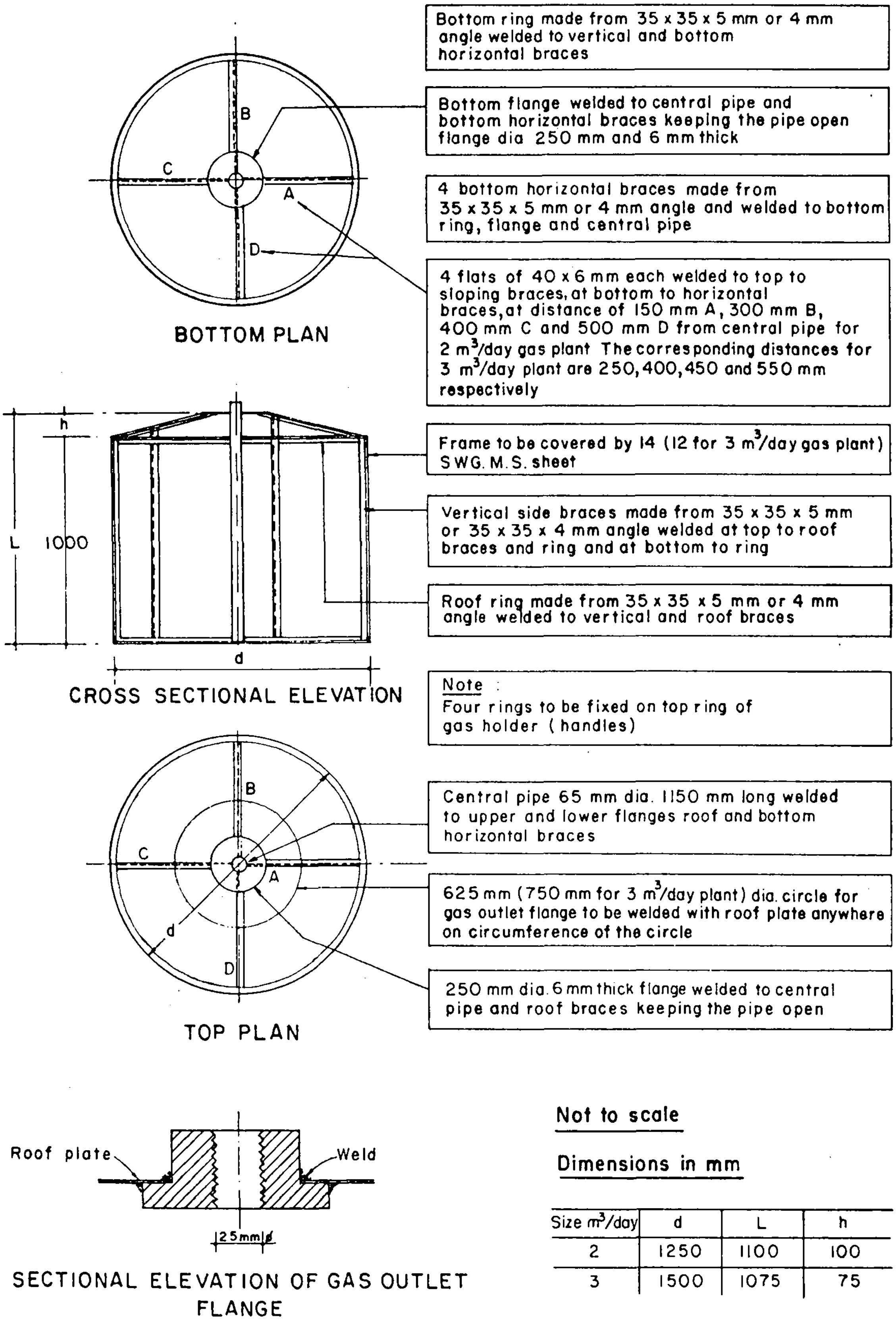


Figure 105a. Floating gas holder digester of 2 and 3 m^3 gas per day, KVIC design (India)



Bottom ring made from 35 x 35 x 5 mm or 4 mm angle welded to vertical and bottom horizontal braces

Bottom flange welded to central pipe and bottom horizontal braces keeping the pipe open flange dia 250 mm and 6 mm thick

4 bottom horizontal braces made from 35 x 35 x 5 mm or 4 mm angle and welded to bottom ring, flange and central pipe

4 flats of 40 x 6 mm each welded to top to sloping braces, at bottom to horizontal braces, at distance of 150 mm A, 300 mm B, 400 mm C and 500 mm D from central pipe for 2 m^3/day gas plant The corresponding distances for 3 m^3/day plant are 250, 400, 450 and 550 mm respectively

Frame to be covered by 14 (12 for 3 m^3/day gas plant) SWG. M.S. sheet

Vertical side braces made from 35 x 35 x 5 mm or 35 x 35 x 4 mm angle welded at top to roof braces and ring and at bottom to ring

Roof ring made from 35 x 35 x 5 mm or 4 mm angle welded to vertical and roof braces

Note :
Four rings to be fixed on top ring of gas holder (handles)

Central pipe 65 mm dia. 1150 mm long welded to upper and lower flanges roof and bottom horizontal braces

625 mm (750 mm for 3 m^3/day plant) dia. circle for gas outlet flange to be welded with roof plate anywhere on circumference of the circle

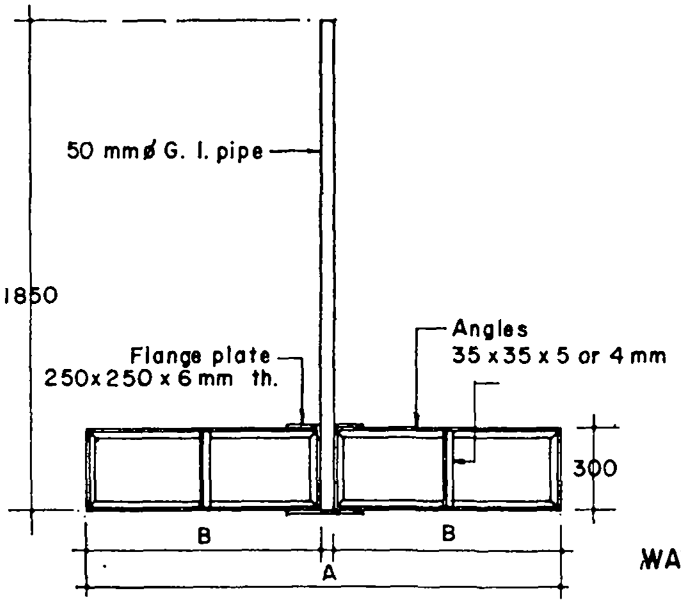
250 mm dia. 6 mm thick flange welded to central pipe and roof braces keeping the pipe open

Not to scale

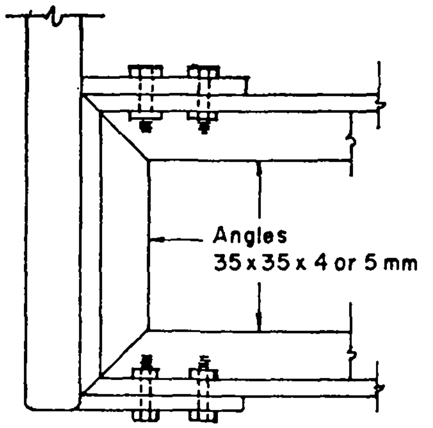
Dimensions in mm

Size m^3/day	d	L	h
2	1250	1100	100
3	1500	1075	75

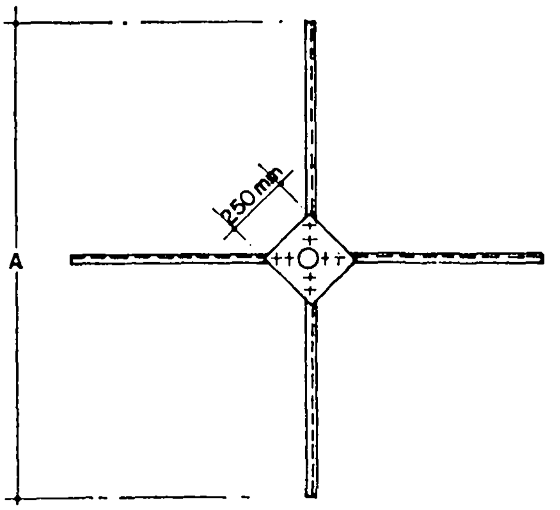
Figure 105 b. Gas holder for 2 and 3 m^3 gas per day, KVIC design (India) (continued)



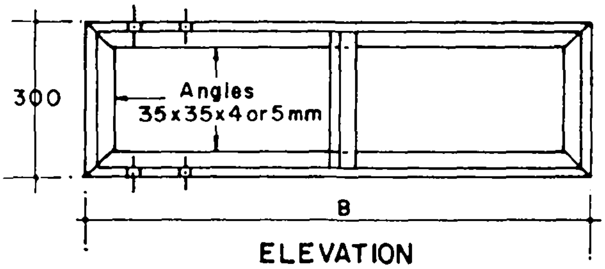
SECTIONAL ELEVATION



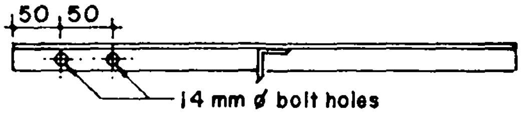
WAY OF JOINING THE ANGLE IRON FRAME WITH G. I. PIPE



PLAN



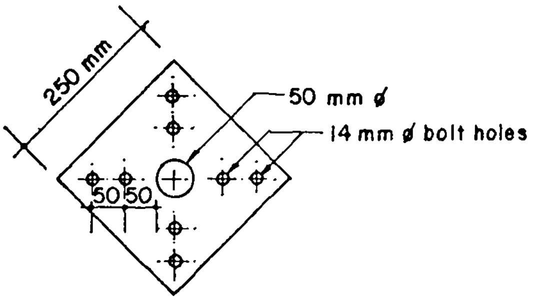
ELEVATION



PLAN OF ANGLE IRON FRAME

Not to scale

Dimension in mm



FLANGE PLATE 250 x 250 x 6mm

Size m^3/day	A	B
2	1810	880
3	2060	1005

Figure 105 c. Gas holder for 2 and 3 m^3 gas per day, KVIC design (India) (continued)

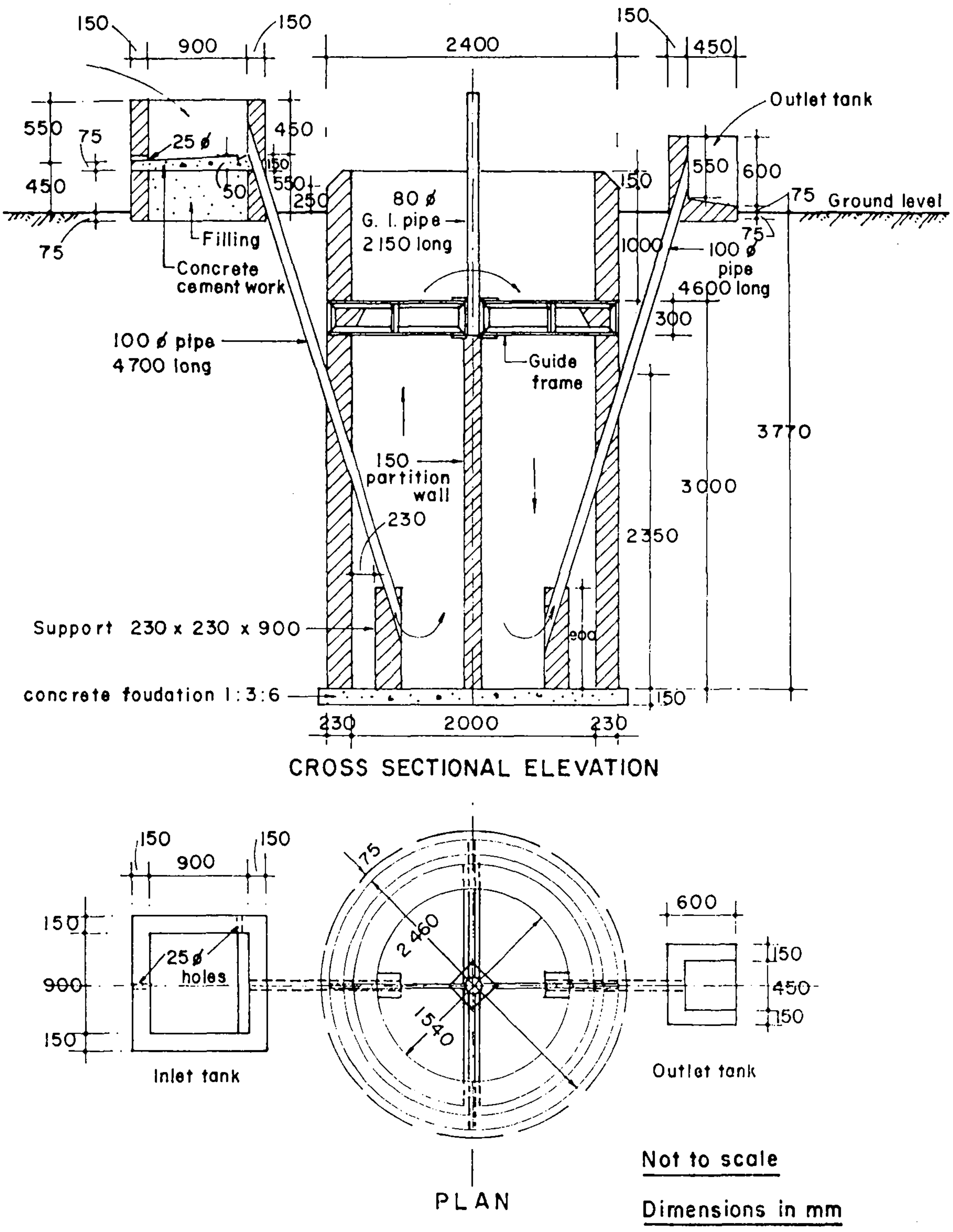
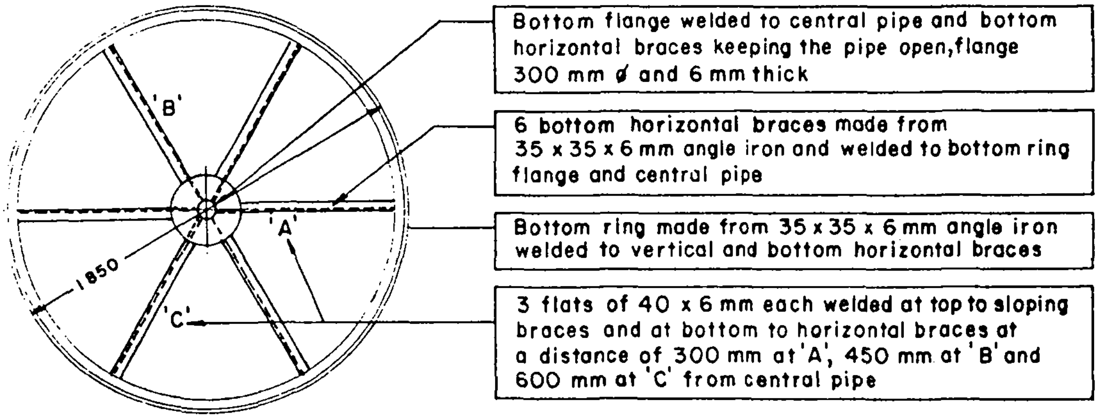


Figure 106 a. Floating gas holder digester of 5 m^3 gas per day, KVIC design (India)



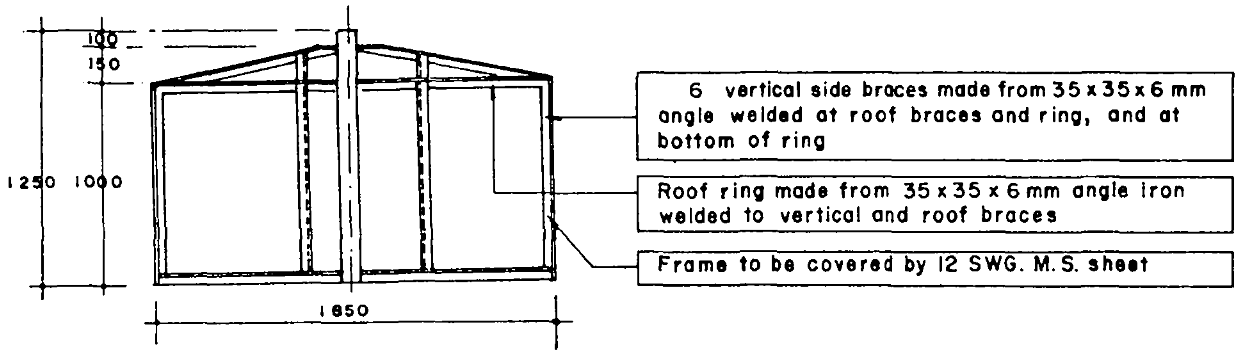
Bottom flange welded to central pipe and bottom horizontal braces keeping the pipe open, flange 300 mm ø and 6 mm thick

6 bottom horizontal braces made from 35 x 35 x 6 mm angle iron and welded to bottom ring flange and central pipe

Bottom ring made from 35 x 35 x 6 mm angle iron welded to vertical and bottom horizontal braces

3 flats of 40 x 6 mm each welded at top to sloping braces and at bottom to horizontal braces at a distance of 300 mm at 'A', 450 mm at 'B' and 600 mm at 'C' from central pipe

BOTTOM PLAN

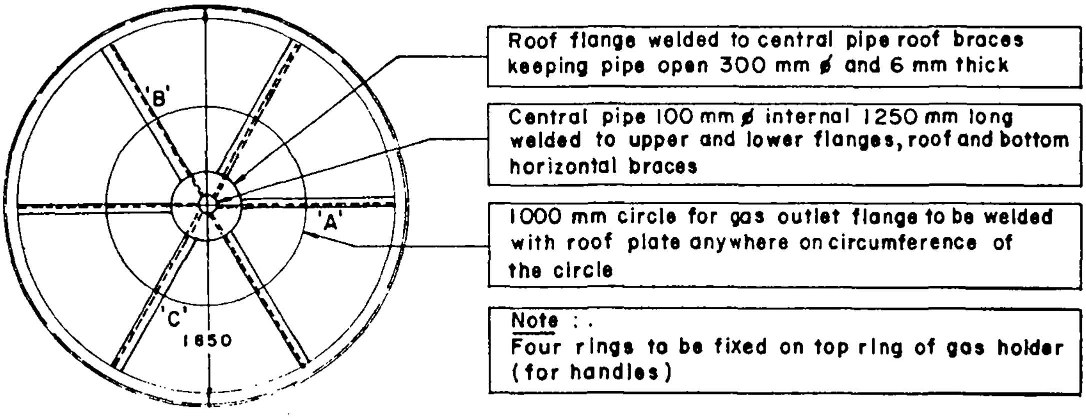


6 vertical side braces made from 35 x 35 x 6 mm angle welded at roof braces and ring, and at bottom of ring

Roof ring made from 35 x 35 x 6 mm angle iron welded to vertical and roof braces

Frame to be covered by 12 SWG. M.S. sheet

CROSS SECTIONAL ELEVATION



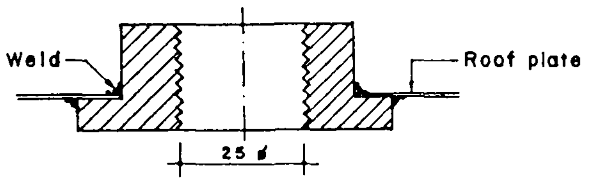
Roof flange welded to central pipe roof braces keeping pipe open 300 mm ø and 6 mm thick

Central pipe 100 mm ø internal 1250 mm long welded to upper and lower flanges, roof and bottom horizontal braces

1000 mm circle for gas outlet flange to be welded with roof plate anywhere on circumference of the circle

Note : .
Four rings to be fixed on top ring of gas holder (for handles)

TOP PLAN



Not to scale

Dimensions in mm

SECTIONAL ELEVATION OF GAS OUTLET FLANGE

Figure 106 b. Floating gas holder for 5 m^3 gas per day, KVIC design (India) (continued)

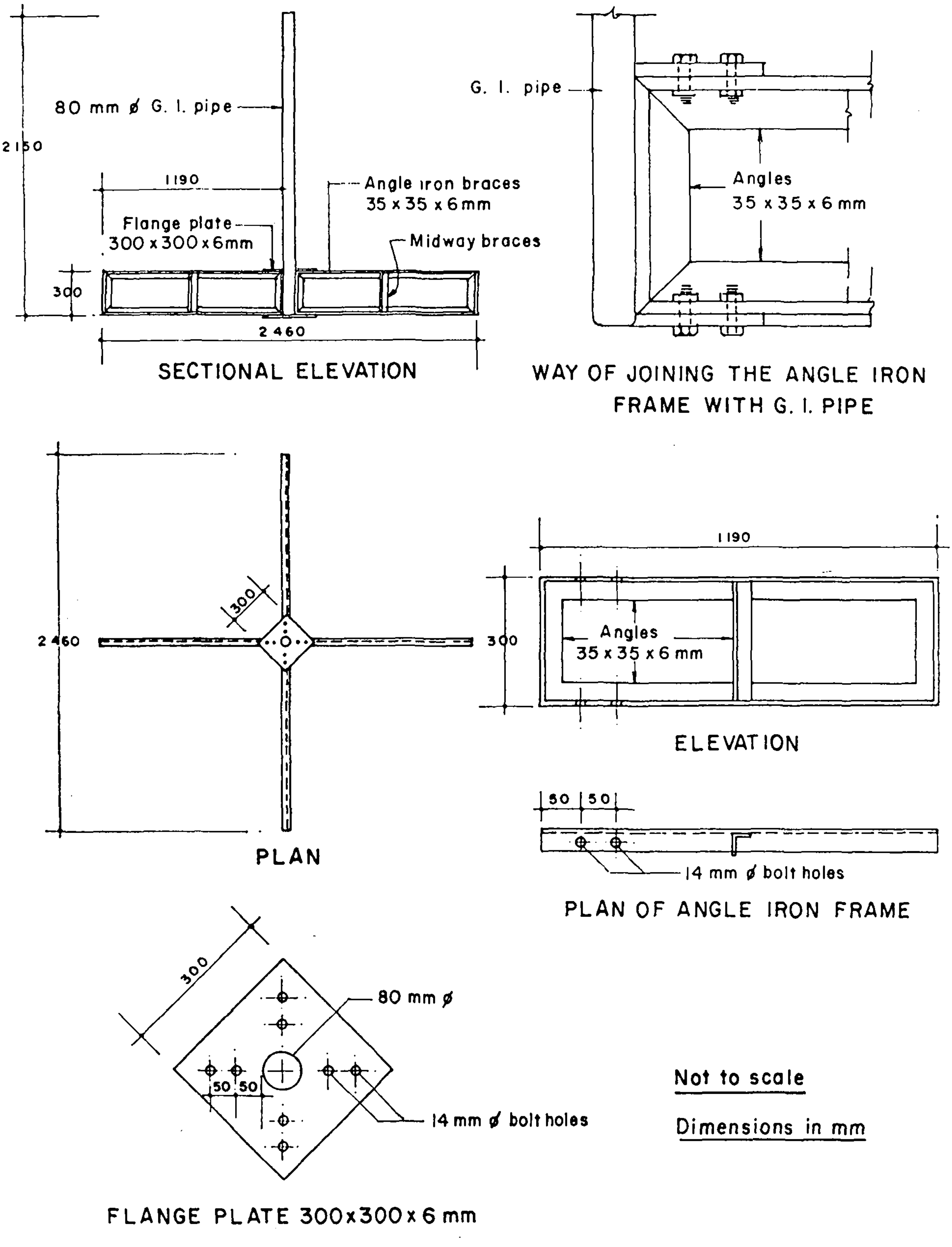


Figure 106 c. Gas holder guide for 5 m^3 gas per day, KVIC design (India) (continued)

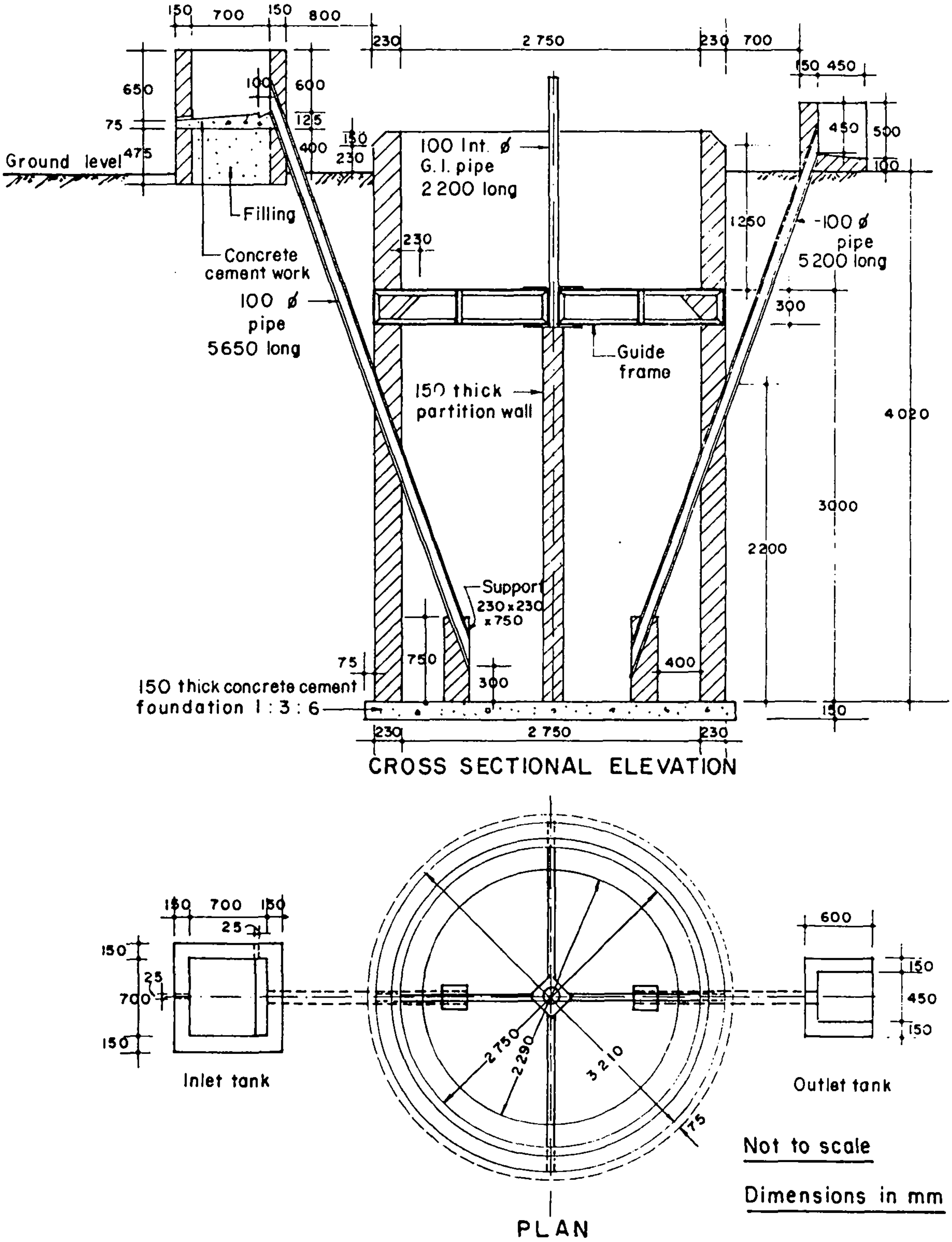
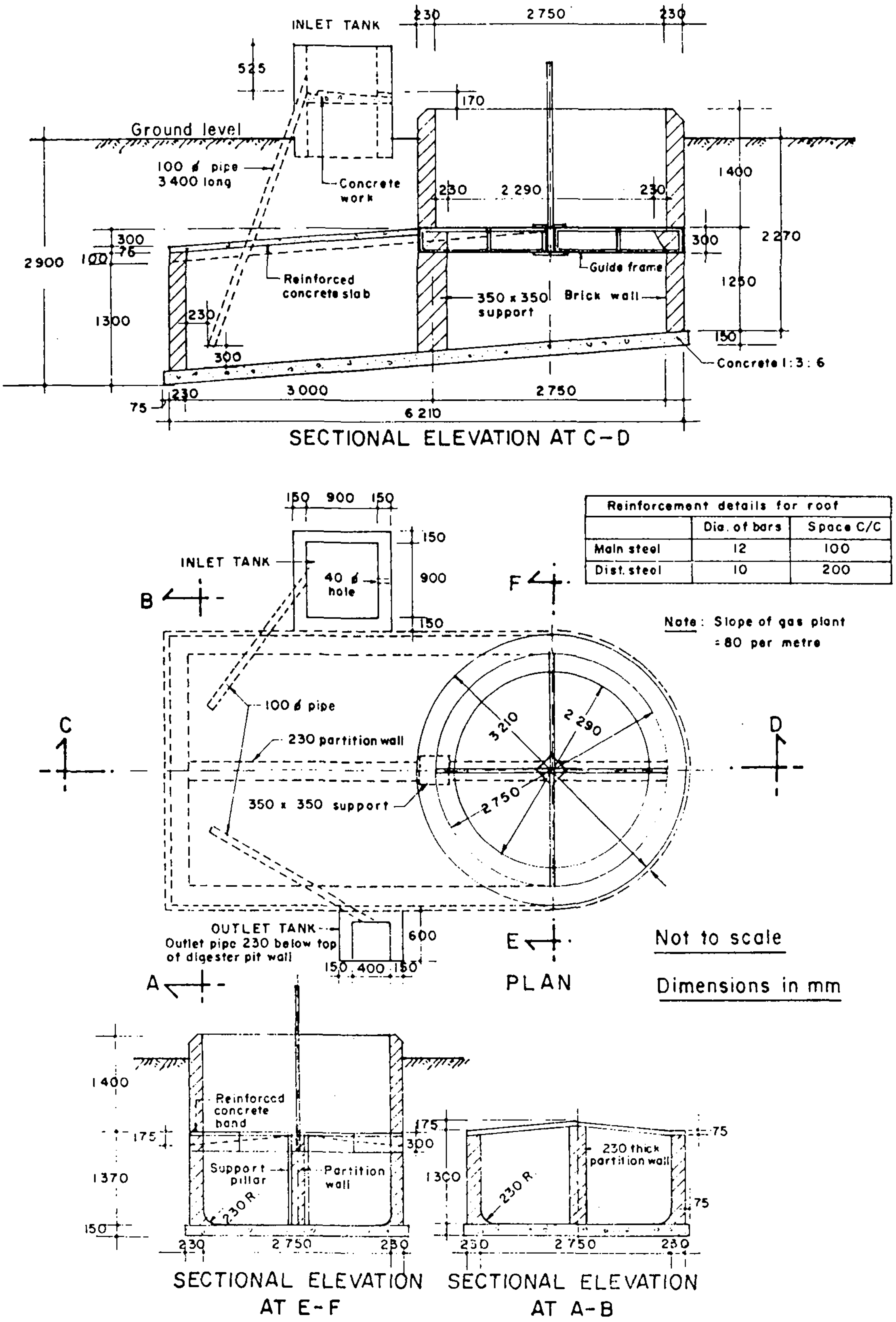


Figure 107 a. Floating gas holder digester of 10 m^3 gas per day, KVIC design (India)

Note: The same design is used for straight and horizontal plants.

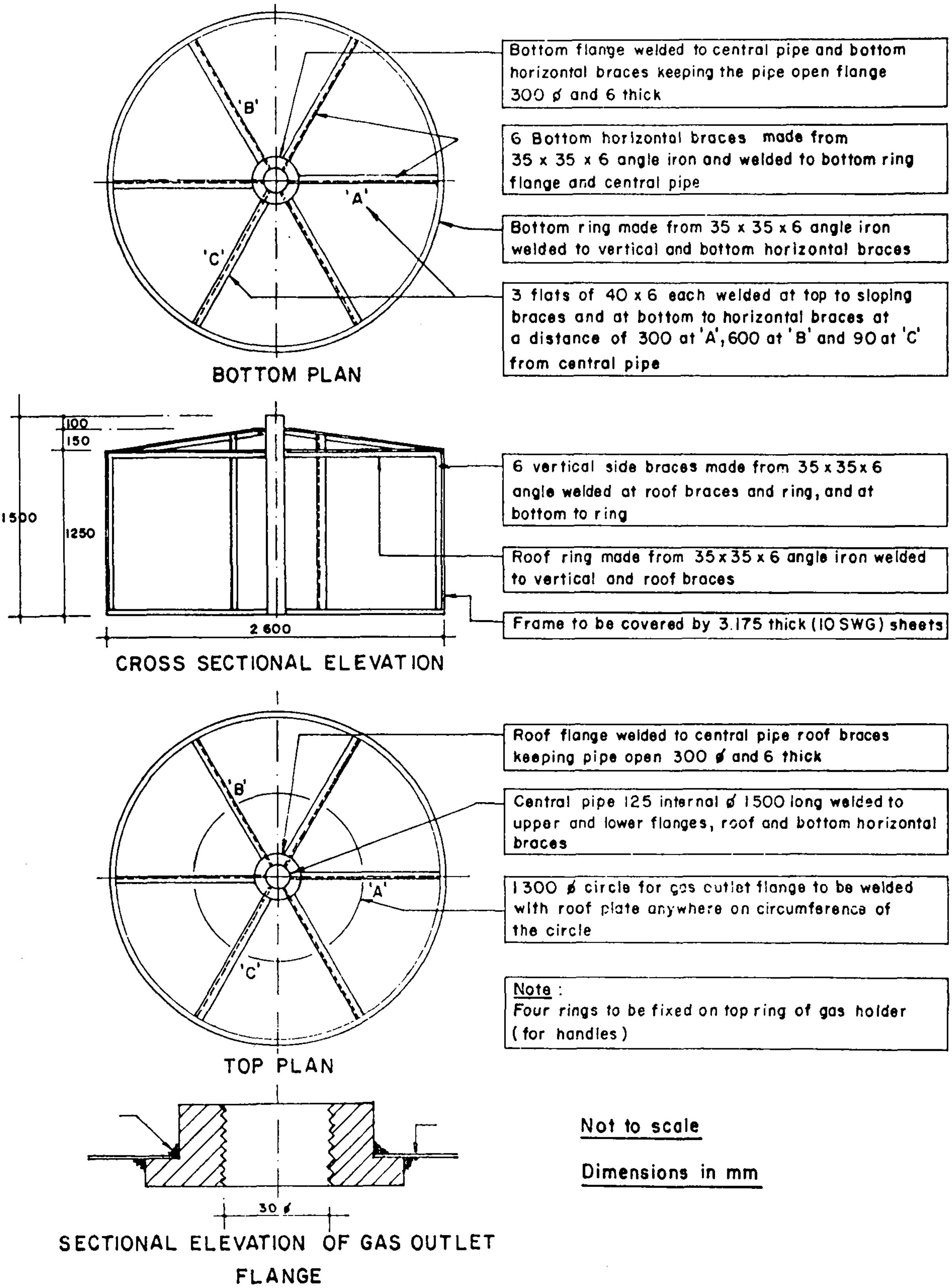


Reinforcement details for roof		
	Dia. of bars	Space C/C
Main steel	12	100
Dist. steel	10	200

Note: Slope of gas plant = 80 per metre

Figure 107 b. Floating gas holder digester of 10 m^3 gas per day, KVIC design (India) (continued)

Note: The same design is used for straight and horizontal plants.



Bottom flange welded to central pipe and bottom horizontal braces keeping the pipe open flange 300 ø and 6 thick

6 Bottom horizontal braces made from 35 x 35 x 6 angle iron and welded to bottom ring flange and central pipe

Bottom ring made from 35 x 35 x 6 angle iron welded to vertical and bottom horizontal braces

3 flats of 40 x 6 each welded at top to sloping braces and at bottom to horizontal braces at a distance of 300 at 'A', 600 at 'B' and 90 at 'C' from central pipe

6 vertical side braces made from 35 x 35 x 6 angle welded at roof braces and ring, and at bottom to ring

Roof ring made from 35 x 35 x 6 angle iron welded to vertical and roof braces

Frame to be covered by 3.175 thick (10 SWG) sheets

Roof flange welded to central pipe roof braces keeping pipe open 300 ø and 6 thick

Central pipe 125 internal ø 1500 long welded to upper and lower flanges, roof and bottom horizontal braces

1300 ø circle for gas outlet flange to be welded with roof plate anywhere on circumference of the circle

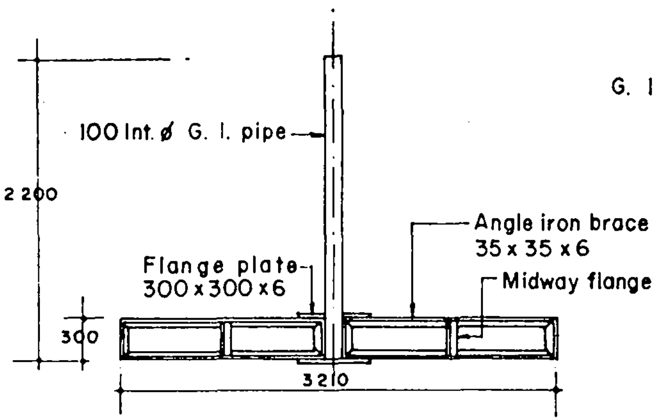
Note :
Four rings to be fixed on top ring of gas holder (for handles)

Not to scale

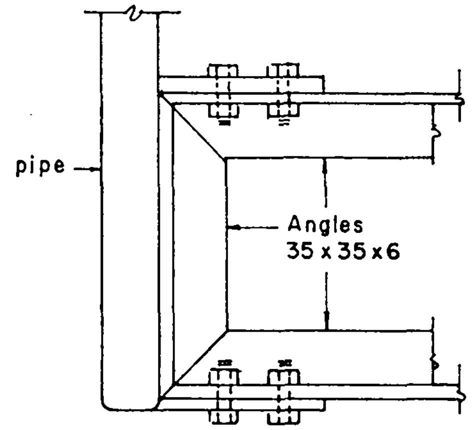
Dimensions in mm

Figure 107 c. Floating gas holder digester of 10 m^3 gas per day, KVIC design (India) (continued)

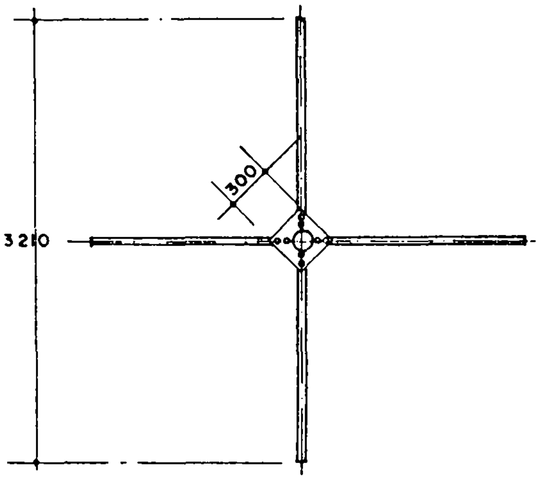
Note: The same design is used for straight and horizontal plants.



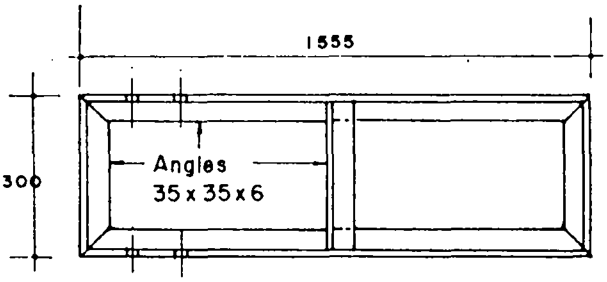
SECTIONAL ELEVATION



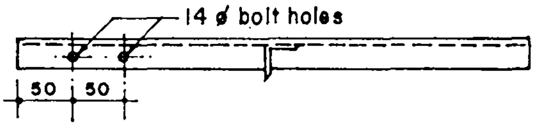
WAY OF JOINING THE ANGLE IRON FRAME WITH G.I. PIPE



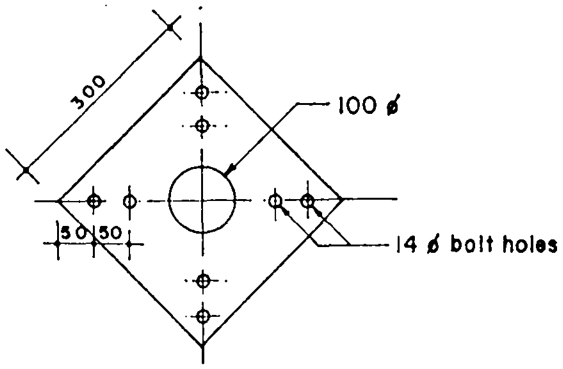
PLAN



ELEVATION



PLAN OF ANGLE IRON FRAME



Not to scale

Dimensions in mm

FLANGE PLATE 300x300x6 mm

Figure 107 d. Floating gas holder digester of 10 m^3 gas per day, KVIC design (India) (continued)

Note: The same design is used for straight and horizontal plants.

Brickwork per m^3 of brickwork Bricks 9" x 4½" x 3"

Mortar mix	1:8
Bricks	500
Cement	50 kg
Sand	0.28 m^3

Mortar mix	1:6 (cement: sand)
Bricks	500
Cement	65 kg
Sand	0.26 m^3

Hand-mixed concrete per m^3 concrete

Mix 1:2:4 (cement:sand:stone)

Cement	320 kg
Sand	0.45 m^3
Broken stone (12 to 25 mm size)	0.90 m^3

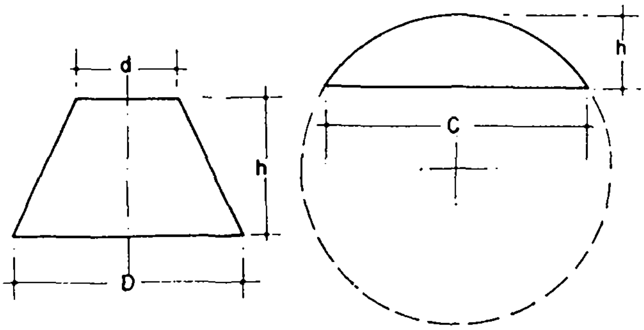
Mix 1:3:6

Cement	220 kg
Sand	0.46 m^3
Broken stone (12 to 25 mm size)	0.92 m^3

Plaster work thickness 12 mm per 10 m^3

Mortar mix 1:4 (cement: sand)

Cement	55 kg
Sand	0.16 m^3



(i) (ii)

Figure 108. Volume of various segments

Annex VII

NIGHT SOIL BIOGAS PLANT

A night soil biogas plant has been evolved by the National Environmental Engineering Research Institute, Nagpur, India. The plant is a masonry structure, partly above ground, with a floating gas dome at the top to collect the gas. There is provision in the digester to feed the night soil slurry and withdraw the digested slurry. Night soil and water in the ratio 1:0.5 is fed into the digester after screening through a 2.5 cm mesh screen. The organic loading in the digester is about 0.8-2.2 kg, 5 kg of slaked lime is added in the beginning for acceleration of gas production. The retention time is 20 days. Gas production ranges from 4.2-5.6 m^3/day. The digested sludge from the night soil digester is withdrawn on to a sludge drying bed, for dewatering and drying. Supernatants obtained from the digester are treated further in stabilization ponds.

Annex VIII

SOCIO-ECONOMIC ASSESSMENT OF BIOGAS TECHNOLOGY

A few case studies based on cost-benefit analysis are given below to illustrate the advantages of biogas technology.

Case study I:
(Parikh, 1979)

The following table is a comparison of the economics of four alternatives for obtaining the same amount of fuel and fertilizer, viz.

(a) Set up a biogas plant;

(b) Burn dung for cooking and heat; purchase fertilizers and kerosene (for lighting);

(c) Use dung for fertilizer; purchase additional dung and kerosene to burn;

(d) Purchase coal, kerosene and fertilizers.

Economic comparison of family biogas plants in India (Amounts per year)

Items	*Alternatives*[a]			
	(a) Install 1.8 m^3/d biogas plant to provide gas and fertilizer	*(b) Burn dung purchase fertilizer and kerosene*	*(c) Use dung for fertilizer; purchase kerosene and supplementary fertilizers*	*(d) Purchase coal, kerosene and fertilizers*
Interest, depreciation and maintenance costs[b] ($)	31	–	–	–
Amount of biogas generated (m^3)	660			
Effective energy yield (giga-joules)	7.92	5.42		
Fertilizer produced (kg of N)	52.6		30	
Purchases[c]				
Kerosene (kg)		25	25	25
Dung cakes (t)		1.50	5.15	
Fertilizer (kg of N)		52.6	22.7	52.6
Coal (t)				3.3
Total cost[d] ($)	31	34.8	41.4	76

(a) For a private owner of five animals with an annual output of dry dung of 3.65 tons.

(b) Based on interest rate of 12 per cent on an initial investment of $200, life of plant of 15 years and cost of painting the drum of $5 per year.

(c) Based on the following assumptions:

(i)	*Calorific value*	*Efficiency of burning percentage*	*Net energy output*
Dung	3200 kcal/kg (13.3 MJ/kg)	11 11	355 kcal/kg (1.48 MJ/kg)
Biogas	4770 kcal/m^3 (20.0 MJ/m^3)	60	2860 kcal/m^3 (12.0 MJ/m^3)

(ii) Cooking energy needs amount to 1.77 Gcal (7.40 GJ) x 10^3 kcal/a and can be met from either 615 m^3 of biogas or 5.15 t of dung cakes;

(iii) Either 25 kg of kerosene or 46 m^3 of biogas are required for lighting;

(iv) An amount of 1 kg of dung when composted gives 0.56 kg of compost with 1.5 per cent N. Through a biogas plant it yields 0.72 kg of dry sludge with 2.0 per cent N.

(d) Based on these prices: kerosene, \$0.12/kg; dung cakes, \$5.5/ton; fertilizer, \$0.45/ton (N); coal (delivered), \$15/ton.

The results for (a) and (c) indicate that for a person using dung for composting the return on investment in a biogas plant is higher under the existing price structure. (In these calculations, the subsidy of \$50 given by the Indian Government for setting up a biogas plant is not taken into account.)

When case (a) is compared with case (b), it can be seen that only a few net dollars can be gained per year from a biogas plant. The cost of dung is not assumed to be zero, which is another reason why the gain does not seem very substantial.

If (a) is compared with (d), however, the benefits are substantial. Besides, since the analysis is done from the consumer's viewpoint, the national investments in mining and transporting coal and their opportunity costs are not considered. For countries where there is no coal and oil has to be purchased in foreign exchange, the costs would be even higher than indicated in (d).

Case study II
(ICAR, 1976)

The economics of cow dung gas plants has been studied using the usual capital budgeting techniques employed in cost-benefit analysis. Having in mind one small-sized gas plant, one medium-sized farm-plant and the two most commonly occurring sizes of family plants, the study has been confined to the following types of gas plants.

Design of gas plant	*Size (cft/day)*
KVIC	60, 100, 200, 500
IARI	100
PRAI	100

The following notations have been used to specify the model:

K = Capacity of the cow dung gas plant (cu ft/day)

I = Investment in the gas plant (Rs)

d = Dung produced per animal per day (kg)

N = Number of animals required per plant

W = Wet dung processed per plant per year = 365 Nd(kg)

D = Dry dung available per year from dung of equivalent quantity as processed in a gas plant (kg)

G = Methane gas produced per plant per year = 365 K(cu ft)

M_1 = Farmyard manure obtained per year from dung of equivalent quantity as processed in a gas plant (kg)

M_2 = Gobar gas manure obtained per plant per year (kg)

c = Efficiency of gas production (varying from 0 to 1)

f = Proportion of cow dung used as fuel in the existing system (varying from 0 to 1)

1-f = Proportion of cow dung used for making manure in the existing system

A = Gross return per year from cow dung gas plant from value of methane gas and gobar-gas manure (Rs)

B = Gross return from existing practice from value of dung fuel and farmyard manure (Rs)

E = Recurring maintenance expenditure per plant per year (Rs)

R = Net return per plant per year over existing usage from the investment in a gas plant (Rs)

= (A-B-E)

i = Rate of interest (per rupee per annum)

n = Economic life of the plant in years

P_1 = Price of methane gas in Rs per cu ft

P_2 = Price of dung fuel in Rs per kg

P_3 = Price of farmyard manure in Rs per kg

P_4 = Price of gobar-gas manure in Rs per kg

Equations in the model

$$A = P_1 (c) G + P_4 M_2$$

$$B = P_2 (f) D + P_3 (1-f) M_1$$

$$E = \frac{K}{2}$$

$$R = (A-B-E)$$

$$NPV = \text{net present value}$$

$$= \sum^{n} \frac{R}{(1+i)^t} - I$$

$$t = 1$$

$$= \frac{(r^n - 1)}{r^n (r - 1)} R - I$$

where $r = 1 + i$

It may be noted that the multiplier of R is the usual present worth factor, and its reciprocal is known as the capital recovery factor.

Results of cost-benefit analysis

The results in this section have been presented under four different heads, net present value, cost-benefit ratios, pay-back period and internal rate of return.

The net present values or net discounted values (at current rates of interest) of the additional benefits accruing from the use of cow dung gas plants, over and above those derived from traditional usages of cattle dung, for 18 different situations are presented in table A.

The following conclusions may be derived from table A.

First, the NPV values, for any given situation, increase rapidly with plant size. Hence, there are definite economies of scale in the additional benefits derived from cow dung gas plants.

Secondly, for any given plant size, the NPV of additional returns from cow dung gas plants increases; (a) as 'c', the efficiency of gas generation, increases; (b) as 'f', the fraction of cattle dung burnt as fuel increases; and (c) as P_1 the price of cow dung gas/cu ft increases.

While (a) and (c) are obvious, the analysis shows that the burning of dung-cakes as fuel is a most wasteful process, the existing returns (values of B in our notation) being the minimum when f = 1, i.e., when the entire dung is burnt as fuel.

Table A. Net present values of investments in cow dung gas plants for different situations (rounded to the nearest Rs. 10)

Design *Plant size K (cu ft)* *Situation*			*Net present values (Rs)*					
			KVIC				*IARI*	*PRAI*
			60	*100*	*200*	*500*	*100*	*100*
c	*f*	P_1						
0.5	0	t	2 040	3 570	8 930	23 820	4 570	4 170
0.5	0	g	1 850	3 080	7 040	17 910	3 540	3 370
0.5	0	s	1 150	2 070	5 950	16 360	3 070	2 670
0.5	0.3	t	2 470	4 240	10 290	27 130	5 240	4 840
0.5	0.3	g	2 270	3 760	8 390	21 220	4 220	4 050
0.5	0.3	s	1 570	2 750	7 310	19 670	3 750	3 350
0.5	1	t	3 460	5 830	13 460	34 850	6 830	6 430
0.5	1	g	3 260	5 350	11 560	28 940	5 800	5 640
0.5	1	s	2 560	4 340	10 470	27 390	5 340	4 940
0.67	0	t	2 620	4 530	10 860	28 630	5 530	5 130
0.67	0	g	2 360	3 890	8 330	20 760	4 160	4 070
0.67	0	s	1 430	2 540	6 880	18 690	3 540	3 140
0.67	0.3	t	3 040	5 210	12 220	31 940	6 210	5 810
0.67	0.3	g	2 780	4 570	9 690	24 070	4 840	4 750
0.67	0.3	s	1 850	3 220	8 240	22 000	4 220	3 820
0.67	1	t	4 030	6 790	15 380	39 660	7 790	7 390
0.67	1	g	3 770	6 150	12 860	31 790	6 420	6 340
0.67	1	s	2 840	4 800	11 410	29 720	5 800	5 400

Note. Symbols t, g, and s refer to thermal, generation and social costs of cow dung gas.

It may further be inferred that the maximum value of NPV occurs in the situation where

$c = 0.67, f = 1, P_1 = 0.0186$

and its minimum value in the situation where

$c = 0.50, f = 0, P_1 = 0.009.$

For any given plant size, the other values of NPV are intermediate between the values for these two limiting situations.

The benefit-cost ratios for the investment in cow dung gas plants may be worked out simply from the formulae already given for NPV (= benefits – costs) for all the 18 situations. Since this ratio is proportional to R, the trend is exactly parallel to that of the NPV values.

As an illustration we consider a typical situation where

$c = 0.67$, $f = 0.3$, P_1 = social cost of gas (i.e., Rs 9/1,000 cu ft)

The benefit-cost ratios for this situation have been presented in table B.

Table B.

Design	*KVIC*				*IARI*	*PRAI*
Plant-size (cu ft)	60	100	200	500	100	100
Benefit-cost ratios	1.92	2.07	2.96	3.59	3.11	2.59

Table B shows that every rupee invested in, for example, a 100 cu ft/day gas plant gives a return of Rs 2 to Rs 3 depending upon the particular design adopted. The investment becomes more and more remunerative with an increase in the size of the gas plant. The benefit-cost ratios would be higher still with an increase in the unit price of gas.

The pay-back period 'm' or the number of years necessary to wait in which the discounted value of the annual returns becomes equal to the initial capital investment, may also be worked out from the above data. It can be easily shown that 'm' decreases with an increase in plant size, and 'm' decreases with an increase in NPV, so that the minimum value of 'm' corresponds to the maximum value of NPV, and vice versa.

Values of the pay-back period for the typical situation considered earlier, have been presented in table C.

Table C.

Design	*KVIC*				*IARI*	*PRAI*
Plant-size (cu ft)	60	100	200	500	100	100
Pay-back period	7	6	4	3	4	5

As may be expected, due to economies of scale, the pay-back period decreases as the size of the gas plant increases.

The pay-back period also decreases with an increase in the unit price of gas. Thus, for the KVIC gas plant of size 100 cu ft/day, and the price of gas at the rate of Rs 9, Rs 15.50 and Rs 18.60 per 1,000 cu ft, the pay-back period comes to six, five and four years, respectively.

It may further be concluded that the investment in a 100 cu ft gas plant can be recovered in a period of four to six years. This period becomes smaller for gas plants of larger size.

The internal rate of return (IRR) is that rate of interest on capital which equalizes the returns and costs (on the basis of present values) over the life-span of the project. The values of IRR for the investment in cow dung gas plants of different designs and sizes for situation under consideration have been worked out as an illustration and are presented in table D.

Table D.

Design	*KVIC*				*IARI*	*PRAI*
Plant-size (cu ft)	60	100	200	500	100	100
IRR percentage	22.2	24.0	34.7	42.1	36.5	30.3

IRR is seen to increase with the size of gas plant. It can also be shown that, for a given size of gas plant, IRR increases with the value of NPV.

It may be concluded that for a 100 cu ft/day gas plant, the rate of return on the capital investment ranges from 24 to 36 per cent. It would be higher still with a higher unit price of gas than what has been considered here.

Private cost-benefit analysis

It will be observed that the results discussed so far refer to cost-benefit analysis from the commercial point of view, as the dung fuel, the manure and the cow dung gas have all been ascribed a cash value. It may, however, be argued that for an individual farmer, no monetary transactions are involved in the use of dung fuel or gas. The additional comforts and the saving in fuel costs from the use of gas are also, for the most part, non-monetized. We are, therefore, left only with the comparative returns from the manure obtained by the two methods, viz., by the traditional method or by passing the dung through the cow dung gas plant, in order to judge their relative merits. This difference in returns from farmyard manure and gobar gas manure represents the net saving in monetary terms which accrues to the farmer in his cash purchases of fertilizer for his crops. Hence, in order that the farmers may regard the cow dung gas plant as an economically feasible proposition, it follows that the differential returns from manure must cover the annual costs (including maintenance and labour costs) associated with the investment in the gas plant.

Using the same notation and assumptions as given earlier, we consider the average situation, $f = 0.3$, i.e., when 30 per cent of the available dung is diverted to making dung cakes for use as fuel and the rest is converted into manure. The life-span of the gas plant is taken as 20 years and the annual rate of interest as 10 per cent. The capital investment and other costs associated with the gas plant are taken to be the same as before. It follows that

$$P_4 M_2 - P_3(1 - f)M_1$$

must exceed the annual cost of the cow dung gas plant.

The cost-benefit analysis, worked out on the above basis for individual farmer is presented in table E.

Table E. Private cost-benefit analysis for different designs and sizes of cow dung gas plants

Design	*KVIC*				*IARI*	*PRAI*
Plant size (cu ft)	*60*	*100*	*200*	*500*	*100*	*100*
Value of manure from gas plant	666	1 066	2 132	5 196	1 066	1 066
Value of farmyard manure	256	409	818	1 993	409	409
Differential return	410	657	1 314	3 203	657	657
Annual cost of gas plant	329	510	808	1 784	392	439

It may be seen from table E that in each case the differential returns are greater than the annual cost of the cow dung gas plant. We may, thus, conclude that from the individual farmer's point of view also, the cow dung gas plant is an economically viable proposition.

Case study III:
(KVIC, India)

The economics of a 3 m^3 gas plant in India have been worked out by the Khadi and Village Industries Commission as follows:

(a) *Investment*

Cost of installation of the gas plant and manure pits at current increased prices will be about Rs 2537 which break down as under:

Gas holder and frame	Rs	701.00
Piping and stoves	Rs	260.00
Civil construction	Rs	1 576.00
Total	Rs	2 537.00

(b) *Annual expenditure*

		Per year
The interest on investment at 9 per cent	Rs	228.33
Depreciation on gas holder and frame at 10 per cent	Rs	70.10
Depreciation on piping and stoves at 5 per cent	Rs	15.00
Depreciation on structure at 3 per cent	Rs	47.28
Add cost of painting every year	Rs	50.00
Total	Rs	408.71
say Rs 409.00		

(c) *Annual income*

Gas 3 m^3 per day Rs 10 per 29 m^3 (1000 cu ft)	Rs	377.58
Manure (pure gobar manure 7 tonnes but composted with refuse) 16 tonnes at Rs 30 per tonne	Rs	480.00
	Rs	857.58
say Rs 858.00		
Now if the dung is converted to farmyard manure the income will be 11 carts at Rs 15 per cart	Rs	165.00
If it is burnt in the form of cakes the value will be 62.5 quintals at Rs 5.40 per quintal (say)	Rs Rs	337.50 338.00
Thus the surplus in the case of use only as manure Rs (858-165)	Rs	693.00
and in case of use as fuel is Rs (858-538)	Rs	520.00
Against this the cost of depreciation, interest and maintenance is only	Rs	409.00

In the above calculations the 9 per cent interest rate is taken into account while the loan from Commission is interest-free. Moreover the subsidy given by Commission for a gas plant is also included in capital on which interest is calculated.

No labour cost is shown because in all cases labour is involved and is common to all these uses.

Thus it will be seen that construction of a gas plant is actually profitable, quite apart from the incidental advantage of hygienic operation, absence of smoke and soot, convenience in burning and richness of manure.

Case study IV:
(Maya Farms, The Philippines)

Data on a biogas works for a 5000 pig farm at the Maya farms are presented below:

Economics of biogas works for a 5,000 pig farm:

Basic data:

Type of digesters	: Continuous feed, 4 rows
Total digester capacity	: 528 m^3
Total gas holder capacity	: 150 m^3
Retention time	: 25 days
Manure input	: 7,500 kg/day
Manure water:ratio	: 1:1.5 by volume
Product output – biogas	: 450 m^3
Dry sludge	: 1 55,000 m^3/year
Liquid sludge	: 5,370 m^3/year

Cost evaluation:

(a) *Biogas*

Biogas produced per annum 155,000 m^3
Values substituted by biogas 1 m^3
biogas =

(i) LPG (= 0.5 kg at 2 peso/kg)	P	155,000
(ii) Gasoline (= 0.54 litre at P 1.50/litre)	P	125,000
(iii) Diesel fuel (= 0.52 litre at P1.20/ litre)	P	96,720
(iv) Electricity		
a) In urban areas (= 1.5 kWh at P 0.35 kWh)	P	81,375
b) In rural area (= 1.5 kWh at P 0.50 kWh)	P	116,250

(b) *Dry sludge*

(i) As feed material, 274 tons x P 600	P	164,400
(ii) as fertiliser 274 tons x P 100	P	27,400

(c) *Liquid sludge as fertilizer*

5,370 m^3 x P 5.14/m^3	P	27,600

Financial analysis:

(a) *Capital investment*

(i) For pollution control or for pollution control and biogas

a) Biogas plant	P	155,000
b) Sludge treatment unit	P	55,000
Total	P	210,000

(ii) For pollution control, biogas and fertilizer

a) Biogas plant	P	155,000
b) Sludge conditioning unit	P	65,000
Total	P	220,000

(iii) For pollution control, biogas and feeds

a) Biogas plant	P	155,000
b) Sludge conditioning unit	P	65,000
c) Feed processing unit	P	35,000

(b) *Operating expenses:*

(i) For pollution control only, or pollution control and biogas

labour	P	9,400
Interest 17.0 per cent	P	35,700
Depreciation 10.0 per cent	P	21,000
Repair and maintenance	P	3,000
Administrative	P	12,000
Total	P	81,100

(ii) For pollution control biogas, fertiliser and feeds

Labour	P	23,500
Interest	P	43,500
Depreciation	P	25,500
Repair and maintenance	P	8,000
Administrative	P	12,000
Total	P	112,350

(c) *Net operating savings and return on investment:*

(i) Biogas works for pollution control and biogas utilization:

	Net operating savings	*Investment recovery period*
a) LPG substitution	P 73,900	2.8 years
b) Gasoline	P 44,450	4.7 years
c) Diesel	P 15,620	14.4 years
d) Electricity		
i) Suburban	P 275	
ii) Rural	P 35,150	6.0 years

(ii) Biogas works for pollution control, biogas and fertilizer utilization:

	Net operating savings	*Investment recovery period*
a) LPG substitution	P 120,500	1.8 years
b) Gasoline	P 91,050	2.4 years
c) Diesel oil	P 62,220	3.5 years
d) Electricity		
i) Suburban	P 46,875	4.7 years
ii) Rural	P 81,750	2.7 years

(iii) Biogas works for pollution control, biogas, fertilizer and feed utilization:

	Net operating savings	*Investment recovery period*
a) LPG substitution	P 234,650	1.1 years
b) Gasoline	P 205,200	1.2 years
c) Diesel Oil	P 176,370	1.4 years
d) Electricity		
i) Suburban	P 161,025	1.6 years
ii) Rural	P 195,900	1.3 years

It is concluded that biogas works installed at Maya Farms are financially viable.

Case study V:
(Reddy and others 1973)

Assumptions:

1. The costs have been computed for three sizes of the plant: 60,100 and 5,000 cu ft/day.
2. The capital costs have been assumed as Rs 1500, 2500, and 41,000 respectively.
3. A life span of 30 years has been assumed. This is the value suggested by Parikh. This appears reasonable if the plant is made of cement and steel and is painted regularly.
4. 10 per cent interest has been assumed and is reasonable for this type of investment.
5. The plant is expected to be painted once in two years. This will cost approximately Rs 1/2 per cu ft of the plant.
6. An operator is necessary for loading the dung and clearing the slurry into drying beds. It is assumed that one full-time operator would be necessary for operating a 1,000 cu ft plant. In Karnataka, village wages are about Rs 3 per day for unskilled labour.
7. A 10 per cent down time has been assumed for the plant.
8. The sale of fertilizer from the plant will more than offset the cost of dung collection.

Annual capital cost has been worked out using the formula:

$$C = I \frac{i(1-i)n_e}{(1-i)^{n}{}_{e}-1}$$

Where C = annual cost
I = Investment
i = Interest rate
n_e = Life span

Annual maintenance cost has been worked out using the formula

$$M = S \frac{i}{(1-i)^{n}\ m-1}$$

Where S is the sum to be accrued at the end of m^n years for painting

Annual labour cost, L = n_L x W x 365

Where n = number of men required to operate the plant
W = daily wage

Net annual energy capacity/cu ft of gas

E = (135 kcals/cu ft) x (1.163×10^{-3} kWh/kcal) x 365 days) x (0.9 operating duration)
= 51.60 kWh/cu ft

$$\text{Energy rate } e = \frac{(C-M-L-) \times 100}{51.6 \times Q} \text{ paise/kWh where}$$

Q = capacity.

The costs in Rs have been tabulated in the table below:

	60 cu ft/day	100 cu ft/day	5000 cu ft/day
Initial costs	1500.00	2500.00	4 1000.00
Annual costs:			
Capital	160.00	266.00	4360.00
Maintenance cost	28.62	46.62	2381.00
Labour cost	65.80	109.50	5475.00
Sub-total	254.42	423.12	1 2216.00
Energy cost paise (kWh)	8.25	8.2	42.74
Kerosene cost (Rs 1.01/litre, equal burning efficiency) (paise/kWh)		10.6	–
Electricity rate (national average)	–	11	–

Annex IX

METHODS OF ANALYSIS

1. Total residue dried at 103-105°C

Apparatus

(a) Evaporating dishes of 100 ml capacity made of the following materials:

- (i) Porcelain, 90 mm diameter
- (ii) Platinum – generally satisfactory for all purposes
- (iii) Vycor*

(b) Muffle furnace for operation at 550° ±50°C

(c) Steam bath

(d) Drying oven, equipped with a thermostatic control capable of maintaining the temperature within a 2°C range

(e) Desiccator, provided with a desiccant containing a colour indicator of moisture concentration

(f) Analytical balance, 200 g capacity, capable of weighing to 0.1 mg

Procedure

(a) Ignite the clean evaporating dish at 550 ±50°C for 1 hour in a muffle furnace.

(b) Cool, desiccate, weigh and store the dish in a desiccator until ready for use.

(c) Transfer the measured sample to the preweighed dish and evaporate to dryness in a steam bath or in a drying oven. Choose a sample volume that will yield a minimum residue of 25 mg to 250 mg. Estimate the volume from the conductivity. If necessary, add successive portions of sample to the same dish. When evaporating in a drying oven lower the temperature to approximately 98°C to prevent boiling and splattering.

(d) Dry the evaporated sample for at least 1 hour at 103° to 105°C.

(e) Cool the dish in a desiccator and weigh.

(f) Repeat the cycle of drying at 103° to 105°C, cooling, desiccating and weighing until a constant weight is obtained or until loss of weight is less than 4 per cent of the previous weight, or 0.5 mg., which-ever is less.

Calculation:

$$\text{mg/l total residue} = \frac{(A-B) \times 1{,}000}{\text{ml sample}}$$

where A = weight of sample + dish and B = weight of dish.

2. Total nonfiltrable residue dried at 103° – 105°C (total suspended matter)

Apparatus

All of the apparatus needed for "Total residue" above and in addition:

(a) Glass fibre filter disks** without organic binder

(b) Filtration apparatus suitable for the type of filter disk selected

- (i) Filter holder: Gooch crucible adapter or membrane filter funnel
- (ii) Gooch cruicible, 25 ml capacity, for 2.2 cm size glass fibre filter

(c) Suction flask, 500 ml capacity

Procedure

(a) Preparation of glass fibre filter disk: Place the disk either on the membrane filter apparatus or the bottom of a suitable Gooch crucible. Apply vacuum and wash the disk with three successive 20 ml portions of distilled water. Continue suction to remove all traces of water from the disk and discard the washings. Remove the filter from the membrane filter apparatus and transfer to an aluminium or stainless steel planchat as a support. Remove the crucible and filter combination if a Gooch crucible is used. Dry in an oven at 103° to 105°C for 1 hour. Store in desiccator until needed. Weigh immediately before use.

---

* A product of Corning Glass Works, Corning, N.Y.

** Reeve Angel type 934 A, 984 H; Gelman type A; or equivalent

(b) Sample treatment: Since excessive residue on the filter may entrap water and extend the drying time, take for analysis a sample that will yield no more than 200 mg total nonfilterable residue. Under vacuum, filter a 100 ml (or a larger volume if total nonfilterable residue is low) well mixed sample. Carefully remove the filter from the membrane filter funnel assembly, and transfer to an aluminium or stainless steel planchat as a support. Remove the crucible and filter combination from crucible adapter if a Gooch crucible is used. Dry for at least 1 hour at 103° to 105°C, cool in a desiccator, and weigh. Repeat the drying cycle until a constant weight is attained or until weight loss is less than 0.5 mg.

Calculation

$$\text{mg/l total nonfiltrable residue} = \frac{(A-B) \times 1{,}000}{\text{ml sample}}$$

where A = weight of filter + residue and B = weight of filter.

3. Total volatile and fixed residue at 550°C

Apparatus

(a) Evaporating dishes: Dishes of 100-ml capacity made of the following materials:

- (i) Porcelain, 90 mm diameter
- (ii) Platinum – Generally satisfactory for all purposes
- (iii) Vycor

(b) Muffle Furnace for operation at 550° ±50°C

(c) Steam bath

(d) Drying oven, equipped with a thermostatic control capable of maintaining the temperature within a 2°C range

(e) Desiccator, provided with a desiccant containing a color indicator of moisture concentration

(f) Analytical balance, 200 g capacity, capable of weighing to 0.1 mg

(g) Glass fibre filter disks, without organic binder

(h) Filtration apparatus suitable for the type of filter disk selected:

- (i) Filter holder: Gooch crucible adapater or membrane filter funnel
- (ii) Gooch crucible, 25 ml capacity, for 2.2 cm size glass fibre filter

(i) Suction flask, 500 ml capacity

Procedure

Ignite the residue produced by method 1 to constant weight in a muffle furnace at a temperature of 550° ± 50°C. Heat the furnace to required temperature before inserting the sample. (Usually, 15 to 20 minutes of ignition are required.) Allow the dish to cool partially in air until most of the heat has been dissipated and transfer to a desiccator for final cooling in dry atmosphere. Do not overload the desiccator. Weigh the dish as soon as it has cooled completely. Report the loss of weight on ignition as total volatile residue and the weighed residue as total fixed residue.

Calculation

$$\text{mg/l volatile residue} = \frac{(A-B) \times 1{,}000}{\text{ml sample}}$$

$$\text{mg/l fixed residue} = \frac{(B-C) \times 1{,}000}{\text{ml sample}}$$

where A = weight of residue + dish before ignition, B = weight of residue + dish after ignition, and C = weight of dish.

4. Nitrogen

The forms of nitrogen of greatest interest are, in order of decreasing oxidation state are nitrate, nitrite, ammonia, and organic nitrogen. Organic nitrogen is defined functionally as organically bound nitrogen in the oxidation trinegative state. It does not include all organic nitrogen compounds. Analytically, organic nitrogen and ammonia can be determined together and have been referred to as "total nitrogen", a term that reflects the technique used in their determination.

(a) *Nitrogen (ammonia)*

The two major factors that influence the selection of the method to determine ammonia are the concentration and the presence of interferences. In general, direct determination of low concentrations of ammonia is confined to drinking waters, clean surface water, and good-quality wastewater effluent. In other instances and where greater precision is necessary a preliminary distillation step is required. For high ammonia concentrations a distillation and titration technique is preferred.

(i) *Preliminary distillation step*

Apparatus

(a) Distillation apparatus: Arrange a pyrex flask of 800-2,000 ml capacity attached to a vertical condenser so that the outlet tip may be submerged in the receiving boric acid solution. Use an all pyrex apparatus or one with condensing units constructed of block tin or aluminium tubes.

(b) pH meter.

Reagents

(a) Ammonia-free water: Prepare by ion-exchange or distillation methods.

(i) Ion exchange: Prepare ammonia-free water by passing distilled water through an ion-exchange column containing a strongly acidic cation-exchange resin mixed with a strongly basic anion-exchange resin. Select resins that will remove organic compounds that subsequently interfere with the ammonia determination. Regenerate the column according to the instructions of the manufacturer.

(ii) Distillation: Eliminate traces of ammonia in distilled water by adding 0.1 ml concentrated H_2SO_4 to 1 l distilled water and redistilling. Alternatively, treat distilled water with sufficient bromine or chlorine water to produce a free halogen residual of 2 to 5 mg/l and redistill after standing at least 1 hour. Discard the first 100 ml distillate. Check the redistilled water for the possibility of a high blank.

Since it is virtually impossible to store ammonia-free water in the laboratory without contamination from ammonia fumes, prepare fresh for each batch of samples. Prepare all reagents with ammonia free water.

(b) Borate buffer solution: Add 88 ml 0.1 N NaOH solution to 500 ml 0.025 M sodium tetraborate ($Na_2B_4O_7$) solution (5.0 g $Na_2B_4O_7$ or 9.5 g $Na_2B_4O_7 10H_2O/1$) and dilute to 1 l.

(c) Sodium hydroxide, 6N: Dissolve 240 g NaOH in 1 l ammonia-free distilled water.

(d) Dechlorinating agent, N/70 Use 1 ml of any of the following reagents to remove 1 mg/l of residual chlorine in 500 ml sample. Prepare the unstable thiosulphate and sulphite solutions fresh.

(i) Phenylarsine oxide- Dissolve 1.2 g C_6H_5AsO in 200 ml 0.3 N NaOH solution, filter if necessary, and dilute to 1 l with ammonia-free water. (Caution: Toxic – take care to avoid ingestion.)

(ii) Sodium arsenite – Dissolve 1.0 g Na AsO_2 in ammonia-free water and dilute to 1 l. (Caution: Toxic – take care to avoid ingestion.)

(iii) Sodium sulphite- Dissolve 0.9 g $Na_2 SO_3$ in ammonia-free water and dilute to 1 l.

(iv) Sodium thiosulphate – Dissolve 3.5 g $Na_2S_2O_3 \cdot 5H_2O$ in ammonia-free water and dilute to 1 l.

(e) Neutralization agent: Prepare with ammonia-free water:

(i) Sodium hydroxide, NaOH, 1N

(ii) Sulphuric acid, H_2SO_4, 1N.

(f) Absorbent solution: Dissolve 20 g H_3BO_3 in ammonia-free water and dilute to 1 l.

Procedure

(a) Preparation of equipment: Add 500 ml ammonia-free water, 20 ml borate buffer, and adjust pH to 9.5 with 6N NaOH solution. Add a few glass beads or boiling chips and use this mixture to steam out the distillation apparatus until the distillate shows no traces of ammonia.

(b) Sample preparation: Use a 500-ml sample or a portion diluted to 500 ml with ammonia-free water. When the ammonia nitrogen content is less than 100 μg/l use a sample volume of 1,000 ml. Remove the residual chlorine in the sample by adding dechlorinating agent equivalent to the chlorine residual. If necessary, neutralize the sample to approximately pH 7 with the dilute acid or base, using a pH meter.

(c) Add 25 ml borate buffer and adjust pH to 9.5 with 6N NaOH using a pH meter or short-range pH paper.

(d) Distillation: To minimize contamination, leave the entire distillation apparatus assembled after the steaming out process until just before starting the sample distillation. Disconnect the steaming-out flask and immediately transfer the sample flask to the distillation apparatus. Distil at a rate of 6 to 10 ml/min with the tip of delivery tube submerged. Collect the distillate in a 500 ml Erlenmeyer flask containing 50 ml boric acid. Collect at least 300 ml distillate. Lower the collected distillate free of contact with the delivery tube and continue distillation during the last minute or two to cleanse the condenser and delivery tube. Dilute to 500 ml with ammonia-free water.

(e) Determine the ammonia by the nesslerization method; the phenate method, or acidimetric method.

(ii) *Nesslerization method (direct and following distillation)*

Apparatus

(a) Colorimetric equipment: one of the following is required:

(i) Spectrophotometer, for use at 400 to 500 nm and providing a light path of 1 cm or longer.

(ii) Filter photometer, providing a light path of 1 cm or longer and equipped with a violet filter having maximum transmittance at 400 to 425 nm. A blue filter can be used for higher ammonia nitrogen concentrations.

(iii) Nessler tubes, matched, 50 ml, tall form.

(b) pH meter, equipped with a high pH electrode.

Reagents

All the reagents listed under "Preliminary distillation", except the borate buffer and absorbent solution are required, plus the following (prepare all reagents with ammonia-free water):

(a) Zinc sulphate solution: Dissolve 100 g $ZnSO_4 \cdot 7H_2O$ and dilute to 1 l.

(b) Stabilizer reagent: Use either EDTA or Rochelle salt to prevent calcium or magnesium precipitation in undistilled samples following the addition of the alkaline nessler reagent.

(i) EDTA reagent: dissolve 50 g disodium ethylenediamine tetracetate dihydrate, also called (ethylenedinitrilo) tetracetic acid disodium salt, in 60 ml water containing 10 g NaOH. If necessary apply gentle heat to complete disolution. Cool to room temperature and dilute to 100 ml.

(ii) Rochelle salt solution: dissolve 50 g potassium sodium tartrate tetrahydrate, $KNaC_4H_4O_6 \cdot 4H_2O$, in 100 ml water. Remove ammonia usually present in the salt by boiling off 30 ml of solution. After cooling, dilute to 100 ml.

(c) Nessler reagent: Dissolve 100 g HgI_2 and 70 g KI in a small quantity of water and add this mixture slowly, stirring, to a cool solution of 160 g NaOH in 500 ml water. Dilute to 1 l. Store in rubber-stoppered pyrex glass-ware and out of sunlight to maintain reagent stability for periods up to one year under normal laboratory conditions. Check the reagent to make sure that it yields the characteristic color with 100-μg/l ammonia nitrogen within 10 minutes after addition and does not produce a precipitate with small amounts of ammonia within two hours. (Caution: Toxic – take care to avoid ingestion.)

(d) Stock ammonium solution: Dissolve 3.819 g anhydrous NH_4Cl, dried at 100 C, in water, and dilute to 1,000 ml; 1.00 ml=1.00 mg N=1.22 mg NH_3.

(e) Standard ammonium solution: Dilute 10.00 ml stock ammonium solution to 1,000 ml with water; 1.00 ml = 10.0 μg N=12.2 μg NH_3.

(f) Permanent colour solutions:

(i) Potassium chloroplatinate solution: Dissolve 2.0 g K_2PtCl_6 in 300 to 400 ml distilled water; add 100 ml concentrated HCl and dilute to 1 l.

(ii) Cobaltous chloride solution: Dissolve 12.0 g $CoCl_2 \cdot 6H_2O$ in 200 ml distilled water. Add 100 ml concentrated HCl and dilute to 1 l.

Procedure

(a) Treatment of undistilled samples: If necessary, remove the residual chlorine of the sample with an equivalent amount of N/70 dechlorineting agent. Add 1 ml $ZnSO_4$ solution to 100 ml sample and mix thoroughly. Add 0.4 to 0.5 ml NaOH solution to obtain a pH of 10.5, as determined with a pH meter and a high-pH glass electrode and mix thoroughly. Let the treated sample stand for a few minutes, whereupon a heavy flocculent precipitate should fall, leaving a clear and colourless supernate. Clarify by centrifusion or filtering. Pretest any filter paper used to be sure no ammonia is present as a contaminant. Do this by running ammonia-free water through and testing the filtrate by nesslerization. Filter the sample, discarding the first 25 ml filtrate.

(b) Colour development:

(i) Undistilled samples: Use 50.0 ml sample or a portion diluted to 50.0 ml with ammonia-free water. If the undistilled portion contains sufficient concentrations of calcium, magnesium, or other ions that produce a turbidity or precipitate with nessler reagent, add 1 drop (0.05 ml) EDTA reagent or 1 to 2 drops (0.05 to 0.1 ml) Rochelle salt solution. Mix well. Add 2.0 ml nessler reagent if EDTA reagent is used, or 1.0 ml nessler reagent if Rochelle salt is used.

(ii) Distilled samples – Neutralize the boric acid used for absorbing the ammonia distillate in one of two ways. Add 2 ml nessler reagent, an excess that raises the alkalinity to the desired high level. Alternatively, neutralize the boric acid with NaOH before adding 1 ml nessler reagent.

(iii) Mix the samples by capping the nessler tubes with clean rubber stoppers (which have been washed thoroughly with ammonia-free water) and then inverting the tubes at least six times. Keep such experimental conditions as temperature and reaction time the same in the blank, samples and standards. Let the reaction proceed for at least 10 minutes after addition of the nessler reagent. Read the colour in the sample and in the standards. If the ammonia nitrogen is very low use a 30-minute contact time for sample, blank and standards. Measure the colour either photometrically or visually as directed in (c) or (d) below:

(c) Photometric measurement: Measure the absorbance or transmittance in a spectrophotometer or a filter photometer. Prepare the calibration curve at the same temperature and reaction time used for the samples. Make the transmittance readings against a reagent blank and run parallel checks frequently against standards in the nitrogen range of the samples. Redetermine the complete calibration curve for each new batch of nessler reagent. For distilled samples, prepare the standard curve under the same conditions as the samples. Distil the reagent blank and appropriate standards – each diluted to 500 ml – in the same manner as the samples. Treat the 300 ml distillate and 50 ml in the same manner as the samples. Bring the 300 ml distillate and 50 ml boric acid absorbant to 500 ml and take a 50-ml portion for nesslerization.

(d) Visual comparison: Compare the colours produced in the sample against those of the ammonia standards. Prepare temporary or permanent standards as directed below:

(i) Temporary standards: Prepare a series of visual standards in nessler tubes by adding the following volumes of standard NH_4Cl solution and diluting to 50 ml with ammonia-free water; 0, 0.2, 0.4, 0.7, 1.0, 1.4, 1.7, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0 and 6.0 ml. Nesslerize the standards and the portions of distillate by adding 1.0 ml nessler reagent to each tube and mixing well.

(ii) Permanent standards can be prepared using potassium chloroplatinate and cobaltous chloride solution.

Calculation

(a) Deduct the amount of nitrogen in the ammonia-free water used for diluting the original sample before computing the final nitrogen value.

(b) Deduct also the reagent blank for the volume of borate buffer and 6N NaOH solutions used with the sample.

(c) Compute the total ammonia nitrogen by the following equation.

$$\text{mg/l ammonia N} = \frac{A}{\text{ml Sample}} \times \frac{B}{C}$$

where A = µg N found colorimetrically, B = total distillate collected, including the acid absorbent and C = ml distillate taken for nesslerization. The ratio B/C applies only to the distilled samples and should be ignored in direct nesslerization.

(iii) *Phenate method*

Apparatus

(a) Colorimetric equipment: one of the following is required:

(i) Spectrophotometer, for use at 630 nm with a light path of approximately 1 cm.

(ii) Filter photometer, equipped with a red-orange filter having a maximum transmittance near 630 nm and providing a light path of approximately 1 cm.

(b) Magnetic stirrer.

Reagents

(a) Ammonia-free water: Prepare as directed in "Preliminary distillation."

(b) Hypochlorous acid reagent: To 40 ml distilled water add 10 ml 5 per cent commercial bleach. Adjust pH to 6.5 to 7.0 with HCl. Prepare this unstable reagent weekly.

(c) Manganese sulphate solution. 0.003 M: Dissolve 50 mg $MnSO_4 . H_2O$, in 100 ml distilled water.

(d) Phenate reagent: Dissolve 2.5 g NaOH and 10 g phenol, C_6H_5OH, in 100 ml ammonia-free water. Because this reagent darkens on standing, prepare weekly.

(e) Stock ammonium solution: Dissolve 381.9 mg anhydrous NH_4Cl, dried at 100 C, in ammonia-free water and dilute to 1,000 ml; 1.00 ml=100 µg N= 122 µg NH_3.

(f) Standard ammonium solution: Dilute 5.00 ml stock ammonium solution to 1,000 ml with ammonia-free water; 1.00 ml =0.500 µg N=0.610 µg NH_3.

Procedure

To a 10.0-ml sample in a 50-ml beaker, add 1 drop (.05 ml) $MnSO_4$ solution. Place on a magnetic stirrer and add 0.5 ml hypochlorous acid solution. Immediately add, a drop at a time, 0.6 ml phenate reagent. Add the reagent without delay using a bulb pipet for convenient delivery. Mark the pipet for hypochlorous acid at the 0.5 ml level and deliver the phenate reagent from a pipet that has been calibrated by counting the number of drops previously found to be equivalent to 0.6 ml. Stir vigorously during addition of the reagents. Because the colour intensity is affected somewhat by the age of the reagents, carry a blank and a standard through the procedure along with each batch of unknowns. Measure absorbance using the reagent blank to zero the spectrophotometer. Colour formation is complete in 10 minutes and is stable for at least 24 hour. Although the blue colour has a maximum absorbance at 630 nm, satisfactory measurements can be made in the 600-660 nm region. Prepare a calibration curve in the ammonia nitrogen range of 0.1 to 5 µg, treating the standards exactly as the sample throughout the procedure.

Calculation

Beer's law governs. Calculate the ammonia concentration as follows:

$$\text{mg/l ammonia N} = \frac{A \times B}{C \times S} \times \frac{D}{E}$$

where: A = absorbance of sample, B = μg ammonia nitrogen in standard taken, and C = Absorbance of standard, S = ml unknown water sample used. D = total distillate collected, including the acid absorbent and E = ml distillate used for colour development.

The ratio D/E applies only to the distilled samples.

(iv) *Acidimetric method*

Apparatus Distillation apparatus as per section 4 (a) (i) above.

Reagents

(a) Mixed indicator solution: Dissolve 200 mg methyl red indicator in 100 ml 95 per cent methyl or isopropyl alcohol. Dissolve 100 mg methylene blue in 50 ml 95 per cent ethyl or isopropyl alcohol. Combine the two solutions. Prepare monthly.

(b) Indicating boric acid solution: Dissolve 20 g H_3BO_3 in ammonia-free distilled water, add 10 ml mixed indicator solution and dilute to 1 1. Prepare monthly.

(c) Standard sulphuric acid titrant: 0.02N: Dilute 200.00 ml 0.1000N standard acid to 1000 ml with distilled or deionized water. Standardize by potentiometric titration of 15.00 ml 0.05 N Na_2CO_3. For greatest accuracy, standardize the titrant against an amount of sodium carbonate that has been incorporated in the indicating boric acid solution to reproduce the actual conditions of the sample titration. If the acid is 0.0200N, 1.00 ml = 280 μg/l.

Procedure

(a) Proceed as described in the "Preliminary distillation" step using indicating boric acid solution as an absorbent for the distillate.

(b) Sludge or sediment samples: Rapidly weigh to within ± 1 per cent a wet sample containing approximately 1g dry solids, in a weighing bottle or crucible. Wash the sample into a 500 ml Kjeldahl flask with ammonia-free distilled water and dilute to 250 ml. Proceed as in (a) but add a piece of paraffin wax to the distillation flask and collect only 100 ml distillate.

(c) Titrate the ammonia in the distillate with standard 0.02N H_2SO_4 titrant until the indicator turns a pale lavender.

(d) Blank: Carry a blank through all the steps of the procedure and apply the necessary correction to the results.

Calculation

$$\text{mg/l ammonia N} = \frac{(A-B) \times 280}{\text{ml sample}}$$

where A = ml H_2SO_4 titration sample and B = ml H_2SO_4 titration blank.

5. Phosphate

(a) **Preliminary digestion steps for total phosphorus**

(i) *Perchloric acid digestion*

Apparatus

(a) Hot plate: A 30 x 50 cm heating surface is adequate.

(b) Safety shield

(c) Safety goggles

(d) Conical flasks, 125 ml, acid-washed and rinsed with distilled water.

(e) Porcelain evaporating dishes, acid-washed and rinsed in distilled water.

Reagents

(a) Nitric acid, HNO_3 concentrate.

(b) Perchloric acid, $HClO_4 . 2H_2O$, purchased as 70 to 72 per cent $HClO_4$, reagent grade.

(c) Sodium hydroxide, NaOH, 6N.

(d) Methyl orange indicator solution.

Procedure

(a) Caution: Heated mixtures of $HClO_4$ and organic matter may explode violently. Avoid this hazards by taking the following precautions:

(i) Do not add $HClO_4$ to a hot solution that may contain organic matter; (ii) Always pretreat samples containing organic matter with HNO_3 before addition of $HClO_4$; (iii) Use a mixture of HNO_3 and $HClO_4$ in starting the digestion step; (iv) Avoid repeated fumings with perchloric acid in ordinary hoods. For routine operations, use hoods of all-stone or asbestoscement. For occasional work with $HClO_4$, connect a water pump to a glass fume eradicator; (v) Never let samples being digested with $HClO_4$ evaporate to dryness.

(b) Measure out a sample containing the desired amount of phosphate (this will be determined by the method to be used for the colorimetric finish). Acidify to methyl orange with concentrated HNO_3, add another 5 ml concentrated HNO_3, and evaporate on a steam bath or hot plate to 15 to 20 ml, covering the vessel with a watch glass when necessary to avoid loss of material by spattering. Place an infrared lamp over the sample to hasten evaporation if desired.

(c) Transfer the evaporated sample to a 125 ml conical flask using 5 ml concentrated HNO_3 and 10 ml 70 to 72 per cent $HClO_4$. After adding a few boiling chips, heat on a hot plate and evaporate gently until dense white fumes of $HClO_4$ just appear. If the solution is not clear at this point, cover the neck of the flask with a watch glass and keep the solution just barely boiling until it clears. If necessary, add 10 ml more HNO_3 to aid the oxidation.

(d) Cool the digested solution and add 1 drop aqueous phenolphthalein solution. Neutralize with 6N NaOH solution. If necessary, filter the neutralized solution, washing the filter liberally with distilled water. Make up to 100 ml with distilled water.

(e) Determine the orthophosphate of the treated sample by either of the methods given below.

(f) Prepare a calibration curve by carrying a series of standards containing orthophosphate (see methods given below) through the digestion step. Do not use orthophosphate standards without treatment, because the salts added in digestion cause an increase in the colour intensity in some methods.

(ii) *Sulphuric acid-nitric acid digestion*

Apparatus

(a) Digestion rack: An electrically or gas-heated digestion rack with provision for withdrawal of fumes is recommended. Digestion racks typical of those used for micro-Kjeldahl digestions are suitable.

(b) Micro-Kjeldahl flasks.

Reagents

(a) Sulphuric acid, H_2SO_4 concentrate

(b) Nitric acid, HNO_3 concentrate

(c) Phenolphthalein indicator solution

(d) Sodium hydroxide, NaOH, 1N

Procedure

(a) Into a micro-Kjeldahl flask, measure a sample containing the desired amount of phosphate (this is determined by the method used for the colorimetric finish). Add 1 ml concentrated H_2SO_4 and 5 ml concentrated HNO_3.

(b) Digest the sample to a volume of 1 ml and then continue the digestion until the solution becomes colourless in order to remove HNO_3.

(c) Cool and add approximately 20 ml distilled water, 1 drop phenolphthalein indicator, and as much 1N NaOH solution as required to produce a faint pink tinge in the solution. Transfer the neutralized solution, filtering if necessary to remove particulate material or turbidity, into a 100-ml volumetric flask. Add the filter washings to the flask and adjust the sample volume to 100 ml with distilled water.

(d) Determine the phosphorus present by either of the methods given below for which a separate calibration curve has been constructed by carrying standards through the acid digestion procedure described above.

(iii) *Persulphate digestion*

Apparatus

(a) Hot plate: A 30 x 50-cm heating surface is adequate.

(b) Autoclave: An autoclave or pressure cooker capable of developing 1 to 1.4 kg/cm^2 (15 to 20 psi) may be used in place of a hot plate.

(c) Glass scoop: To hold approximately 0.4 g ammonium persulphate.

Reagents

(a) Phenolphthalein indicator solution.

(b) Sulphuric acid solution: Carefully add 300 ml concentrated H_2SO_4 to approximately 600 ml distilled water and then dilute to 1 l with distilled water.

(c) Ammonium persulphate, solid.

(d) Sodium hydroxide, Na OH, 1 N.

Procedure

(a) Use 50 ml or a suitable portion of thoroughly mixed sample. Add 1 drop (0.05 ml) phenolphthalein indicator solution. If a red colour develops, add H_2SO_4 solution dropwise the colour is just discharged. Then add 1 ml H_2SO_4 solution and 0.4 g solid ammonium persulphate.

(b) Boil gently on a preheated hot plate for 30 to 40 minutes or until a final volume of 10 ml is reached. Cool, dilute to 30 ml with distilled water, add 1 drop (0.05 ml) phenolphthalein indicator solution, and neutralize to a faint pink colour with NaOH solution. Alternatively, heat for 30 minutes in an autoclave or pressure cooker at 1.0 to 1.4 kg/cm^2 (15 to 20 psi). Cool, add 1 drop (0.05 ml) phenolphthalein indicator solution and neutralize to a faint pink colour with NaOH solution. Make up to 100 ml with distilled water. In some samples a precipitate may form at this stage. Do not filter. For any subdividing of the sample after this stage, shake the sample well. The precipitate (which is possibly a calcium phosphate) will redissolve under the acid conditions of the colorimetric phosphate test. Determine the phosphate present by either of the methods for which a separate calibration curve has been constructed by carrying the standards through the persulphate digestion procedure.

(b) Vanadomolybdophosphoric acid colorimetric method

Apparatus

(a) Colorimetric equipment: Visual comparison in nessler tubes is not recommended because the sensitivity of the method is dependent on the wavelength used. One of the following is required.

(i) Spectrophotometer, for use at approximately 400 to 470 nm.

(ii) Filter photometer, provided with a blue or violet filter exhibiting maximum transmittance between 400 to 470 nm.

The wavelength at which colour intensity is measured depends on the sensitivity desired, because the sensitivity varies tenfold with wavelengths from 400 to 490 nm. Ferric iron causes interference at low wavelengths, particularly at 400 nm. A wavelength of 470 nm is usually used. Concentration ranges for different wavelengths are:

Range mg/lP	*Wavelength nm*
1.0 – 5.0	400
2.0 – 10	420
4.0 – 18	470

(b) Acid-washed glassware: Use acid-washed glassware for determining low concentrations of phosphate. Phosphate contamination is common because of its adsorption on glass surfaces. Avoid using commercial detergents containing phosphate. Clean all glassware with hot dilute HCl and rinse well with distilled water. Alternatively, fill the glassware with concentreted H_2SO_4, let stand overnight and then rinse thoroughly, preferably reserve the glassware only for the determination of phosphate, and after use wash it and keep it filled with water until needed. If this is done, the acid treatment is required only occasionally.

Reagents

(a) Phenolphthalein indicator solution.

(b) Hydrochloric acid, HCl, concentrated.

(c) Activated carbon.

(d) Vanadate-molybdate reagent:

(i) Solution A: Dissolve 25 g ammonium molybdate, $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$ in 400 ml distilled water.

(ii) Solution B: Dissolve 1.25 g ammonium metavanadate, NH_4VO_3 by heating to boiling in 300 ml distilled water. Cool and add 330 ml concentrated HCl.

Cool Solution B to room temperature, pour Solution A into solution B, and dilute to 1 l.

Note: H_2SO_4, $HClO_4$, or HNO_3 may be substituted for HCl. The acid concentration in the determination is not critical but a final sample concentration of 0.5 N is recommended.

(e) Standard phosphate solution: Dissolve in distilled water 219.5 mg anhydrous potassium dihydrogen phosphate, KH_2PO_4, and dilute to 1,000 ml; 1.00 ml = 50.0 μg PO_4 – P.

Procedure

(a) Sample pH adjustment: If the pH of the sample is between 4 and 10, no adjustment is necessary. If the pH is less than 4, dilute 50 ml to 100 ml in a volumetric flask with distilled water and mix thoroughly. Use this dilute sample in the following steps. If the pH is greater than 10, add 1 drop phenolphthalein indicator to 50.0 ml sample and discharge the red colour with concentrated HCl before diluting to 100 ml. (Dilution also is useful when concentrations greater than 15 mg PO_4–P/l are present. When dilutions are made, correctly interpret "ml sample" in the calculation as the volume of original (undiluted) sample contained in the portion taken for the colour development (step (c) below).

(b) Colour removal from sample: Remove any excessive colour present in the sample by shaking about 50 ml sample with 200 mg activated carbon in an Erlenmeyer flask for five minutes, then filtering the sample through filter paper to remove the carbon. Check each batch of carbon for phosphate because some batches produce high reagent blanks.

(c) Colour development in sample. Place 35 ml or less of the sample, containing 50 to 1,000 μg P, in a 50 ml volumetric flask. Add 10 ml vanadate-molybdate reagent and dilute to the mark with distilled water. Prepare a blank in which 35 ml distilled water is substituted for the sample. Ten minutes or more after adding the vanadate-molybdate reagent, measure the transmittance of the sample versus the blank at a wavelength of 400 to 490 nm, depending on the sensitivity desired. The colour is stable for days and its intensity is unaffected by variations in room temperature.

(d) Preparation of calibration graph: Prepare a calibration curve by using suitable volumes of standard phosphate solution and proceeding as in (c). When the ferric level is low enough not to interfere, plot a family of calibration curves of one series of standard solutions for various wavelengths. This permits a wide latitude of concentrations in one series of determinations. Analyse at least one standard with each set of samples.

Calculation

$$\text{mg/lp} = \frac{\text{mg P} \times 1{,}000}{\text{ml sample}}$$

(c) **Stannous chloride method**

Apparatus

The same apparatus is required as for the previous method, except when the extraction step is used, in which case a safety aspirator also is required. Set the spectrophotometer at 625 nm in the measurement of benzene-isobutanol extracts, and at 690 nm for aqueous solutions. Use a wavelength of 650 nm for the aqueous solutions, with somewhat reduced sensitivity and precision, if the instrument is not equipped to read at 690 nm.

Reagents

(a) Phenolphthalein indicator solution.

(b) Strong acid solution: Slowly add 300 ml concentrated H_2SO_4 to about 600 ml distilled water. When cool, add 4.0 ml concentrated HNO_3 and dilute to 1 l.

(c) Ammonium molybdate reagent I: Dissolve 25 g $(NH_4)_6Mo_7O_{24}.4H_2O$ in 175 ml distilled water. Cautiously add 280 ml concentrated H_2SO_4 to 400 ml distilled water. Cool, add the molybdate solution, and dilute to 1 l.

(d) Stannous chloride reagent I: Dissolve 2.5 g of fresh $SnCl_2.2H_2O$ in 100 ml glycerol. Heat in a water bath and stir with a glass rod to hasten dissolution. This reagent is stable and requires neither preservatives nor special storage.

(e) Standard phosphate solution: As in the previous method.

(f) Reagents for extraction:

(i) Benzene-isobutanol solvent: Mix equal volumes of benzene and isobutyl alcohol. (Caution: This solvent is highly flammable)

(ii) Ammonium molybdate reagent II: Dissolve 40.1 g $(NH_4)_6Mo_7O_{24}.4H_2O$ in approximately 500 ml distilled water. Slowly add 396 ml molybdate reagent I. Cool and dilute to 1 l.

(iii) Alcoholic sulphuric acid solution: Cautiously add 20 ml concentrated H_2SO_4 to 980 ml methyl alcohol with continuous mixing.

(iv) Dilute stannous chloride reagent II: Mix 8 ml stannous chloride reagent I with 50 ml glycerol. This reagent is stable for at least six months.

Procedure

(a) Preliminary sample treatment: To a 100-ml sample containing not more than 0.2 mg P and free from colour and turbidity, add 0.05 ml (1 drop) phenolphthalein indicator. If the sample turns pink, add strong acid solution dropwise to discharge the colour. If more than 0.25 ml (5 drops) is required, take a smaller sample and dilute to 100 ml with distilled water after first discharging the pink colour with acid.

(b) Colour development: Add, with thorough mixing after each addition, 4.0 ml molybdate reagent I and 0.5 ml (10 drops) stannous chloride reagent I. The rate of colour development and the intensity of colour depend on the temperature of the final solution each 1°C increase producing about 1 per cent increase in colour. Hence, samples, standards, and reagents should be within 2°C of one another and in the temperature range between 20° and 30°C.

(c) Colour measurement: After 10 minutes but before 12 minutes, using the same specific interval for all determinations, measure the colour photometrically at 690 nm and compare with a calibration curve, using a distilled water blank. Light path lengths suitable for various concentration ranges are as follows.

Approximate P range μg/l	*Light path cm*
0.3 – 2	0.5
0.1 – 1	2
0.007 – 0.2	10

Always run a blank on the reagents and distilled water. Inasmuch as the colour at first develops progressively and later fades, maintain equal timing conditions for samples as for standards. Prepare at least one standard with each set of samples or once each day the tests are made. The calibration curve may deviate from a straight line at the upper concentrations of the 300-2,000-μg/l range.

(d) Extraction: When increased sensitivity is desired or interferences must be overcome, extract the phosphate as follows: Pipet a suitable portion into a 100 ml graduated extraction cylinder and dilute, if necessary, to 40 ml with distilled water. Add 50.0 ml benzene-isobutanol solvent and 15.0 ml molybdate reagent II. Close container at once and shake vigorously for exactly 15 seconds. If polyphosphate is present, any delay will increase the amount of it that will be included in the orthophosphate value. Remove the stopper and withdraw 25.0 ml of separated organic layer, using a pipet and a safety aspirator. Transfer to a 50-ml volumetric flask, and 15 to 16 ml alcoholic sulphuric acid solution, swirl, add 0.50 ml (10 drops) dilute stannous chloride reagent II, swirl, and dilute to the mark with alcoholic sulphuric acid, Mix thoroughly. After 10 minutes but before 30 minutes read against the blank at 625 nm. Prepare the blank by carrying 40 ml distilled water through the same procedure used for the sample. Read the PO_4 concentration from a calibration curve prepared by taking known phosphate standards through the same procedural steps used for the samples.

Calculation

Calculate the results from the direct and the extraction procedures by the following equation:

$$\text{mg/l P} = \frac{\text{mg P} \times 1{,}000}{\text{ml sample}}$$

(d) Ascorbic acid method

Apparatus

(a) Colorimetric equipment: one of the following is required:

(i) Spectrophotometer, with infrared phototube for use at 880 nm. providing a light path of 2.5 cm (1 in.) or longer.

(ii) Filter photometer, equipped with a red colour filter and a light path of 0.5 cm or longer.

(b) Acid-washed glassware: See "Vanado molybdophosphoric colorimetric method".

Reagents

(a) Sulphuric acid solution 5N: Dilute 70 ml concentrated H_2SO_4 with distilled water to 500 ml.

(b) Potassium antimonyl tartrate solution: Dissolve 1.3715 g K (SbO) $C_4H_4O_6.1/2\ H_2O$ in 400 ml distilled water in a 500 ml volumetric flask and dilute to volume. Store in a glass-stoppered bottle.

(c) Ammonium molybdate solution. Dissolve 20 g $(NH_4)_6Mo_7O_{24}.4H_2O$ in 500 ml distilled water. Store in a plastic bottle at 4°C.

(d) Ascorbic acid, 0.1M: Dissolve 1.76 g ascorbic acid in 100 ml distilled water. The solution is stable for about 1 wk at 4°C.

(e) Combined reagent: Mix the above reagents in the following proportions for 100 ml of the combined reagent: 50 ml 5N H_2SO_4, 5 ml potassium antimonyl tartrate solution, 15 ml ammonium molybdate solution, and 30 ml ascorbic acid solution. Mix after addition of each reagent. All reagents must reach room temperature before they are mixed and must be mixed in the order given. If turbidity forms in the combined reagent, shake and let it stand for a few minutes until the turbidity disappears before proceeding. The reagent is stable for four hours.

(f) Stock phosphate solution: See "Vanadomolybdophosphoric method".

(g) Standard phosphate solution: Dilute 50.0 ml stock phosphate solution to 1,000 ml with distilled water; 1.00 ml = 2.50 μg P.

Procedure

(a) Treatment of sample: Pipet 50.0 ml sample into a clean dry test tube or 125 ml Erlenmeyer flask. Add 1 drop phenolphthalein indicator. If a red colour develops add 5N H_2SO_4 solution dropwise so the colour is just discharged. Add 8.0 ml combined reagent and mix thoroughly. After at least 10 minutes but no longer than 30 minutes, measure the colour absorbance of each sample at 880 nm, using the reagent blank as the reference solution.

(b) Correction for turbidity or interfering colour: The natural colour of water generally does not interfere at the high wavelength used. In the case of highly coloured or turbid waters, prepare a blank by adding all the reagents except ascorbic acid and antimonyl potassium tartrate to the sample. Subtract the absorbance of the blank from the absorbance of each of the unknown samples.

(c) Preparation of calibration curve: Prepare individual calibration graphs from a series of six standards within the expected phosphate ranges. Use a distilled water blank with the combined reagent to make the photometric readings for the calibration curve. Plot absorbance vs phosphate concentration to give a straight line passing through the origin. Test at least one phosphate standard with each set of samples.

Calculation

$$\text{mg/l p} = \frac{\text{mg P} \times 1{,}000}{\text{ml sample}}$$

6. Steam distillation method for volatile acids

Apparatus

(a) Steam generator: 1l capacity, with a safety tube and a steam bypass valve.

(b) Distillation flask, 1 l.

(c) Condenser, at least 76 cm (30 in.) long.

(d) Receiving flask, provided with a soda-lime tube to protect the distillate from air.

(e) Buchner funnel, 14 cm (5.5 in.), with suction.

Reagents

(a) Sulphuric acid, H_2SO_4, 1+1,

(b) Ferric chloride solution: Dissolve 82.5 g $FeCl_3 . 6H_2O$ in 1 l distilled water.

(c) Diatomaceous-silica filter aid.

(d) Magnesium sulphate: $Mg SO_4 . 7H_2O$.

(e) Standard sodium hydroxide titrant, 0.1/N

(f) Phenolphthalein indicator solution.

Procedure

Adjust a sample, 200 to 1,000 ml, to pH 3.5 with 1 + 1 H_2SO_4. Add 6 ml $FeCl_3$ solution/l sample (equivalent to 500 mg l); add 50 g filter aid/l. Mix well. Filter by suction, using a Buchner funnel containing a filter paper freshly coated with a thin layer of filter aid. Wash the residue thoroughly three or four times with water and adjust the filtrate to pH 11 with NaOH solution. Concentrate by evaporation to 150 ml and cool in a refrigerator.

Adjust the cooled filtrate to pH 4 with 1 + 1 H_2SO_4 and add it quantitatively and quickly to the distilling flask. Add $MgSO_4$ to slight excess of saturation. Apply heat with a small flame to the flask until rapid evolution of volatile acids commences. This will prevent excessive increase in the volume of the mixture. Steam distil slowly so that about 200 ml of distillate will be collected in 25 minutes. Increase the rate of distillation and continue until a total of 600 ml is collected. By careful control of the steam rate, excessive foaming can be prevented readily.

Titrate the distillate with 0.1 N NaOH, using phenolphthalein indicator.

Calculation

$$\begin{array}{l}\text{mg/l volatile acids}\\ \text{as acetic acid}\end{array} = \frac{\text{ml NaOH} \times 6{,}000}{\text{ml sample}}$$

7. Biochemical oxygen demand (BOD)

Apparatus

(a) Incubation bottles, of 250-300 ml capacity with ground-glass stoppers. Clean bottles with a good detergent, rinse thoroughly, and drain before use. As a precaution against drawing air into the dilution bottle during incubation, use a water seal. Satisfactory water seals are obtained by inverting the bottles in a water bath or adding water to the flared mouth of special BOD bottles.

(b) Air incubator or water bath, thermostatically controlled at 20°C ± 1°C, to exclude all light to prevent formation of DO by algae in the sample.

Reagents

(a) Distilled water: Use only high quality water distilled from a block tin or all-glass still. Alternatively, use deionized water. The water must contain less than 0.01 mg/l copper, and be free of chlorine chloramines, casutic alkalinity, organic material, or acids.

(b) Phosphate buffer solution: Dissolve 8.5 g potassium dihydrogen phosphate KH_2PO_4; 21.75 g dipotassium hydrogen phosphate, K_2HPO_4; 33.4 g disodium hydrogen phosphate heptahydrate, $Na_2HPO_4.7H_2O$; and 1.7 g ammonium chloride, NH_4Cl, in about 500 ml distilled water and dilute to 1 l. The pH of this buffer should be 7.2 without further adjustment. Discard the reagent (or any of the following reagents) if there is any sign of biological growth in the stock bottle.

(c) Magnesium sulphate solution: Dissolve 22.5 g $Mg SO_4.7H_2O$ in distilled water and dilute to 1 l.

(d) Calcium chloride solution: Dissolve 27.5 g anhydrous $CaCl_2$ in distilled water and dilute to 1 l.

(e) Ferric chloride solution: Dissolve 0.25 g $Fe Cl_3.6H_2O$ in distilled water and dilute to 1 l.

(f) Acid and alkali solutions, 1N: For neutralization of caustic or acidic waste samples.

(g) Sodium sulphite solution, 0.025 N; Dissolve 1.575 g anhydrous Na_2SO_3 in 1,000 ml distilled water. This solution is not stable; prepare daily.

(h) Seeding: The purpose of seeding is to introduce into the sample a biological population capable of oxidizing the organic matter in the waste-water. Where such micro-organisms are already present, as in domestic waste-water or unchlorinated effluents and surface waters, seeding is unnecessary and should not be used.

When the sample contains very few micro-organisms, as a result, for example, of chlorination, high temperature, or extreme pH, seed the dilution water. The standard seed material is settled domestic waste-water that has been stored at 20°C for 24 to 36 hour. Use sufficient seed to produce a seed correction of at least 0.6 mg/l.

Some samples, for example, certain industrial wastes, may require seeding because of low microbial population, but they contain organic compounds that are not readily oxidized by domestic wastewater seed. In order to evaluate the effect of such a waste in a treatment system, it is better to use specialized seed material containing organisms adapted to the use of the organic compounds present. Obtain such adapted seed from the effluent of a biological treatment process receiving the waste in question. When these sources are not available develop adapted seed in the laboratory by continuously aerating a large sample of water and feed it with small daily increments of the particular waste, until a satisfactory microbial population has developed. The special circumstances that call for the use of adapted seed also may require a seed concentration higher than the standard 1 to 2 ml/l. Decide on the kind and amount of seed required for such special purpose studies on the basis of prior experience with the particular waste and the purpose for which the determination is being made.

Procedure

(a) Preparation of dilution water: Before use, store the distilled water in cotton-plugged bottles long enough for it to become saturated with DO; or, if such storage is not practical, saturate the water by shaking the partially filled bottle or by aerating with a supply of clean compressed air. Use distilled water at 20°±1°C. Place the desired volume of distilled water in a suitable bottle and add 1 ml each of phosphate buffer, $MgSO_4$, and $FeCl_3$ solutions/l of water. If dilution water is to be stored in the incubator, add the phosphate buffer just before using the dilution water.

(b) Seeding: If the dilution water is seeded, use it the same day it is prepared.

(c) Pretreatment:

(i) Caustic, alkaline or acidic samples. Neutralize to about pH 7.0 with 1N H_2SO_4 or NaOH, using a pH meter or bromthymol blue as an outside indicator. The pH of the seeded dilution water should not be changed by the preparation of the lowest dilution of sample.

(ii) Samples containing residual chlorine compounds. If the samples stand for one to two hour the residual chlorine often will be dissipated. Prepare BOD dilutions with properly seeded standard dilution water. Destroy higher chlorine residuals in neutralized samples by adding Na_2SO_3. Determine the appropriate quantity of sodium sulphite solution on a 100 to 1,000 ml portion of the sample by adding 10 ml of 1 + 1 acetic acid or 1 + 50 H_2SO_4, followed by 10 ml KI solution (10 g/100 ml) and titrating with 0.025 N Na_2SO_3 solution to the starch iodide end point. Add to a volume of sample the quantity of Na_2SO_3 solution determined by the above test, mix, and after 10 to 20 minutes test a sample for residual chlorine to check the treatment. Prepare BOD dilutions with seeded standard dilution water.

(iii) Samples containing other toxic substances. Samples such as those from industrial wastes, for example, toxic metals derived from plating wastes, frequently require special study and treatment.

(iv) Samples supersaturated with DO. Samples containing more than 9 mg/l DO at 20°C may be encountered during winter months or in localities where algae are growing actively. To prevent loss of oxygen during incubation of these samples, reduce the DO to saturation by bringing the sample to about 20°C in a partly filled bottle and agitating it by vigorous shaking or by aerating with compressed air.

(d) Dilution technique: Make several dilutions of the prepared sample to obtain the required depletions. The following dilutions are suggested: 0.1 to 1.0 per cent for strong trade wastes, 1 to 5 per cent for raw and settled sewage, 5 to 25 per cent for oxidized effluents, and 25 to 100 per cent for polluted river waters.

(i) Carefully siphon standard dilution water, seeded if necessary, into a graduated cylinder of 1,000 to 2,000 ml capacity, half filling the cylinder without entrainment of air. Add the quantity of carefully mixed sample to make the desired dilution and dilute to the appropriate level with dilution water. Mix well with a plunger type mixing rod, avoiding entrainment of air. Siphon the mixed dilution into two BOD bottles, one for incubation and the other for determination of the initial DO in the mixture; stopper tightly and incubate for five days at 20°C. Water-seal the BOD bottles by inverting in a tray of water in the incubator or by using a special water-seal bottle. Prepare succeeding dilutions of lower concentration in the same manner or by adding dilution water to the unused portion of the preceeding dilution.

(ii) The dilution technique may be greatly simplified when suitable amounts of sample are measured directly into bottles of known capacity with a large-tip volumetric pipet and the bottles are filled with sufficient dilution water to permit insertion of the stopper without leaving air bubbles. Make dilutions greater than 1:100 by diluting the waste in a volumetric flask before adding it to the incubation bottles for final dilution.

(e) Determination of DO. If the sample represents 1 per cent or more of the lowest BOD dilution, determine DO on the undiluted sample. This determination is usually omitted on sewage and settled effluents known to have a DO content of practically zero. With samples having an immediate oxygen demand use a calculated initial DO, in as much as such a demand represents a load on the receiving water.

(f) Incubation. Incubate the blank dilution water and the diluted samples for five days in the dark at 20°C. Then determine the DO in the incubated samples and the blank using the azide modification of the iodimetric method or a membrane electrode. Unless the membrane electrode is used, use the alum flocculation method for incubated samples of muds and the copper sulphate-sulphamic acid method for activated sludges. In special cases, other modifications may be necessary. Those dilutions showing a residual DO of at least 1 mg/l and a depletion of at least 2 mg/l are most reliable.

(g) Seed correction. If the dilution water is seeded, determine the oxygen depletion of the seed by setting up a separate series of seed dilutions and selecting those resulting in 40 to 70 per cent oxygen depletions in five days. Use one of these depletions to calculate the correction due to the small amount of seed in the dilution water. Do not use the seeded blank for seed correction because the five days seeded dilution water blank is subject to erratic oxidation due to the very high dilution of seed, which is not characteristic of the seeded sample.

(h) Dilution water control. Fill two BOD bottles with unseeded dilution water. Stopper and water-seal one of these for incubation. Determine the DO before incubation in the other bottle. Use the DO results on these two bottles as a rough check on the quality of the unseeded dilution water. Do not use the depletion obtained as a blank correction. It should not be more than 0.2 mg/l and preferably not more than 0.1 mg/l.

(i) Glucose-glutamic acid check. The BOD test is a bioassay procedure consequently, the results obtained are influenced greatly by the presence of toxic substances or the use of a poor seeding material. Distilled waters frequently are contaminated with toxic substances – most often copper – and some sewage seeds are relatively inactive. The results obtained with such waters are always low.

The quality of the dilution water, the effectiveness of the seed, and the technique of the analyst should be checked periodically by using pure organic compounds having known or determinable BOD. If a particular organic compound is known to be present in a given waste, it may well serve as a control on the seed used. For general BOB work, a mixture of glucose and glutamic acid (150 mg/l of each) has certain advantages. Glucose has an exceptionally high and variable oxidation rate with relatively simple seeds. When it is used with glutamic acid, the oxidation rate is stablized and is similar to that obtained with many municipal wastes (0.16 to 0.19 exponential rate). In exceptional cases, a given component of a particular waste may be the best choice to test the efficacy of a particular seed.

To check the dilution water, the seed material, and the technique of the analyst, prepare a standard solution containing 150 mg/l each of reagent-grade glucose and glutamic acid that have been dried at 103°C for one hour. Pipet 5.0 ml of this solution into calibrated incubation bottles, fill with seeded dilution water, and incubate with seed control at 20°C for five days. On the basis of a mixed primary standard containing 150 mg/l each of glucose and glutamic acid, the five-day BOD varies in magnitude according to the type of seed, and precision varies with the quality of seed.

(j) Immediate dissolved oxygen demand. Substances oxidizable by molecular oxygen, such as ferrous iron, sulphite, sulphide, and aldehyde, impose a load on the receiving water and must be taken into consideration. The total oxygen demand of such a substrate may be determined by using a calculated initial DO or by using the sum of the immediate dissolved oxygen demand (IDOD) and the five-day BOD. Where a diffentiation of the two components is desired, determine the IDOD. The IDOD does not necessarily represent the immediate oxidation by molecular DO but may represent an oxidation by the iodine liberated in the acidification step of the iodometric method.

The depletion of DO in a standard water dilution of the sample in 15 minutes has been arbitrarily selected as the IDOD. To determine the IDOD, separately measure the DO of the sample (which in most cases is zero) and the DO of the dilution water. Prepare an appropriate dilution of the sample and dilution water and determine the DO after 15 minutes. The calculated DO of the sample dilution minus the observed DO after 15 minutes is the IDOD in milligrams per litre of the sample.

Calculation

(a) Definitions:

D_0 = DO of original dilution water

D_1 = DO of diluted sample 15 minutes after preparation

D_2 = DO of diluted sample after incubation

S = DO of original undiluted sample

D_c = DO available in dilution at zero time

= $D_0p + SP$

P = decimal fraction of dilution water used

P = decimal fraction of sample used

B_1 = DO of dilution of seed control before incubation

B_2 = DO of dilution of seed control after incubation

f = ratio of seed in sample to seed in control

$$= \frac{\text{percentage of seed in } D_1}{\text{percentage of seed in } B_1}$$

Seed correction = $(B_1 - B_2)f$.

(b) *Biochemical oxygen demand:*

When seeding is not required

$$\text{mg/l BOD} = \frac{D_1 - D_2}{P}$$

When using seeded dilution water,

$$\text{mg/l BOD} = \frac{(D_1 - D_2) - (B_1 \quad B_2)f}{P}$$

Including IDOD if small or not determined,

$$\text{mg/l BOD} = \frac{D_c - D_2}{P}$$

(c) *Immediate dissolved oxygen demand:*

$$\text{mg/l DOD} = \frac{D_c - D_1}{P}$$

The DO determined on the unseeded dilution water after incubation is not used in the BOD calculations because this practice would overcorrect for the dilution water. In all the above calculations, corrections are not made for small losses of DO in the dilution water during incubation. If the dilution water is unsatisfactory, proper corrections are difficult and the results are questionable.

8. Oxygen demand (chemical)

Apparatus

Reflux apparatus, consisting of 500 ml or 250 ml Erlenmeyer flasks, with ground-glass 24/40 neck, and 300 mm jacket Leibig, West, or equivalent condensers with 24/40 ground-glass joint, and a hot plate having sufficient power to produce at least $1.4 W/cm^2$ ($9 W/in^2$) of heating surface or equivalent, to insure adequate boiling of the contents of the refluxing flask.

Reagents

(a) Standard potassium dichromate solution, 0.250N. Dissolve 12.259 g $K_2Cr_2O_7$, primary standard grade, previously dried at 103°C for two hour in distilled water and dilute to 1,000 ml.

(b) Sulphuric acid reagent. Concentrated H_2SO_4 containing 22 g silver sulphate, Ag_2SO_4, per 4 kg (9 lb) bottle (1 to 2 days required for dissolution).

(c) *Standard ferrous ammonium sulphate titrant,* 0.1N: Dissolve 39 g $Fe(NH_4)_2(SO_4)_2.6H_2O$ in distilled water. Add 20 ml concentrated H_2SO_4, cool and dilute to 1,000 ml. Standardize this solution daily against the standard $K_2Cr_2O_7$ solution.

Standardization. Dilute 10.0 ml standard $K_2Cr_2O_7$ solution to about 100 ml. Add 30 ml concentrated H_2SO_4 and cool. Titrate with the ferrous ammonium sulphate titrant, using two to three drops (0.10 to 0.15 ml) ferroin indicator.

$$\text{Normality} = \frac{\text{ml } K_2Cr_2O_7 \text{ x } 0.25}{\text{ml } Fe(NH_4)_2(SO_4)_2}$$

(d) Ferroin indicator solution. Dissolve 1.485 g 1, 10-phenanthroline monohydrate, together with 695 mg $FeSO_4.7H_2O$ in water and dilute to 100 ml. This indicator solution may be purchased already prepared.

(e) Mercuric sulphate, $HgSO_4$ crystals.

(f) Sulphamic acid. Required only if the interference of nitrites is to be eliminated.

Procedure

(a) Treatment of samples with COD values over 50 mg/l, Place 50.0 ml sample or a smaller sample portion diluted to 50.0 ml in 500-ml refluxing flask. Add 1g $HgSO_4$, several boiling chips, and 5.0 ml H_2SO_4. Add the

H_2SO_4 very slowly, with mixing to dissolve the $HgSO_4$. Cool while mixing to avoid possible loss of volatile materials in the sample. Add 25.0 ml 0.250 N $K_2Cr_2O_7$ solution and again mix. Attach the flask to the condenser and start the cooling water. Add the remaining acid reagent (70 ml) through the open end of the condenser. Continue swirling and mixing while the acid is being added. Mix the reflux mixture thoroughly before heat is applied; if this is not done, local heating occurs in the bottom of the flask and the mixture may be blown out of the condenser. Alternatively, use sample volumes from 10.0 ml to 50.0 ml and adjust volumes, weights and normalities accordingly.

Use 1 g $HgSO_4$ with a 50.0 ml sample to complex 100 mg chloride (2,000 mg/l). For smaller volume samples use less $HgSO_4$, according to the chloride concentration. Maintain a 10:1 ratio of $HgSO_4$:Cl. A slight precipitate does not affect the determination adversely. As a general rule, COD cannot be measured accurately in samples containing more than 2,000 mg/l chloride.

Reflux the mixture for two hour or use a shorter period for particular wastes if it has been found to give maximum COD. Cover the open and of the condenser with a small beaker to prevent foreign material from entering the refluxing mixture. Cool and wash down the condenser with distilled water.

Dilute the mixture to about twice its volume with distilled water, cool to room temperature, and titrate the excess dichromate with standard ferrous ammonium sulfate, using ferroin indicator. Generally, use two or three drops (0.10 or 0.15 ml) indicator. Although the quantity of ferroin is not critical, use a constant volume. Take as the end point the sharp colour change from blue-green to raddish-brown, even though the blue-green may reappear within minutes.

Reflux in the same manner a blank consisting of distilled water, equal in volume to that of the sample, together with the reagents.

(b) Alternate procedure for low-COD samples. Follow the standard procedure, with two exceptions. (i) Use 0.025 N standard $K_2Cr_2O_7$ and (ii) back-titrate with 0.10 ferrous ammonium sulphate. Exercise extreme care with this procedure because even a trace of organic matter in the glassware or the atmosphere may cause a gross error. If a further increase in sensitivity is required, reduce a larger sample to 20 ml (final total volume 60 ml) by boiling in the refluxing flask on a hot plate in the presence of all reagents. Carry a blank through the same procedure. This technique has the advantage of concentrating the sample without significant loss of easily digested volatile materials. Hard-to-digest volatile materials such as volatile acids are lost, but an improvement is gained over ordinary evaporative concentration also increase and more $HgSO_4$ is required.

(c) Determination of standard solution: Evaluate the technique and quality of reagents with a standard solution of either glucose or potassium acid phthalate.

Calculation

$$\text{mg/l COD} = \frac{(a-b)\,N \times 8{,}000}{\text{ml sample}}$$

where COD = chemical oxygen demand from dichromate, a = ml $Fe(NH_4)_2\ (SO_4)_2$ used for blank, b = ml $Fe(NH_4)_2\ (SO_4)_2$ used for sample, and N = normality of $Fe(NH_4)_2\ (SO_4)_2$.

9. Sludge digester gas

(a) *Selection of method*

Two different procedures are described for gas analysis, the volumetric method and the gas chromatographic method. Volumetric analysis is suitable for the determination of carbon dioxide, hydrogen, methane, and oxygen, Nitrogen is estimated indirectly by difference. Although the method is time-consuming the equipment is relatively simple. Because no calibration is needed before use, the procedure is particularly appropriate when analyses are conducted on an infrequent basis.

The principal advantage of gas chromatography is speed. Commercial equipment is specifically designed for ambient-temperature gas analysis and permits the routine separation and measurement of carbon dioxide, nitrogen oxygen and methane in less than five minutes. The requirement for a recorder, pressure regulated bottles of carrier gas, and certified standard gas mixtures for calibration raise costs to the point where infrequent analyses by this method may be uneconomical. The advantages of this system are freedom from the cumulative errors found in sequential volumetric measurements, adaptability to other gas component analyses, adaptability to intermittent on-line sampling and analysis, and the use of samples of 1 ml or less.

(b) *Sample collection*

When the source of gas is some distance from the apparatus used for analysis, collect samples in sealed containers and bring to the instrument. Displacement collectors are the most suitable containers. Long glass tubes with three-way glass stopcoks at each end, are particularly useful. These also are available with centrally located ports provided with septa for syringe transfer of samples. Connect one end of the collector to the gas source and vent the three-way stopcock to the atmosphere.

Clear the line of air by passing 10 to 15 volumes of gas through the tube. If the gas supply is limited, fill the tube with a liquid that is displaced with gas. Use either mercury solution or an acidified salt solution. The latter solution is easier and less expensive to use, but dissolves gases to some extent. Therefore, fill the collection tube completely with the gas and seal off from any contact with the displacement fluid during temporary storage. When transferring gas to the gas-analysing apparatus do not transfer any fluid.

(c) *Volumetric method*

Apparatus

Orsat-type gas-analysis apparatus, consisting of at least (a) a water-jacketed gas burette with leveling bulb; (b) a carbon dioxide-absorption pipet; (c) an oxygen absorption pipet (d) a cupric oxide-hydrogen oxidation assembly; (e) a shielded catalytic methane-oxidation assembly or slow-combustion pipet assembly; and (f) a leveling bulb. If the slow-combustion pipet is used, use a controlled source of current to heat the platinum filament electrically. Mercury is recommended as the displacement fluid. Aqueous sodium $Na_2SO_4-H_2SO_4$ solution for sample collection also has been used successfully. Use any commercially available gas analyzer having these units.

Reagents

(a) Potassium hydroxide solution. Dissolve 500 g KOH in distilled water and dilute to 1 l.

(b) Alkaline pyrogallol reagent. Dissolve 30 g pyrogallol (also called pyrogallic acid) in distilled water and make up to 100 ml. Add 500 ml KOH solution.

(c) Oxygen gas. Use approximately 100 ml for each gas sample analyzed.

(d) Displacement liquid. Mercury, or 200 g Na_2SO_4 plus 30 ml concentrated H_2SO_4/800 ml water.

Procedure

(a) Sample introduction. Transfer 5 to 10 ml gas sample into the gas burette through a capillary-tube connection to the collector. Expel this sample to the atmosphere to purge the system. Transfer up to 100 ml gas sample to the buret. Bring the sample in the burette to atmospheric or reference pressure by adjusting the levelling bulb. Measure the volume accurately and record as V_1.

(b) Carbon dioxide absorption. Remove CO_2 from the sample by passing it through CO_2–absorption pipet charged with the KOH solution. Pass the gas back and forth until the sample volume remains constant. Before opening the stopcocks between the burette and any absorption pipet make sure that the gas in the burette is under a slight positive pressure to prevent reagent in the pipet from contaminating the stopcock or manifold. After absorption of CO_2, transfer the sample to the burette and measure its volume. Record as V_2.

(c) Oxygen absorption. Remove O_2 by passing the sample through the O_2 absorption pipet charged with alkaline pyrogallol reagent until the volume of the sample remains constant. Measure the volume accurately and record as V_3. In the case of a digester gas sample, continue as directed in (d). For methane in water, store the gas in the CO_2 pipet and proceed to (e).

(d) Hydrogen oxidation. Remove the H_2 by passing the sample through the CuO assembly maintained at a temperature in the range of 290° to 300°C. When a constant volume has been obtained, transfer the sample back to the burette, cool and measure its volume accurately. Record as V_4. Waste to the atmosphere all but 20 to 25 ml of the remaining gas. Measure the volume accurately and record as V_5. Store temporarily in the CO_2 absorption pipet.

(e) Methane oxidation. Purge the inlet connections to the burette with oxygen by drawing 5 to 10 ml into the burette and expelling to the atmosphere. Oxidize the methane by either the catalytic oxidation process for digester gas and the gas phase of water samples or the slow-combustion process for the gas phase of water samples.

(i) Catalytic oxidation process. For catalytic oxidation of digester gas and the gas phase of water samples, transfer 65 to 70 ml 0_2 to the burette and measure accurately. Record this volume as V_6. Pass the 0_2 into the CO_2 absorption pipet so that it will mix with the sample stored there. Bring this mixture back to the burette and measure its volume accurately. Record as V_7. This volume should closely equal V_5 plus V_6. Pass the 0_2 sample mixture through the catalytic oxidation assembly, which should be heated in accordance with directions from the manufacturer. Keep rate of passage less than 30 ml/min. After the first pass, transfer the mixture back and forth through the assembly between the burette and the reservior at a rate not faster than 60 ml/min until a constant volume is obtained. Record as V_8.

(ii) Slow-combustion process. For slow combustion of the gas phase of the water samples, transfer 35 to 40 ml 0_2 to the burette and measure accurately. Record this volume as V_6. Transfer the 0_2 to the slow-combustion pipet and then transfer the sample from the CO_2 absorption pipet to the burette. Heat the platinum coil in the combustion pipet to yellow heat while controlling the temperature by adjusting the current. Reduce the presure of 0_2 in the pipet to somewhat less than atmospheric pressure by means of the levelling bulb attached to the pipet. Pass the sample into the slow-combustion pipet at the rate of approximately 10 ml/min. After the first pass, transfer the sample and oxygen mixture back and forth between the pipet and burette several times at faster rate, allowing the mercury in the pipet to rise to a point just below the heated coil. Collect the sample in the combustion pipet, turn off the coil, and cool pipet and sample to room temperature with a jet of compressed air. Transfer the sample to the burette and measure its volume. Record as V_8.

(f) Measurement of carbon dioxide produced. Determine the amount of CO_2 formed in the reaction by passing the sample through the CO_2 absorption pipet until the volume remains constant. Record the volume as V_9.

Check the accuracy of the determination by absorbing the residual oxygen from the sample. After this absorption, record the final volume as V_{10}.

Calculation

(a) Methane and hydrogen are usually the only combustible gases present in sludge digester gas. When this is the case, determine the percentage by volume of each gas as follows:

$$\text{Percentage } CO_2 = \frac{(V_1-V_2) \times 100}{V_1}$$

$$\text{Percentage } O_2 = \frac{(V_2-V_3) \times 100}{V_1}$$

$$\text{Percentage } H_2 = \frac{(V_3-V_4) \times 100}{V_1}$$

$$\text{Percentage } CH_4 = \frac{V_4 \times (V_8-V_9) \times 100}{V_1 \times V_5}$$

Percentage N_2 = 100–(percentage CO_2 + percentage O_2 + percentage H_2 + percentage CH_4)

(b) Alternatively, calculate methane by either of the two following equations:

$$\text{Percentage } CH_4 = \frac{V_4 \times (V_6 + V_{10} - V_9) \times 100}{2 \times V_1 \times V_5}$$

$$\text{Percentage } CH_4 = \frac{V_4 \times (V_7 - V_8) \times 100}{2 \times V_1 \times V_5}$$

Results from the calculations for methane by the three equations should be in reasonable agreement. If not, repeat the analysis after checking the apparatus for sources of error, such as leaking stop-cocks and connections. Other combustible gases, such as ethane, butane, or pentane, will cause a lack of agreement among the calculations; however, the possibility that digester gas contains a significant amount of any of these is remote.

(d) *Gas chromatographic method*

Apparatus

(a) Gas chromatograph. Use any commercially available instrument equipped with a thermal conductivity detector. With some column packings, ovens and temperature controls are necessary. A unit with a gas sampling valve is desirable.

(b) Recorder. Use a 10 mV full-span strip chart recorder for the gas chromatograph. When minor components such as hydrogen and hydrogen sulphide are to be detected, a 1 mV full span recorder is preferable.

(c) Column packing. Some commercially available column packings useful for separating sludge gas components are listed below alongwith the routine separations possible at room temperature:

(i) Silica gel at room temperature. H_2, air ($O_2 + N_2$), CH_4, (CO_2 slow).

(ii) Molecular sieve 13 x H_2, 0_2, N_2, CH_4.

(iii) HMPA (bexamethylphosphoramide) 30 per cent on chromosorb P: CO_2 from (O_2, N_2, H_2, CH_4).

(iv) DEHS (Di-2-ethylhexylsefacate) 30 per cent on chromosorb P: CO_2 from (O_2, N_2, H_2, CH_4).

Combinations of columns (i) and (ii), (iii) and (ii) or (iv), and (ii) when properly sized and used in the sequence first column, detector, second column, detector, will readily separate H_2, O_2, N_2, CH_4 and CO_2. Commercial equipment specifically designed for such operations is available.

(d) Sample introduction apparatus. Preferably use an instrument equipped with gas-sampling valves designed to permit automatic injection of a specific sample volume into the chromatograph. If such an instrument is not available, introduce samples with a 2 ml syringe fitted with a 27 gauge hypodermic needle. Reduce escape of gas by greasing the plunger lightly with mineral oil or by using a special gas-tight syringe.

Reagents

(a) Carrier gas. Use helium for separating digester gases. If hydrogen is to be determined, use argon as a carrier gas to increase the sensitivity greatly.

(b) Calibration gases. Use pure samples of methane, carbon dioxide, and nitrogen, or mixtures of known composition, for calibration. Also use samples of oxygen, hydrogen and hydrogen sulphide if these gases are to be measured.

Procedure

(a) Preparation of gas chromatograph. Adjust the carrier gas flow rate to 60 to 80 ml/min. Turn on the oven heaters, if used, and the detector current and adjust to the desired values. The instrument is ready for use when the recorder yields a stable base line. Silica gel and molecular sieve columns gradually will loss activity because of absorbed moisture or materials permanently absorbed at room temperature. If insufficient separations occur, reactivate by heating or repacking.

(b) Calibration. For accurate results, prepare a calibration curve for each gas to be measured because different gas components do not give equivalent detector reponses on either a weight or a molar basis. Calibrate with synthetic mixtures or with pure gases.

(i) Synthetic mixtures. Use purchased gas mixtures of known composition or prepare in the laboratory. Inject a standard volume of each mixture into the gas chromatograph and note the response for each gas. Compute the detector response, either as the area under a peak or as the height of the peak, after correcting for attenuation. Read peak heights accurately and correlate with concentration of the component in the sample. Reproduce operating preameters exactly from one analysis to the next. If sufficient reproducibility cannot be obtained by this producure, use peak areas for calibration. Prepare the calibration curve by plotting either peak area or peak height against volume per cent for each component.

(ii) Pure gases. Introduce pure gases into the chromatograph individually with a syringe. Inject sample volumes of 0.25, 0.5, 1.0 ml etc., and plot the detector response, correct for attenuation, against the gas volume.

When the analysis system yields a linear detector response with increasing gas component concentration from zero to the range of interest, run standard mixtures alongwith samples. If the same sample size is used, calculate gas concentration by direct proportions.

(c) Sample analysis. If samples are to be injected with a syringe, equip the sample collection container with a port closed by a rubber or silicon septum. To take a sample for analysis, expel air from the barrel of the syringe by depressing the plunger and force the needle through the septum. Withdraw the plunger to take the gas volume desired, pull the needle from the collection container and inject the sample rapidly into the chromatograph.

When samples are to be injected through a gas-sampling valve, connect the sample collection container to the inlet tube. Permit gas to flow from the collection tube through the valve to purge the dead air space and fill the sample tube. About 15 ml are normally sufficient to clear the lines and to provide a sample of 1 to 2 ml. Transfer the sample from the loop into the carrier gas stream by following the manufacturer's directions. Bring samples to atmospheric pressure before injection.

When calibration curves have been prepared with synthetic mixture, use the same sample volume as that used during calibration. When calibration curves are prepared by the procedure using varying volumes of pure gases, inject any convenient gas sample volume up to about 2 ml.

Calculation

(a) When calibration curves have been prepared with synthetic mixtures and the volume of the sample analysed is the same as that used in calibration, read the volume percentage of each component directly from the calibration curve after the detector response for that component is computed.

(b) When calibration curves are prepared with varying volumes of pure gases, calculate the percentage of each gas in the mixture as follows:

$$\text{Volume percentage} = \frac{A}{B} \times 100$$

where A = partial volume of component (read from calibration curve) and B = volume sample injected.

(c) Where standard mixtures are run with the samples and instrument response is linear from zero to the concentration range of interest:

$$\text{Volume percentage} = \text{Vol percentage (std)} \times \frac{C}{D}$$

where C = recorder value of sample and D = recorder value of standard.

Annex X

REPORT OF THE WORKSHOP ON UNIFORMITY OF INFORMATION REPORTING FOR BIOMETHANATION SYSTEMS

The Workshop on Uniformity of Information Reporting for Biomethanation Systems was held at Bangkok from

2 to 6 May 1983. The Workshop was organized by Equity Policy Centre (EPOC) and ESCAP with the financial support of the Government of Japan, the Commonwealth Science Council and the United States Agency for International Development (USAID).

Background

The Workshop had its origin in the growing concern among specialists in the development and application of renewable-energy technologies about the difficulty they were experiencing in benefiting from the experience of others and applying reported results to their own situations. That difficulty had been particularly serious with regard to biomethanation (biogas).

Although biomethanation systems had been in use for many years in many parts of the world, the lack of a systematic way of reporting the results of experiementation with and the use of such systems had made comparisons among them and their relative evaluation extremely difficult. The problem arose from the lack of agreement on parameters and variables to be measured, the conditions of measurement, and even the units of measurement.

Compounding the confusion was the fact that there existed no basis for cost comparisons because different direct costs were usually reported, and many important indirect costs, such as taxes and subsidies, were frequently not taken into account. The situation had deteriorated to the point where there were even disagreements over whether or not a given system "worked". Thus, the task of the policy-maker in establishing programmatic budget priorities in energy systems had been made particularly difficult.

In an effort to set in motion a process that would help accelerate the useful application of biomethanation techniques, a survey had been conducted among experts by EPOC, on behalf of USAID. As a result of the uniformly positive response from those surveyed that a meeting was needed to address the issue, EPOC (on behalf of USAID), ESCAP (with the assistance of the Government of Japan), and the Commonwealth Science Council co-operated to organize the Workshop.

The Workshop was attended by experts from Burma, China, Indonesia and Thailand. Also participating were experts representing OLADE, the Commonwealth Science Council/African Energy Programme, the Commission of the European Communities, the International Reference Centre for Waste Disposal, the National Research Centre, Cairo, and others attending in their individual capacity.

United Nations bodies and specialized agencies represented at the meeting were: Food and Agriculture Organization of the United Nations (FAO) and United Nations Educational, Scientific and Cultural Organization (UNESCO).

RECOMMENDATIONS OF THE WORKSHOP

Process design and construction

Specialists dealing with biomethanation technology were urged to characterize the systems used by reporting a thorough description of the design, the design parameters and any ancillary equipment used with the system. The description was to include the type, geometry, dimensions and materials of construction of the digester and gas holder, and the specifications of ancillary equipment. It was important that the cost of constructing the digester (and gas holder) be reported in detail, including the cost and specifications of the materials and the cost of labour, with the latter disaggregated to the number of man-hours required and the cost per man-hour for each of the different skills required.

Only by possessing such information would specialists in other regions or countries be able to benefit from the results and experience of others in planning their own designs.

Operating conditions, analytical measurements and monitoring

The Workshop recommended that measurements of a minimum number of parameters associated with operation of a biomethanation plant be reported in a uniform way, using international units, so that results of a biomethanation experiement, whatever the scale and wherever performed, could be understood and used by people in other locations. To facilitate the gathering of data, operators in the field should be provided with centrally-managed, mobile laboratories to monitor minimum system parameters. In addition to such measurements, measurement of other parameters was recommended as useful, or even necessary in some cases, for the analysis of the feedstock and for characterizing the end uses of the biomethanation system and its products (such as the use of gas for energy and of residue for fertilizer, the treatment of wastes, or improving public health and sanitation), or for assessing or monitoring digester performance. The Workshop recommended a uniform way of expressing measurement results in terms of concentrations, rates and yields. It noted precautions to be taken while sampling or performing analyses to insure the integrity of results.

The panel also recommended methods for collecting data in the field where little or no instrumentation or laboratory facilities were available, and suggested the development of others, where necessary.

Use of the products, public health and sanitation, and socio-economic issues

Biomethanation systems were accepted and used only to the extent that their products met a need and that both the systems and their products met certain socio-economic criteria. The Workshop recommended a list of parameters the measurements of which were needed to enable comparisons to be made among similar uses for the products (gas and liquid/solid effluent) and the systems. Recommendations were also made for the system of units in which those measurements should be reported.

The Workshop stressed, however, the overriding importance of the socio-economic issues in arriving at realistic choices of biomethanation systems that would be accepted and used by the people for whom they were intended. The Workshop noted that initial decisions and choices were generally made on the basis of technical criteria alone, with information that heretofore had usually been insufficient for an adequate basis for comparison. Even with the improved data base that would be established by adoption of its technical recommendations, the Workshop noted that the consideration not only of an economic analysis but also of the many tangible and intangible social and ecological costs and benefits that could not be quantified in conventional analyses would be more significant in the decision-making process. Such an analysis should be based on a checklist at least as inclusive as the suggestions made in the report.

National statistics

A major part of the difficulty in evaluating the actual or potential usefulness of biomethanation to a national economy was the lack of statistical information on current use of that technology. Governments generally collected information only on systems installed under government programmes. The Workshop therefore recommended that national Governments include information on biomethanation systems in statistics gathered on a national basis. Such information should include the number in use, the aggregate energy produced, the aggregate fertilizer produced, the kinds of uses of the energy, and the increased crop production attributable to the use of the fertilizer.

Follow-up task force

The Workshop recommended that a task force be formed by ESCAP and EPOC to follow-up its recommendations. The primary concern of the task free should be the identification of institutions and field projects with which to co-operate in testing the approach recommended by the Workshop. Such tests should be designed to span at least a year of operation, and the results should be presented to a follow-up meeting.

Circulation for professional comment

Practical considerations had received limited attentions in the Workshop owing to the relatively small number of participants. Therefore, the Workshop recommended that its report be circulated for comment to a representative group of recognized experts and professional organizations for professional comment.

The Workshop urged that its report be translated into Spanish, French and other appropriate languages to enable widespread dissemination and use, particularly in the developing countries.

ADOPTION OF THE REPORT

The Workshop adopted its report on 6 May 1983.

Appendix I

PROCESS DESIGN AND CONSTRUCTION
(Report of working group I)

A. Classification of biogas systems

There are a number of different types of biogas units and these have been classified in several ways. Classifications by scale and type are given below.[a]

(a) Scale:

(i) Family-size;

(ii) Community-size;

(iii) Large-(agricultural) size;

(iv) Industrial-size

When reporting on plants in any of the above categories the total volume of the digester should be given in cubic metres (m^3) and the active volume should be given as a percentage of the total volume.

(b) Type of system;

(i) Batch;

(ii) Semi-continuous with or without recycle;

(iii) Continuous with or without recycle.

B. Design of biogas systems

The principal unit in a biogas system is the digester or reaction vessel. Digester types, and detailed designs and specifications, are given in several publications.[b] A listing of digester types is given below:

(a) Digester types:

(i) Fixed geometry:

a. Gas stored inside ("water-pressure", e.g., Chinese type – approximately 7 million of these digesters are in China);

b. Gas stored outside;

(ii) Floating cover (e.g., Indian or KVIC type), extensively used throughout the world. Gas produced is trapped under a floating cover;

(iii) Flexible bag design. Bag digester is a cylindrical bag, usually of plastic. Gas is stored in the reactor under a flexible membrane. Gas can also be stored in a separate gas bag;

(iv) Plug flow digester. Essentially a horizontal digester in which the ratio of length to diameter is 1 and accordingly the internal flow pattern is near to an ideal flow system;

(v) Batch dry fermentation. Substrate and inoculum fed to a reactor vessel. The Reactor is sealed and fermentation proceeds for a period up to six months. Batch digesters are well adapted to the use of agricultural residues;

(vi) Anaerobic filter. A packed column, liquid waste is passed through the column in either an upflow or down-flow manner. Anaerobic organisms are attached to the packing media and digest organic matter in the feedstock. Essentially limited to soluble wastes. In early stages of development and use;

(vii) Anaerobic baffled reactor. Over-and-under baffled reaction tank for treating liquid wastes. In early development stage;

(viii) Anaerobic contact digester. Flow diagram similar to aerobic activated sludge process. Useful for highly concentrated liquid wastes. High level of technology required.

(The batch, fixed geometry, floating-cover and bag-type biogas reactors are most suitable for use with the substrates commonly found in rural areas in developing nations.)

(b) Digester specifications. Several factors should be considered in the preparation of specifications for construction of digesters, as follows:

(i) Construction materials:

a. Bricks;

---

[a] See chapter VI of this publication for another classification that has been widely, used the arrangement used for collecting the gas.

[b] *Ibid.* See also National Academy of Sciences, *Methane Generation from Human, Animal, and Agricultural Wastes,* (Washington D.C., National Academy of Sciences, 1977. National Academy of Sciences, *Food, Fuel and Fertilizers from Organic Wastes* (Washington D.C., National Academy Press, 1981) and David C. Stuckey, *The Integrated Use of Anaerobic Digestion (Biogas) in Developing Countries: A State of the Art Review* (Oubendorf, Switzerland, World Bank, IRCWD (forth coming).

b. Concrete;
c. Metal;
d. Plastic;
e. Rubber;
f. Others;

(ii) Finish of surface and inside walls:

a. Plastering;
b. Coating;
c. Painting;
d. Other;

(iii) Geometry:

a. Sphere;
b. Cylinder;
c. Rectangular;
d. Tunnel;
e. Others;

(iv) Dimensions expressed in metres;

(v) Principal features:

a. Inlet;
b. Outlet;
c. Mixing facilities;
d. Sampling ports and devices;
e. Others;

(vi) Installation:

a. Above ground, Insulation:
  i. Type;
  ii. Thermal conductivity in S.I. units;
  iii. Thickness in metres;
  iv. Permanent or replaceable;
b. Below ground:
  i. Portion covered in m^2;
  ii. Portion not covered in m^2, insulation:
    Type;
    Thermal conductivity in S.I. units;
    Thickness in m;
    Permanent or replaceable;
  iii. Mean temperature of earth surrounding digester in °C;

(vii) External heating:

a. Source:
  i. Solar;
  ii. Waste-heat recycle;
  iii. Biogas;
  iv. Other fuel;
b. Heat load in Joules/sec and Joules/joule gas produced
c. Type, design and efficiency of system in Joules/joule energy used.

(viii) Mixing: Type:

a. Mechanical power input in S.I. units;
b. Gas recirculation rate in m^3/h;
c. Manual;
d. Sludge recycle in m^3/h;

(ix) Process control and measurements:

a. Safety device:
  i. Pressure relief valves;
  ii. Flame trap;
  iii. Water trap;
b. Temperature measurements control
c. Flow-level control;
d. Sampling ports and devices

(x) Gas storage:

a. Gas holder:
  i. Integrated with digester, volume in m^3
  ii. Separate, volume in m^3
b. Materials of construction;
c. Geometry and size;
d. Gas pressure in cm of water head;

(xi) Handling and disposal of effluent:

a. Facilities for storage of effluent (if any);
b. Processing effluent before disposal:
  i. Dewatering (specific type)
  ii. Post-composting
  iii. Drying (specify type)
  iv. Enriching
  v. Others

(xii) Method of disposal, if land disposal process used, e.g. pumping, gravity flow, hauling.

C. Process design parameters

In building a biogas system the success of performance depends on a number of parameters which control the biomethanation process. Process temperature and the characteristics of the substrate are the prime factors influencing the rate of gas production. Process temperatures directly affect process conditions by controlling microbial growth rates, since the methanogenic bacteria are very sensitive to sudden changes in temperature. Likewise, the physical and chemical characteristics of the substrate are also important factors, the composition of which may lead to fluctuations in the production of methane gas. The factors concerning these two principal parameters are outlined below.

In addition, other parameters needed include loading rate, flow rate, volume of digester, and detention time. These are also outlined below with recommendations as to units of measurement for each parameter.

(a) Temperature:

(i) Ambient: monthly:

a. diurnal range in °C;

b. average range in °C;

(ii) Slurry

a. Feed in °C

b. Digester (specify location of measurement) °C

(b) Substrate:

(i) Physical characterization:

a. Qualitative description (animal dung by species of animal, poultry droppings, night soil, solid waste, liquid wastes, crop residues);

b. Specific gravity;

c. Particle size and distribution, Range and average in mm;

d. Total volatile solids in weight/weight, expressed as a percentage, and in weight/volume;

(ii) Chemical characterization expressed as percentage of dry weight, C, N, P, K; pH; and COD in mg/l of feed slurry;

(iii) Processing:

a. Pretreatment, mechanical, thermal, and biochemical;

b. Feed total solids content in weight per weight, expressed as a percentage, and in weight/volume;

(c) Loading rate, which may be different depending on the type of the digester, the nature of the substrate and other environmental conditions:

(i) kg volatile solids fed/m^3/day;

(ii) kg total solids fed/m^3/day;

(iii) COP fed/m^3/day;

(d) Flow rate in m^3/day;

(e) Volume of the digester in m^3;

(f) Detention time (theoretical) in days;

(g) Gas. Under this heading are included the production, yield, composition, purification and utilization of the gas. The gas production rate usually expressed by m^3 gas/m^3 digester/day, is needed to evaluate the gas-production efficiency of the digester. The yield of gas should also be given in terms of m^3 per kg total solids fed and per kg of volatile solids fed in order to understand the capability of the system to produce gas from the organic matter.

(i) Production rate, gas volume/digester volume, in m^3/m^3/day;

(ii) Yield of gas in m^3/kg total solids fed and m^3/kg volatile solids fed;

(iii) Composition, CH_4, CO_2, H_2S, H_2, in percentage;

(iv) Purification in terms CO_2 and or H_2S removal;

(v) Utilization showing application, e.g., burners, lamps, internal conbustion engines refrigerators, heating etc., and indicating type and efficiency;

(h) Residue

(i) Rate of production in m^3/day;

(ii) Total solids in kg/m^3;

(iii) Proximate analysis (N, P, K) in percentages.

(i) Utilization of residues: The effluent from the biomethanation process (i.e., the residue from the digestion of the organic matter) has many applications, depending on local conditions and needs. For example, the residue may have a higher value if adapted for use as an animal feed supplement rather than as a fertilizer. The value of the parameters in (h) (above) can thus alter the feasibility of the entire process, and therefore their affect should be clearly given.

(i) Fertilizer and soil conditioner

(ii) Animal feed

(iii) Others (algae, Fish etc.)

D. Process cost estimation

It is difficult to list the various items pertaining to the construction and operation of all the types of biogas systems, and assign a cost against each of these uniformity, because of the dissimilarities that exist in their designs. However, in order to compare the costs associated with the construction and operation of the different types of biogas systems in different countries, a classification is suggested to group various costs under different categories, which are applicable uniformly for any type of biogas system. The costs associated with the individual items under the different categories can be summed up and the capital cost for the biogas system obtained. The categories for which costs are to be determined can be classified as follows:

(a) Digester;

(b) Gas holder;

(c) Ancillaries and accessories;

(d) Process design and supervision.

These categories along with examples of the items that constitute these categories are presented in table 1. Data from this table could be used with any type of digester to make the required evaluation. It is important that all costs should be reported in local currency with a United States dollar equivalent along with the years on which the costs were based.

Table 1. Capital cost of a biomethanation plant

Category	*Unit*	*Quantity*	*Cost per unit*	*Man-hours*	*Cost per man-hour*	*Total*
A. Digester						
Materials:						
Item 1				–	–	
Item 2				–	–	
.				.	.	
.				.	.	
.				.	.	
Subtotal						
Labour:						
Excavation						
Building						
Plastering						
Backfilling						
Subtotal						
Transportation of materials						
Other costs (itemized						
B. Gas holder						
Materials:						
Item 1				–	–	
Item 2				–	–	
.				.	.	
.				.	.	
Subtotal						
Labour:						
Fabrication						
Painting						
Subtotal						
Transportation						
Other costs (itemized)						
C. Ancillaries						
(Itemized)						
D. Process design and supervision						
(Itemized)						
Total						

E. Preliminary techno-economic evaluation

Based on the construction costs and the yields of gas and slurry, a financial analysis based on market prices can be carried out. This type of analysis is useful in determining the rates of return for a particular biogas plant and can help in evaluating the various technical options available to satisfy specific end-uses, e.g. cooking, lighting, power. However, a financial analysis is fairly narrow in its scope since it uses market prices rather than "shadow" prices which reflect the true economic worth to society of the inputs and outputs of the project. In addition, a financial analysis does not incorporate "secondary" benefits, e.g. improved public health, reduced reliance on imported fossil fuels, reduced deforestation. These benefits are difficult to quantify, but nevertheless are extremely important in assessing the technology. These latter factors are incorporated in a social analysis (social cost-benefit), and will be discussed in more length later. However, it is strongly recommended that this social analysis be used by governments to assess the viability of biogas since it most accurately reflects the effect of the project on the fundamental objectives of the whole economy.

The actual construction cost of a digester is relatively easy to assess, although at some periods during the year unskilled labour costs may be virtually negligible since it is virtually idle. Determining plant life (depreciation) is difficult since there is still little information available, and assumptions vary between 15 and 40 years. However, depending on the discount rate, a life of more than about 25 years has little impact on benefit-cost ratios. Obviously, different parts of the plant will have different lives, and these should be assessed accordingly.

Maintenance costs can also vary considerably depending on the design used. For example, a steel floating cover requires considerable attention and maintenance to prevent corrosion. In contrast, the water pressure digester requires little maintenance besides the usual biannual loading and unloading of agricultural residues. Also, while land costs can contribute significantly to overall costs, except in the most densely settled villages land can be treated as a zero cost item since the quantities involved are so small. Finally, the labour involved in collecting the feed, e.g. manure, agricultural residues, mixing it with water and feeding it to the digester has to be evaluated. However, in many cases this time is minimal and is often equivalent to the labour required to collect the biomass for traditional uses, e.g. as a fuel or manure. Hence, in many cases this cost can be neglected.

Evaluating the quantifiable benefits of a biogas plant is also fraught with many difficulties. The output of a plant consists of two streams: gas and slurry. Valuation of the gas depends on three complex considerations: the quantity and composition of the gas; the mix of end-uses, and the price, type and burning efficiency of another substitute fuel, e.g. kerosene, LPG, coal, electricity. The first factor depends entirely on the feedstock and process design parameters. However, the mix of end-uses determines what fuels may be used for calculating replacement costs. Finally, since the price and burning efficiency of substitutable fuels varies considerably, this factor can radically alter the value of biogas from the plant.

The benefits from the slurry depend on whether it is used as a fertilizer/soil conditioner, an animal feed, a feed to fish ponds or to grow algae, water hyacinth etc. The value of the slurry in increasing crop yields depends strongly on the handling procedures used and hence the fate of nitrogen. In some cases this increase may be equivalent to spreading the biomass directly on the land without digestion and hence no benefits should be claimed. If the slurry is used to refeed animals then the benefits from the slurry could be considerably greater than from the gas. Considerable care should be exercised in evaluating the benefits from the slurry, and these should be related to an original quantity of biomass.

Table 2. Preliminary economic appraisal of the biomethanation plant

	Amount
Investment costs:	
Digester construction	
Gas holder	
Connections and end use devices	
Others	
Total investment costs	
Annual production costs:	
Cost of dung, water and other	
Labour required for plant operation	
Rent of plant site	
Repairs and maintenance	
Depreciation:	
Civil construction (10-20 years depending on type of digester)	
Connections and end-use devices (10 years)	
Gas holder (10 years if metalic)	
Others (number of years should be selected reasonably)	
Total depreciation	
Others	
Total annual production costs	
Annual tangible benefits:	
Biogas (kerosene, LPG butane gas, . . . equivalent)	
Residue (fertilizer, animal feed, . . .)	
Others	
Total annual income	
Profit (annual income – annual production costs)	
Return on invested capital = $\frac{\text{Profit}}{\text{Total investment cost}} \times 100$	

Appendix II

STANDARDIZATION OF REPORTING DATA ON OPERATING CONDITIONS, ANALYTICAL MEASUREMENT AND MONITORING OF BIOMETHANATION PLANTS FOR PILOT PLANTS AND FIELD OPERATION

(Report of working group II)

This report contains the recommendations of the working group on standardization of reporting data on operating conditions, analytical measurement and monitoring of biomethanation plants. The initial section is devoted to start-up and operating conditions and the types of information relating thereto which should be reported. This covers the entire spectrum of beginning with an empty digester and continues through the establishment of a stable operating system.

Recommended data which should be reported for various purposes are listed in tabular form. Listed also are representative methods of analysis to obtain the data, but it is beyond the scope of this working group to compare various analytical methods and propose specific recommended analytical procedures.

Accepted international units, with slight modification, for the expression of results in terms of concentrations, rates, and yields are recommended. In the final section, remarks on recommendations are given on operating conditions relating to sampling and analyses, and the processes of sampling and analyses in order to provide standardized and meaningful results.

Operating conditions are the conditions which are prescribed for starting and operating a digester. The operating conditions to be reported are:

(a) Starting procedure and inoculum;

(b) Duration of the run at reported conditions (in days);

Table 1. Minimum parameters necessary to describe a biomethanation process

Parameters	*Units*	*Place of measurement*		
		Feedstock		*Digester*
		Solids and slurries	*Wastewaters*	
Total solids (TS)	kg/kg, kg/m^3	X	X	X
Total suspended solid (TSS)	kg/m^3		X	X^a
Volatile solids (VS), mineral matter, and ash content	kg/kg, kg/m^3	X	X	X
Volatile suspended solids (VSS)	kg/m^3		X^b	X^a
Chemical oxygen demand (COD)^c (at least for more dilute wastes)	kg/m^3	X	X^b	X^d
Total Kjeldahl nitrogen (TKN)	kg/kg, kg/m^3	X	X	
Ammonium nitrogen (NH_4^+)	kg/m^3			X
Volatile fatty acids (VFA) (C_2 + C_3 to C_5)	kg/m^3			X
pH	–	X	X	X
Gas composition (percentage CH_4)	Percentage	X	X	X
Gas production rate per unit volume m^3/m^3.d				X
Particle size	–	X		

[a] Only for digester treating wastewater.

[b] Either one or the other.

[c] COD is the best way to express the concentration of a substrate because any change in COD between influent and effluent can be directly related to the methane produced (at the exception of accumulation or loss of biomass in the digester). In addition, volatile solids determinations are often unreliables. However, COD determination of slurries and solids are rendered delicate by the difficulty to get a representative sample within small amount. Grinders should be used to homogenize the material before sampling and great care should be used when sampling. At least three repetitions should be obtained before a result can be declared valid.

[d] In effluent if measured in influent.

(c) Volumetric loading rate and frequency of loading (kg of volatile solids/m^3/day, kg COD/m^3/day) (not for batch systems);

(d) Temperature of feed (mixed feed, water, solids) in °C;

(e) Mean retention time (hydraulic, solids) (symbol 0, in days);

(f) Recycling with details (biomass, effluents);

(g) Mixing method, frequency and duration, relation to loading if semi-continuous;

(h) Mixing power input if full-scale;

(i) Physical and chemical conditions inside digester (pH, temperature, pressure);

(j) Ambient temperature (air and/or soil);

(k) Pressure in gas holder

Table 1 lists the minimum parameters necessary to describe biomethanation processes. They include analyses of both solid and slurry feedstocks as well as digester contents. It is understood that in some field operations not all these minimum parameters will be determinable because adequate analytical instruments are not available. When this is the case, it should be clearly noted.

In the majority of cases operators of biogas systems are not able to collect data on the minimum parameters. It is, therefore, recommended that operators should be provided with centrally managed mobile laboratory units to monitor the minimum biogas system parameters.

In addition to these minimum necessary parameters, other parameters are useful for describing all biomethanation processes because they may influence their performance. With the exception of the tendency to scum formation, they all require more or less sophisticated laboratory facilities. These parameters are alkalinity (kg HCO_3/m), acid-soluble phosphate (kg PO_4/m), nitrogen (kg N/m^3), heavy metal and toxic compounds (kg/m^3), Kjeldahl thermal conductivity (J/m^3.m.°C), microbial biomass or microbial activity (F_{420}, others), scum (thickness, composition, hardness), gas composition (hydrogen).

Table 2. Parameters which are necessary (A) or useful for characterization of feedstock, products and uses

Parameter	*Units*	*Feed stock*	*Uses of digestion end-products*					
			Health & Sanitation	*Fuel Energy*	*Agriculture*			*Waste treatment*
					Weed control[a]	*Fertilizer*	*Feed*	
Volatile fatty acids	kg/m^3	X	–	–	–	–	–	–
Total carbon	kg/kg, kg/m^3	X	–	–	–	–	–	–
Cellulose, hemicellulose lignin	kg/kg, kg/m^3	X	–	X	–	X	X	–
Starch	kg/kg, kg/m^3	X	–	–	–	–	–	–
5-day biological oxygen demand (BOD5)	kg O_2/m^3	–	–	–	–	–	–	xA
Sulphates	kg/m^3	X	–	–	–	–	–	–
Acid-soluble phosphate	kg/kg, kg/m^3	X	–					
H_2S	Percentage	–	–	X	–	–	–	–
Ca, Mg, Na	kg/m^3	–	–	–	–	X	–	–
Total P,N,K	kg/m^3	–	–	–	–	xA	–	–
Pathogens, parasites	viable count/ 100 ml	–	xA	–	–	X	xA	X
Seeds	viable count/ 100 ml	–	–	–	xA	X	–	–
Heavy metals, toxic	kg/m^3	X	X	–	–	X	X	–
Protein content	kg/m^3, kg/kg	xA	–	–	–	–	xA	–
Amino acids, nucleic acids	kg/m^3, kg/kg	–	–	–	–	–	X	–
Viscosity	–	–	–	–	–	X	–	–
Heat capacity (solid)	J/kg	X	–	–	–	–	–	–
Thermal conductivity	J/m^2 .m°C	X	–	–	–	–	–	–
Biodegradable/non-biodegradable matters	Percentage, kg/kg	–	–	X	–	X	X	X

[a] Weed control means the inactivation of seeds of undesireable plants by biomethanation processes.

Table 2 lists data which are either necessary or useful for feedstock characterization and different end-uses of the products of biomethanation processes. Most of these data would be applicable only when a laboratory is available. Necessary data are designated as A.

Results should be reported in a consistent system of units. The working group has adopted, with modifications, the expression of results suggested by the International Union of Pure and Applied Chemistry (IUPAC) and the International Association on Water Pollution Research (IAWPR) (*Reference:* R&D Programme, Recycling of Urban and Industrial Waste, Document XII/MPS/15/82-EN, 8.9.82 Rev.2, Commission of the European Communities, Brussels).

The following subscripts are to be used:

o	influent
e	effluent
r	removed

Concentrations

Concentrations must be related to unit volume or weight (if wet, specify dry weight). To avoid confusion, recommended symbols are:

Symbol	*Name*	*Units*
S	substrate	kg/m^3, g/l
X	active biomass	kg/m^3, g/l

Examples: S_0: kg (TS, VS or COD in load) /m^3

X_e: kg (TS, VS or COD in effluent) /m^3

Rates

Rates should be expressed as per unit working volume and per unit time. Recommended rates and symbols are the following:

Symbol	*Name*	*Units*
$B_V{}^a$	Volumetric loading rate	kg/m^3/day or g/l/d
$r_V{}^a$	Gas (specify methane content) or methane production rate per unit volume	m^3/m^3/day or l/l/d

Examples: $B_{V.\,COD}$: kg (COD)/m^3/day

$B_{V.\,TS}$ or $B_{V.VS}$: kg (TS or VS)/m^3/day

$r_{V.gas}$: m^3 (gas)/m^3/day (65 percentage CH_4,^{b} for example)

$r_{V.CH_4}$: m^3 (CH_4)/m^3/day

Notes:

[a] Subscript V refer to volume whose symbol is V. It means that loading rate and gas/methane production rate are per unit working volume.

[b] Specify conditions, i.e. STP, temperature, pressure, wet or dry gas.

Yields

Yields should always indicate output over input. "Yield" expresses the amount (fraction) of a given product or output (methane, biogas, volatile solids or COD removed), (CH_4, gas, COD_r) obtained from a given amount of feedstock fed to the digester, or input (volatile or total solids or COD) (VS_0, TS_0, COD_0). Recommended yields and symbols are the following:

Symbol	*Name*	*Units*
$Y_{CH_4/So}$	Methane yield	m^3/kg or l/g
$Y_{Sr/So}$	Conversion	kg/kg g/g

Examples: Y_{CH_4/COD_0} : m^3 (CH_4) / kg (COD_0)

Y_{CH_4/COD_2} : m^3 (CH_4) / kg (COD_2)^a

Y_{CH_4/TS_0} : m^3 (CH_4) / kg (TS)

Y_{COD_r/COD_0} : kg (COD_r) / kg (COD_0)

Y_{VS_r/VS_0} : kg (VS_r) / kg (VS_0)

a/ Theoretical value = 0.350 interpret differences

Knowledge of the operating conditions of the digester is necessary in order to make any test or to draw conclusions. It should be stated if the results refer to a transient or steady-state condition. The test procedure and results in steady-state conditions are only meaningful if the digester conditions are held constant during the period of the test, and for a period prior to the test. Any variations in key parameters (temperature feeding, pH, gas production rate etc.) during the test must be recorded.

For convenience the time scale is the retention time of the digester. It is commonly accepted that a steady-state condition is not reached before at least two or three mean hydraulic retention times under the same running conditions have been established. A test should preferably be carried out over several retention times. It is suggested that each test be carried out over a minimum of one retention time with daily (or more frequent) monitoring of key parameters, and variables. Averaged values over this test period should be used.

Regarding sampling, representative samples should be taken at all stages of the process. The methods of sampling and storage, if any, and the frequency of sampling should be given. It is stressed that good sampling of slurries is difficult since decantation occurs very rapidly; this leads to samples that are not always representative of feedstock or digester content. Also when small samples of feedstock or digester contents containing particles or fibrous materials are taken, the number of these particles has a large influence on whether the sample is indeed representative. The use of a grinder is often necessary.

The given information on sampling should be complete enough to evaluate the quality of the sampling.

Analyses should be made on both the soluble and insoluble fraction or their mixture in feedstock and output effluent plus gas plus mixed liquids if different from the effluent. If determinations are made on solid or liquid phases, the separation method and running conditions are to be specified. When mean values are given, the number of measurements (alternatively, continuous recording and the span of time) should be indicated.

In expressing results, it should be revealed that the methane production rate is different from the gas production rate, the gas containing only a certain amount (often 50 or 65 per cent) of methane. Whenever giving the gas production rate, the methane content (percentage) should be given if possible. The presence of methane in the gas is indicated if the gas burns. When giving a concentration of phosphorus, it must be stated under which form this concentration is calculated (mg elemental phosphorus/kg, mg PO_4/kg, ma Na_3PO_4/kg). The concentration of nitrogen should be stated as the amount of nitrogen in the form of ammonium ion, or gNH_4^+ – N/kg. If nitrogen content is given in kg/kg substrate (crop residues. . .) it should refer to the dry weight, or the percentage of moisture, or the percentage of total solids should be given.

These methods which can be used to obtain analytical data are listed as examples. The list is not exhaustive nor does it mean that the listed methods are recommended.

Data	*Methods*
Total solids (TS)	Oven: T = 105°C until constant weight
Volatile solids (VS), mineral matter and ash content	Oven: T = 450°C, 12 hr or 600°C, 3 hr (not reliable because varying losses)
Chemical oxygen demand (COD) (at least for more diluted wastes)	Standard methods (with slurries, pay attention to homogenization method)
Ammonium nitrogen (NH_4^+ – N)	Distillation (pH)[a] direct chemical measurement, electrode[a]
Volatile fatty acids (VFA) (C_2 + C_3 to C_5)	Steam distillation and titration, chromatography (gas, HPLC)
pH	pH meter (pH changes due to loss of CO_2)[a], litmus paper, pH indicating paper
Total alkalinity	Titration
Gas composition	CO_2 absorption, gas chromatography, I.R., mass spectrometry
Particle size	Sieve
Volatile or total suspended solids	Centrifugation and oven (or filtration, decantation [a]
Total organic carbon (TOC)	Special apparatus (apparatus expensive ! for homogenization, microdis-membrator)

Data	*Methods*
Cellulose, hemicellulose, lignin	Van Soest or more specific (interpretation) [a]
Starch	Hydrolysis + sugar determination
Soluble sugars	Chemical or enzymatic method or chromatography
Organic nitrogen	Kjeldhal (total protein content) Total organic nitrogen
Biochemical oxygen demand (BOD) for (wastewater)	Winkler,) interpretation [a] Respirometry)
Bicarbonate alkalinity	Titration, CO_2 elimination + back titration
F_{420}	Fluorescence spectrometry
Amino acids and other nynhydrin positive compounds, before and after hydrolysis	Ion exchange chromatography HPLC
Calcium, magnesium, sodium and potassium	Flame photometry
Total phosphorus	Chemical
Microbial biomass or activity	ATP (interpretation) [a] F_{420} [a] Specific enzymatic activity[a] Coenzymes [a] Specific components[a] Dehydrogenase[a] Total protein content
Biodegradable/non-biodegradable matter	Batch digestion
Compounds toxic to microorganisms	Culture tests
Pathogenic and parasitic organisms	Culture on specific media

[a] Interpretation of results is difficult or method is difficult to use.

If a collection is made of all the data mentioned above they will be extremely useful in evaluating the technical and economic potential of the biomethanation system, and will enable vigorous comparisons to be made of different systems in different countries. However, due to the difficulties in obtaining steady state in semi-continuous systems, and the fact that many substrates are difficult to analyse vigorously, it is considered advisable that the data obtained be checked for internal consistency to ensure that the conclusions drawn are valid. There are a number of ways to check for consistency;

(a) COD balance. Based on the theoretically derived relationship that 0.35 litres of methane are produced at STP per gram of COD destroyed, the difference in the COD of the influent and effluent (in grams/day) multiplied by 0.35 should result in the volume of methane produced per day. If these figures do not agree within ± 10 per cent (due to the standard deviation of the COD analysis on heterogeneous organics) then the reactor is not at steady state, and hence valid conclusions cannot be drawn about performance. To preserve a redox balance this theoretical relationship must hold, and any deviations from it are an indication of gross analytical errors or non-steady-state, e.g. accumulation of organics in the reactor, or washout.

(b) Gas composition. If the chemical composition of the feed is determined, e.g. by COD, organic N, TS, organic C, then the stoichiometric composition of the feed can be calculated, i.e. $C_aH_bO_cN_d$. Using this expression the oxidation state of the carbon can then be determined by assuming $H = +1$, $O = -2$ and $N = -3$, with C resulting in a zero oxidation state of the overall compound. For example, with a typical carbohy-drate, $C_6H_{12}O_6$, the oxidation state of C is O. To produce methane and carbon dioxide from this compound the carbon is oxidized to CO_2 to release 4 electrons. To maintain electro-neutrality these electrons have to reduce a certain amount of the substrate C to CH_4. Since the C in CO_2 has an oxidation state of O + 4, and the C in methane has an oxidation state of –4, the gas produced from the carbohydrate should be approximately 50 per cent CH_4 and 50 per cent CO_2. In reality, some of the CO_2 is dissolved in the liquid phase leading to a gas composition of approximately 55 per cent CH_4 and 45 per cent CO_2. With compounds containing reduced carbon, e.g. long-chain fatty acids in fats, $(CH_2)_n$, the C has an oxidation state of –2. Hence three moles of CH_4 are produced per mole of CO_2, and the gas composition from digesting fat is approximately 75 per cent CH_4 and 25 per cent CO_2. The final composition will depend on pH and the pressure in the gas phase. Hence if the chemical composition of the feed is known the gas composition can be calculated, and this should be close to the actual measured composition. The gas should only contain CO_2 and CH_4, with trace quantities of H_2S and N_2. If N_2 is present in quantities greater than a few per cent then there is an air leak in the system. Also H_2 should only be present in the gas in minute quantities, i.e. 0.1 per cent. Quantities higher than this indicate analytical errors or inhibition.

(c) Inorganic balance. One very simple method to determine whether the digester is at steady state is to analyse the inorganic content of the influent and effluent. This figure is obtained from the difference between the TS and VS contents of the respective streams. Since inorganics elements are conservative, is unaffected by digestion, the content of inorganics in the effluent should be the same as in the influent (± the standard deviation of the respective methods). If they are significantly lower then there is an accumulation of mass in digester, and if they are higher then there is washout. In either case the digester is not at steady state, and some caution should be exercised in drawing firm conclusions from the data.

Finally, in order to ensure that the conclusions drawn from the experimental data are valid, a vigorous statistical analysis of the data should be carried out. This will entail determining the precision of the various analytical methods used, and whether differences in data are statistically significant.

Appendix III

UTILIZATION, HEALTH, AND ENVIRONMENTAL ISSUES

(Report of working group III)

The ultimate success of biomethanation systems is their usefulness to people. That usefulness involves the use of the products, the uses that the system itself may serve, and, most important, the socio-economic aspects of these uses, including the tangible and intangible impacts on a community. Thus, in this report an examination of the use of the products is made first, followed by consideration of useful purposes served by the system, and a discussion of socio-economic issues and impacts.

A. Uses of the products of biomethanation

In table 1, the uses of the gas as an energy source are listed, together with recommendations of the parameters to be measured and the units in which these measurements should be reported.

In considering these uses, one should note that with one or two exceptions the parameters to be measured can generally be measured in the field, under normal conditions of use. The calorific value in joules per cubic metre can not normally be measured in the field. It can be inferred, however, from the methane content, which can be determined precisely enough by measuring a given gas volume before and after the CO_2 has been removed by absorption in water (or limewater). In the case of shaft (mechanical) power, while the time rate of consumption can be measured in the field, the consumption per unit power output will generally be inferred from the nameplate rating of the device and estimates of its efficiency.

Agriculture uses of the outputs of biomethanation systems are listed in table 2, which also lists parameters to be measured and the units in which to record the measurements, as recommended by this working group. This table is based on the assumption that all measurements are being made on a defined effluent stream, i.e., sludge (filtrate), liquid (supernatant), slurry (liquid plus suspended solids after agitation of digester contents), or any combination of these. In addition, any treatment of this effluent stream, such as drying and communition, must be clearly specified before the values of the measured parameters can be meaningfully interpreted by others.

B. Uses of biomethanation as a system

Although consideration of the uses of the products of biomethanation systems involves some health issues, as shown in tables 1 and 2, the system itself plays an important role in public health and sanitation.

Table 1. Energy uses of biomethanation system outputs

Use	*Parameter*	*Units*
Cooking	Calorific value	kj/m^3
	Methane content	Percentage CH_4
	Rate of consumption[a]	m^3/h
Lighting	Rate of consumption[b,c]	m^3/h
Shaft power[d]	Rate of consumption	$m^3/h, m^3/kWh$
Refrigeration (absorption)	Rate of consumption[e]	m^3/h
Process heat[f]	Rate of consumption[e]	m^3/h
Space heating	Rate of consumption[g]	m^3/h
Drying	Rate of consumption[h]	m^3/h

[a] Depends on efficiency of conversion.

[b] Meaningful only if related to light output (lumens).

[c] Light output is not a normal field measurement.

[d] Includes electricity generation, transportation, milling, water lifting.

[e] Meaningful only if $\angle T$ and C_p are reported.

[f] Includes domestic water heating.

[g] Depends on qualitative measure of comfort.

[h] Meaningful only in conjunction with ambient temperature (°C) moisture content (percentage of water), and relative humidity.

Table 2. Agricultural uses of biomethanation system output

(All entries imply an initial definition of the effluent stream that is being considered. See text.)

Use	*Parameter*	*Units*
Fertilizer	Rate of consumption	kg/ha (dry weight)
	Nutrient content (dry weight basis):	
	Available N,[a] P, K (w/w)	g/kg
	Trace elements (w/w)	mg/kg
	Toxic substances concentration (dry weight basis):	
	Toxic heavy metals (w/w)	mg/kg
	Pesticide residues (w/w)	mg/kg
	Viable seeds content	number/species, kg percentage germination
Soil conditioner	*Humus content*	*Percentage organic matter*
Animal feed	Rate of consumption	kg/head/day or kg/ha./day (for fish)
	Nutrient content (dry weight basis):	
	Available Ca, P, fat, protien, carbohydrates (w/w)	mg/g or percentage
	Vitamins	I.U./g
	Trace elements (w/w)	mg/kg
	Toxic substances (dry weight basis):	
	Toxic heavy metals (w/w)	mg/kg
	Pesticide residues (w/w)	mg/kg
	Microbiological quality:	
	Pathogens/parasites	number/g
Livestock Seeding	*Microbiological quality: Pathogens/parasites*	*Number/g*

[a] Includes both organic and ammonia nitrogen

In table 3, the working group has attempted to deal with this role by identifying the parameters to be measured for the two major aspects of this use of such systems, and the corresponding units for reporting these measurements.

The last aspect of the use of biomethanation systems considered by the working group was control of weeds and disease vectors. These are listed in table 4, together with parameters to be measured and units of measurement.

Table 3. Public health and sanitation aspects of biomethanation systems[a]

Use	*Parameter*	*Units*
Residue treatment:		
Animal residues)	(Rate of production	kg/day or t/day
Domestic (human) residues)	(Rate of treatment	kg/day or t/day
Agricultural residues)	(COD conversion[b]	percentage[b]
Industrial residues)	(BOD conversion[b]	percentage[b]
Forest residues)	(Pathogen kill rate[c]	log/day[c]
Water treatment:		
(Removal of pollutants by biological means)	COD conversion[b] BOD conversion[b] Pathogen kill rate[c]	percentage[b] percentage[b] log/day[c]
Vector control[d]	Population	larvae/kg eggs/kg population/ha

[a] See tables 5, 6 and 7 for detailed discussion of parameters and units.

[b] Conversion ratios would be measured where laboratory facilities are available. If only occasional monitoring of field installations is available, with no regular monitoring of the input, then measurement of BOD and COD of the effluent may be all that is practical.

[c] With no laboratory available to monitor the input materials occasional monitoring of field installations would be confined to total viable counts of pathogens and parasites per liter of effluent.

[d] Includes insects and parasites

Table 4. Use of biomethanation systems for controlling weeds

Use	*Parameter*	*Units*
Weed control:		
Aquatic weeds)	(Production rate	t/ha/yr
Terrestrial weeds)	(Removal rate	percentage

It should be noted that table 4 refers to controlling weeds by harvesting them and using them as a feedstock for biomethanation. This is distinct from the survival of viable weed seeds in biomethanation effluents used as fertilizers.

C. Socio-economic issues and social and ecological impacts of biomethanation systems

The technical parameters and characteristics of biomethanation systems play an important role in the acceptance and use of such systems. The technical questions are the first ones asked and preliminary choices are generally made on the basis of how well a particular design meets certain technical criteria. This is an inadequate basis for a choice, however, because more important than the technical characteristics of a system, in terms of acceptance and use, are the quantifiable economic costs and benefits, the quantifiable impacts on an ecological system, and the many intangible non-quantifiable costs, benefits and impacts that a society experiences.

1. Uses of the products of biomethanation

Conventional economic cost/benefit analyses take account of the tangible aspects of the use of biomethanation products by considering such things as:

(a) Costs of energy sources supplemented or displaced by biogas;

(b) Cost of transporting, distributing and converting energy supplemented or displaced;

(c) Cost of fertilizers supplemented or displaced by biomethanation residues;

(d) Cost of transporting and applying fertilizers supplemented or displaced;

(e) Cost of capital;

(f) Cost of labour;

(g) Cost of operation and maintenance;

(h) Cost of end-use devices.

Generally not included, however, in the choice of a biomethanation system to be promoted with public funds is the not easily quantifiable value (or cost) to society of the impact of this alternative energy source on:

(a) Deforestation;

(b) Watershed management;

(c) Health and sanitation;

(d) Food preservation;

(e) Labour;

(f) Employment

(g) Self-sufficiency;

(i) Perception of status;

(j) General quality of life.

An attempt has been made to summarize these issues for energy use in table 5, which should be read in conjunction with table 1, and for agricultural uses in table 6, which should be read in conjunction with table 2. Similarly, in table 7 are summarized these socio-economic issues for health and sanitation aspects of the use of biomethanation systems, as a supplement to table 3.

Table 5. Use of energy from biomethanation – socio-economic issues

Quantifiable aspects

- Fuels or systems displaced (relative calorific value vs. cost):
  - Firewood
  - Charcoal
  - Crop residues
  - Dung
  - Other biomass systems:
    - Gasification
    - Ethanol
    - Methanol[a]
  - Fossil fuels:
    - Kerosene
    - Gasoline
    - Diesel oil
    - LPG
  - Electricity:
    - Grid
    - Local generator
  - Water power (mechanical)
  - Solar energy:
    - Cooking
    - Drying
    - Photovoltaics
  - Wind
- Labour costs
  - Construction
  - Operation and maintenance
- Capital costs
  - Digester
  - Gas storage and distribution
- Cost of end-use appliances/equipment

Non-(or not easily) quantifiable aspects

- Impact on:
  - Food preservation (from cooking smoke and heat)
  - Insect repelling (from cooking smoke and heat)
  - Space heating side effects from cooking
  - Deforestation:
    - Erosion
    - Water control
    - Water tables
  - Alternative use of limited labour pool
  - Employment generation:
    - Construction
    - Collection of feedstock
    - Operation and maintenance
    - New jobs created by increased availability of energy
  - Employment displaced:
    - Jobs associated with previous uses of substrate
    - Jobs displaced by new energy source
  - Human resource/skills:
    - Availability of manpower for technical assistance, maintenance
    - Skills training needed
    - Education
  - Communication (public education required to encourage acceptance)

---

[a] Methanol production is not yet a commercial practice, but it is a laboratory and pilot-plant process.

Table 6. Agricultural uses of biomethanation residues – socio-economic issues

Quantifiable aspects	*Non-(or not easily) quantifiable aspects*
Fertilizer	
Fertilizer/soil conditioner displaced (relative value vs. cost):	Impact on:
Dung	Self sufficiency
Crop residues	Human resources/skills:
Forest residues	Availability of manpower for technical assistance, maintenance
Chemical fertilizer	Skills training needed
Night soil	Education
Effects on crop yields	Communication (education needed for acceptance and use)
Labour costs:	Pollution:
Transportation	Air
Application	Water
Equipment costs:	Soil
Transportation	Habitat for pests
Storage	Soil fertility and land value
Application	Land carrying capacity
Income generation from sale of residues	Employment generation:
Energy costs:	Handling, processing, storing residues
Transportation	Employment displaced:
Processing	Jobs associated with previous uses of feedstock
Application	Safety (sanitation)
Manufacture (of displaced fertilizer)	
Relative concentration of toxic substances	
Feed	
Feed/fooder supplemented or displaced:	Impact on:
Crop residues	Self sufficiency
Commercial feeds	Human resources/skills:
Fooder/forage	Availability of manpower for technical assistance, maintenance
Effect on yield/productivity	Skills training needed
Labour costs:	Education
Transportation	Communication (education needed for acceptance and use)
Packaging/handling	Pollution:
Storage	Air
Use	Water
Equipment costs:	Employment generation:
Transportation	Handling, processing, storage
Storage	Safety (sanitation)
Income generation from sale	Land carrying capacity
Energy costs:	
Processing	
Manufacture Transportations (of displaced feed etc.)	

Table 7. Public Health/Sanitation – Socio-Economic Issues

Quantifiable aspects	*Non-(or not easily) quantifiable aspects*
Capital cost (equipment)[a]	Human resources:
Use of outputs:[b]	Availability of manpower for technical assistance, maintenance
Cost of use	Skills training needed
Income generated	Education
	Communication (education needed for acceptance and use)
	Social organization needed for successful use of systems:
	Latrines
	Night soil/dung collection

[a] Allocation of these costs must be shared among other uses for biomethanation systems, because these systems would not be constructed solely for public health/sanitation purposes.

[b] These are the same as listed in table 1 and table 2.

Annex XI

INSTITUTIONS INVOLVED IN BIOGAS DEVELOPMENT AND RESEARCH

I. Asian and Pacific region

Afghanistan

Department of Agricultural Extension and, Training, Kabul

Ministry of Agricultural Research and Soil Studies, Kabul

Faculty of Science, Kabul University, Kabul

Bangladesh

Bangladesh Agricultural University, Mymensingh

Bangladesh Agricultural Research Institute, Joydebpur

Bangladesh Council for Scientific and Industrial Research, Dhaka

Institute of Fuel Research and Development, Dhaka

Bangladesh Planning Commission, Dhaka

Bangladesh Small & Cottage Industries Corporation

Bangladesh University of Energy & Technology, Dhaka

Environmental Pollution Control Board, Dhaka

Burma

Agricultural Corporation

Livestock Development and Marketing Corporation

China

Biogas Research Institute, Chengdu, Sichuan Province

Sichuan Provincial office for Biogas Development, Chengdu

Sichuan Provincial Institute of Industrial Building Designs, Chengdu

Chengdu Biological Research Institute, Chinese Academy of Sciences

Sichuan Provincial Anti-parasite Research Institute

Sichuan Provincial Agricultural Machinery Research Institute

Sichuan Provincial Academy of Agricultural Science

Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences

Institute of Industrial Microbiology, Shanghai

Internal Combustion Engine Institute, Shanghai

Academy of Agricultural Science Research, Shanghai

Tongji University, Shanghai

Zhejiang Agricultural University, Hangzhou

Zhejiang Biogas and Solar Energy Institute, Hangzhou

Zhejiang Provincial Machinery Research Institute

Zhejiang University of Agriculture

Beijing Solar Energy Institute

Beijing Environmental Protection Institute

Beijing Public Utilities Research Institute

Beijing Teachers Training College

Shandong Provincial Energy Research Institute

Liaoning Provincial Energy Research Institute Liaoning University

Henan Provincial Energy Research Institute

Hebai Provincial Research Institute of Architecture

Hubai Provincial Academy of Agricultural Science

Jiangsu Provincial Biogas Research Institute

Fujian Provincial Research Institute of Microbiology

Jiangsu Provincial Anti-schistosomo Institute

Wuhan University

Chongching South-Western Teachers Training College

Nanjing Academy of Agriculture

Helongjiang Provincial Designing Institute of Architecture

Xinan Biogas Research Institute

China Agricultural Engineering Design Research Institute Microbial Research Institute, Chinese Academy of Sciences

Energy Research Institute, China Economic Planning Commission

Environmental Protection Institute, Ministry of Light Industry

Joint Commission of Rural Reconstruction, Nan Hai Road, Taipei.

Fiji

Department of Agriculture, Suva

University of South Pacific, Suva

Fiji National Youth Council, Suva

Hong Kong

Chinese University of Hong Kong

University of Hong Kong

India

Action for Food Production, New Delhi

Agricultural College and Research Institute, Coimbatore, Tamilnadu

Agricultural Tools Research Centre, Bardoli, Gujarat

Appropriate Technology Development Association, Lucknow

Banaras Hindu University, Varanasi

Bhartiya Agro-Industry Foundation, Pune

Central Arid Zone Research Institute, Jodhpur

Central Food Technology Research Institute, Mysore

Centre for Development Alternatives, Madras

Central Institute of Agricultural Engineering, Bhopal

Central Mechanical Engineering Research Institute, Durgapur

Centre for Study of Science, Technology and Development, New Delhi

Centre for Water Research, Development and Management, Kerala

Central Salt & Marine Chemicals Research Institute, Gujarat

Cotton Technology Research Laboratory, Bombay

Dadar Sewage Purification Plant, Bombay

Directorate of Rural Development, Madras

Gandhian Institute of Studies, Varanasi

G.B. Pant University of Agriculture & Technology, Nainital

Gobar Gas Research Station, Ajitmal, Etawah

Haryana Agricultural University, Hissar

Himachal Pradesh University, Palampur

Indian Agricultural Research Institute, New Delhi

Indian Council of Agricultural Research, New Delhi

Indian Institute of Management, Ahmedabad

Indian Institute of Management, Bangalore

Indian Institute of Petroleum, Dehradun

Indian Institute of Sciences, Bangalore

Indian Institute of Technology, Bangalore

Indian Institute of Technology, Bombay

Indian Institute of Technology, New Delhi

Indian Institute of Technology, Kanpur

Indian Standards Institution, New Delhi

Institute of Economic Growth, New Delhi

Institute of Technology, Coimbatore, Tamilnadu

Khadi and Village Industries Commission, Bombay

Lucknow University, Lucknow

Maharashtra Association for Cultivation of Science, Pune.

Management and Development Institute, New Delhi

Ministry of non-conventional Energy, New Delhi

Ministry of Science and Technology, New Delhi

National Dairy Research Institute, Karnal

National Environmental Engineering Research Institute, Nagpur

National Sugar Institute, Kanpur

Punjab Agricultural University (Department of Soil Science and Department of Agricultural Engineering), Ludhiana

Resources Development Institute, Bhopal

Sewage Disposal Works, Okhla, New Delhi

C.C. Shroff Research Institute, Bombay

Sircilla Cooperative Electric Supply Society, Karimnagar

Small Industry Extension Training Institute, Hyderabad

Sri Parasakthi College for Women, Tirunelveli, Temilnadu

State Planning Institute (Planning, Ressarch and Action Division), Lucknow

Tamilnadu Agricultural University (Department of Farm Machinery), Coimbatore

Tata Energy Research Institute, Bombay

University of Agricultural Sciences, Bangalore

Indonesia

Department of Agriculture, Jakarta

Industrial Research Institute, Jakarta

Padjadjaran University (Institute of Ecology), Bandung

Soil Research Institute, Bogor

Institute of Technology, Bandung

Appropriate Technology Group, Jalan Karto Muja Muja, Yogyakarta

Iran

Bn-Ali Sina University, Hamadan

Selselah Integrated Development Project, Alashtar, Lorestan

Japan

Fermentation Research Institute, Tsukuba-gun

National Institute of Animal Industry, Tsukuba Norindanchi

Agency of Industrial Science & Technology, Ministry of International Trade & Industry, China

Japan Environmental Sanitation Centre, Kawasaki

Asian Environmental Society, Tokyo

Lao People Democratic Republic

Department of Agriculture, Vientiane

Malaysia

ASEAN Protein Project

Malaysian Agricultural Research and Development Institute Serdang

Department of Environmental Sciences, University of Pertanian

National Institute for Scientific and Industrial Research, Kelang

Asian Environmental Society, School of Engineering, Selangor

Sime Darby Plantations, Kuala Lumpur

Nepal

Department of Soil Science and Agricultural Chemistry, Ministry of Agriculture

United Mission, Development and Consulting Services, Butwal

Institute of Agriculture and Animal Science, Tribhuvan

University, Chitwan

Pakistan

College of Engineering, University of Peshawar, Peshawar

National Fertilizer Development Centre, Islamabad

Pakistan Agricultural Research Commission, Islambad

Appropriate Technology Development Organisation, Islamabad

Energy Resources Cell, 167, G-6/3 Islamabad

University of Agriculture, Faislabad

Papua New Guinea

Department of Agriculture, Konedobu

South Pacific Appropriate Technology Foundation, Boranko

University of Technology, Faculty of Agriculture, Box 793 Lae

Department of Environment, Port Moresby

Philippines

Bureau of Agricultural Extension, Manila

Bureau of Animal Industry, Manila

Bureau of Plant Industry, Manila

Bureau of Soils, Manila

Central Luzon State University, Munoz Nunoz Ecija

Maya Farms of Liberty Flour Mills Inc., Manila

Energy Research and Development Centre, Ministry of Energy, Manila

Bureau of Energy Development, Ministry of Energy, Manila

National Science and Technology Authority, Manila

Technology Resource Centre, Ministry of Human Settlements, Manila

University of Philippines, Los Banos

Republic of Korea

Institute of Agricultural Science, office of Rural Development, Suweon

Livestock Experimental Station, Office of Rural Development, Suweon

Department of Rural Energy resources, Office of Rural Development, Suweon

Research Bureau, Office of Rural Development, Suweon

Ministry of Science and Technology, Seoul

Ministry of Agriculture and Fisheries, Seoul

Seoul National University, College of Agriculture, Suweon

Singapore

International Development Research Centre

Faculty of Engineering, University of Singapore

Environmental Engineering Division, Ministry of Environment

Sri Lanka

Engineering Industry Group, Industrial Development Board, Moratuwa

In-service Training Institute, Peradeniya

Department of Small Industries, Colombo

Department of Agricultural Chemistry, University of Peradeniya

Agricultural Research Institute, Mahai Capalama

National Engineering Research and Development Centre, E Kala Jaela

Department of Civil Engineering, University of Sri Lanka, Colombo

Appropriate Technology Group, Hemas Buildings, Colombo

Thailand

Asian Institute of Technology, Bangkok

Department of Agricultural Engineering, Department of Agriculture, Bangkhen, Bangkok

Soil and Fertiliser Division, Department of Agricultural Extension, Bangkhen

Mahidol University

Technical Division, National Energy Administration, Bangkok

Thailand Institute of Science & Technology Research, Bangkok

Applied Scientific Research & Environment Research Departmen, Bangkhen

Sanitation Division, Department of Health, Bang

Viet Nam

Soil and Fertiliser Research Institute, Hanoi

II. Latin America

Argentina

National Agricultural Technology Institute

National University of Tucuman

Brazil

National Technology Institute

Compania de Desenvolvimento Technologico

Centrais Electricas Barasileiras S.A.

Chile

INTEC

Colombia

DER Unit-Regional Ecosystems

National University of Colombia

Guatemala

Mesoamerican Appropriate technology Centre

Central American Industrial Research and Technology Institute

Bionomic Resources Company

Mexico

Metropolitan Autonomous University, Xochimilco

Michoacan University, San Nicolas, Hidalgo

Electric Research Institute

Eco-development Systems

Bioconservacion -S.A.

Trinidad and Tobago

Deptt. of Chemical Engineering, University of West Indies

Govt. of Trinidad

III. Europe

Belgium

Association Internationale de Developpement Rural, Brussels

Institute Agronomique de l'Etat, Gembloux Pe' ronnes-les-Binche, Henegouwen

Laboratory of Applied Enzymology and Natural Polymers, University of Louvain.

Laboratory of General and Applied Microbial Ecology, University of Ghent.

Denmark

Carl Bros. International A/s, Malervangen 1, Glostrup

France

Societe Centrale d' Approvisionnements aux Agri-Culteurs de France (SCAAF)

La Cooperative d' Elevage du Bassin Lyonais

Le Génie Rural

Academy of Agriculture

Ministry of Agriculture

German Democratic Republic

Technical University, Dresden

Germany, Federal Republic of

Technical University, Berlin

Technical University, Darmstadt

Kuratorium fur Technik in der Landwirtschaft, Frankfurt

Institute for soil science and Agricultural Chemistry, Göttingen University

Hohenheim University

München University

Ferdinand Schmidt Deutsche - Futter Konservierungs - Gesellschaft, Verden

Institute for Humus Research, Federation Research

Institute for Agriculture Volkenrode

Technical University, Hanover

Hungary

Institute of Heat Transfer, Budapest

Agricultural University, Szekeres

Research Institute for Soil Science and Agro-chemistry, Hungarian Academy of Sciences

State Design Office of Civil Engineering, Budapest

Italy

Stazione Sperimentale dell'Ente Autonomo Acquedatto Pugliese

University of Milan

University of Turin

Netherlands

Department of Water Pollution Control, Agricultural University, Wageningen

Spain

Ministry of Agriculture

Institute of Nasional de investigaciones Agronomicos, Madrid

Switzerland

Swiss State Agricultural Research Institute, Bern

USSR

All-Union Research Institute of Fertilizers and Agronomic Soil Sciences

United Kingdom

Rothamsted Experimental Station, Hertz

National Agricultural Advisory Service

Agricultural Land Service

National Institute of Agricultural Engineering

Institution of British Agricultural Engineers

Microbiology Department, University College, Cardiff

Department of Mechanical and Production Engineering, The Polytechnic of Wales, Wales

Water Research Centre, Elderway, Hertfordshire

Rowett Research Institute, Aberdeen

North of Scotland College of Agriculture, Aberdeen

Energy Technology Support Unit, Atomic Energy Research Establishment, Oxfordshire

Department of Chemical Engineering and Chemical Technology, Imperial College, London

IV. Other countries

Canada

Division of Biological Sciences, National Research Council of Canada, Ottawa

University of Alberta, Edmonton

University of Manitoba, Winnipeg

University of Western Ontario, Ontario

Brock University, Ontario

University of Toronto, Toronto

University of Guelph, Guelph

Environment Canada, Burlington

University of Waterloo, Waterloo

University of British Columbia, Vancouver

New Zealand

Invermay Agricultural Research Centre, Mosgiel

United State of America

State Water Survey Division, Illinois

Bureau of Chemistry and Soils, United State of America Department fo Agriculture

Department of Sanitary Engineering, University of Illinois, Urbana

Department of Microbiology University of Illinois, Urbana

Department of Bacteriology, University of Wisconsin, Madison

College of Engineering, University of California

Department of Agricultural Engineering, Cornell University

Agricultural Research, Science and Education Administration, United State of America Department of Agriculture

V. International Organizations

Economic and Social Commission for Asia and the Pacific (ESCAP)

Food and Agriculture Organization of the United Nations (FAO)

United Nations Development Programme (UNDP)

World Health Organisation (WHO)

United Nations Educational Scientific and Cultural Organization (UNESCO)

United Nations Environment Programme (UNEP)

United Nations Children's Fund (UNICEF)

United Nations Industrial Development Organization (UNIDO)

United Nations University (UNU)

Commonwealth Science Council (CSC)

International Development Research Centre (IDRC)

International Development Bank (IDB)

Annex XII

CONVERSION FACTORS AND USEFUL EQUATIONS

Area of rectangle = length x breadth
circle = π x (radius)^2

Area of sides of a cylinder = π x diameter x height

Volume of rectangle tank = length x breadth x height

Volume of a cylindrical tank = π x (radius)^2 x height

Volume of frustrum of a cone = (cf. figure 108a) = 0.2618h ($D^2 + Dd + d^2$)
(used for taper design gas plants)

1 metre = 39.37 in = 3.28 ft

1 foot = 0.305 metre = 30.5 cm

1 inch = 2.54 cm

1 m^2 = 10.764 sq ft

1 ft^2 = 0.0929 m^2

1 m^3 = 1,000 litres

1 m^3 = 35.3 cu ft

1 litre (cubic decimetre) = 10^3 cm^3 = 0.0353 cu ft

1 kgf/cm^2 = 0.0283 m^3 = 28.3 litres

1 lb/in^2 (psi) = 6.89 kN/m^2 = 0.0703 kgf/cm^2
= 27.7 in water gauge
= 0.06805 atmospheres

1 kg/cm^2 = 14.22 lb/in^2
= 0.9678 atmospheres
= 10,000 mm water gauge

1 lb = 0.454 kg

1 kg = 2.21 lb

1 MJ = 238.8 kcal = 947.9 BTU

(1 MJ/m^3 = 26.75 BTU/ft^3)

1 BTU = 1.055 kJ = 0.252 kcal

1 BTU/ft^3 = 37.2 kJ/m^3 = 8.894 kcal/m^3

1 United States gallon = 3.785 litres

1 British (Imperial) gallon = 4.55 litres

Lumens = Candle power x 2 π

25 watt bulb ≅ 230 lumens

40 watt bulb ≅ 430 lumens

60 watt bulb ≅ 730 lumens

100 C P ≅ 620 lumens

Annex XIII

GLOSSARY OF TERMS

Anaerobic bacteria:	Bacteria which do not require oxygen to live.
Cattle:	In this publication "cattle" refers to "cows" and "buffaloes".
C P:	Candle power, a measure of light.
Digestion:	The process by which complete organic molecules are broken down into simpler molecules; in this case the anaerobic process (fermentation), by which bacteria accomplish this decomposition.
Effluent:	The liquid that comes out of the gas plant (see slurry).
Flame lift off :	Used to describe a flame which does not touch the flame port of the stove. It can lift off so much that the flame goes out.
Gobar gas:	Alternative name for biogas where gas is formed from cow or buffalo dung (Gobar is the Hindi and Nepalese word for these specific types of dung).
Marsh gas:	Alternative name for biogas where gas is formed in marshes.
Parasite:	Something which lives on a different larger animal, e.g., worms living in the stomach of an animal.
Pathogens:	Organisms which can cause disease in both animals and humans, e.g., typhoid.
Retention time or residency:	Time the slurry spends in the digester.
Scum:	Light material that rises to the surface of the slurry in the digester.
Sludge:	The precipitate at the bottom of the digester formed mostly of solid substances.
Sludge gas:	Alternative name for biogas where gas is formed in sewerage.
Slurry:	The liquid manure that comes out of the gas plant. It is sometimes called effluent.
Total solids:	The ratio by weight of solids left after all the water has evaporated at about 100°C to the original sample of slurry.
Toxins:	Poisons which can kill bacteria.
Volatile acids:	Low molecular weight fatty acids.

REFERENCES

1. A Chinese Biogas Manual. Translated from the Chinese by Michael Crook and edited by Ariane van Buren from the original by the Office of the Leading Group for the Propagation of Marshgas, Sichuan Province. China (London, Intermediate Technology Publications, 1979).

2. Andrew Barnett, "Biogas technology : a social and economic assessment", in Andrew Barnett, Leo Pyle and S.K. Subramanian, Biogas Technology in the Third World : A multidisciplinary Review (Ottawa, Canada, International Development Research Centre, 1978).

3. Hesse, P.R. and R.V. Misra Prospects and problems of energy conservation through Organic recycling in Asia. In "Energy Conservation and Use of Renewable Energies in the Bio-Industries", Pergamon Press, Oxford 1982.

4. Hesse, P.R. Storage and Transport of Biogas. Field Doc. 23 RAS/75/004 Food and Agriculture Organisation of the United Nations, Rome.

5. 'Home Made Biogas' Field Doc. 4 RAS/75/004. Food & Agriculture Organisation of the United Nations, Rome.

6. Indian Council of Agricultural Research. The Economics of Cow Dung Gas Plants – A Report 1976.

7. Information made available by the Chinese authorities to the members of the Interregional Bio-gas Study Tour in China from 1 to 21 September 1979, organized by the United Nations.

8. Mahdi, S.S. and R.V. Misra Meeting the fuel energy and fertiliser needs of the rural sector through biogas system. In "Organic Recycling in Agriculture" Fertiliser Division, Ministry of Agriculture and Irrigation, Government of India, New Delhi.

9. Parikh, J.K. Planning of rural energy Systems : issues and perspectives. In "Monographs on Appropriate Industrial Technology" No.5, United Nations 1979.

10. Raman N.V. and others. "Ferrocement gas holder for biogas plants", paper submitted to the International Conference on Materials of Construction for Developing Countries, held in Bangkok in August 1978.

11. Reddy, A.K.N. ; Prasad, C.R; and Krishna Prasad, K. 1973 Biogas Plants : prospects, problems and tasks. Indian Institute of Science, Bangalore – 560012.

12. Srinivasan, H. "Design aspects of biogas plants", paper submitted to the Expert Group Meeting on Biogas Development, held at ESCAP from 20 to 26 June 1978.

13. Singh Ram Bux, Biogas Plant. Gobar Gas Research Station, Ajitmal, Ettawah, India, 1971.

14. Sichuan Provincial Institute of Industrial Buildings Design, "Construction of marsh-gas-producing tanks (digesters) in simple ways"

15. Simplified Biogas Digester Drawings. Compiled by the South-west Engineering Institute, Beijing, 1979. (In Chinese).

16. Sichuan Provincial Office of Biogas Development, "Bio-gas technology and utilization", Chengdu Seminar, China, 1979.

17. Teaching Materials UNDP-ESCAP-FAO-China Biogas Training Course, Chengdu Biogas Scientific Research Institute, People's Republic of China.

18. Standard Methods for the Examination of Water and Wastewater, XIV Edition, American Public Health Association 1015 Eighteenth Street NW Washington, DC 20036.

19. Van Brakel, J. The Ignis Fattus of Biogas, Delft University Press, The Netherlands 1980.

ENERGY RESOURCES DEVELOPMENT SERIES

1. RURAL ELECTRIFICATION. United Nations publication, Sales No. 54.II.F.1. Price $US 0.80. Available in English.
2. PROCEEDINGS OF THE REGIONAL SEMINAR ON ENERGY RESOURCES AND ELECTRIC POWER DEVELOPMENT. United Nations publication, Sales No. 62.II.F.8. Price $US 5.00. Available in English.
3. RURAL ELECTRIFICATION IN ASIA AND THE FAR EAST. United Nations publication No. ST/TAO/SER.C/63. Available in English.
4. PUBLIC ELECTRICITY SUPPLY – A MANUAL ON MANAGEMENT. United Nations publication, Sales No. 66.II.F.3. Price $US 2.00. Available in English.
5. THE ROLE AND APPLICATION OF ELECTRIC POWER IN THE INDUSTRIALIZATION OF ASIA AND THE FAR EAST. United Nations publication, Sales No. 66.II.F.4. Price $US 1.50. Available in English.
6. COMPREHENSIVE ENERGY SURVEYS – AN OUTLINE OF PROCEDURE. United Nations publication, Sales No. 67.II.F.14. Price $US 1.00. Available in English.
7. PUBLIC ELECTRICITY SUPPLY – A MANUAL ON UNIFORM SYSTEM OF ACCOUNTING. United Nations publication, Sales No. 67.II.F.16. Price $US 2.00. Available in English.
8. THERMAL POWER STATIONS – A TECHNO-ECONOMIC STUDY. United Nations publication, Sales No. E.70.II.F.2. Price $US 1.50. Available in English.
9. REPORT OF THE SEMINAR-CUM-STUDY TOUR ON LOAD DESPATCH TECHNIQUES AND APPLICATION OF COMPUTER TECHNOLOGY TO POWER SYSTEM ENGINEERING PROBLEMS. United Nations publication, Sales No. E.71.II.F.14. Price $US 4.00. Available in English.
10. BOILER CODES IN THE ECAFE REGION: SUGGESTED GUIDELINES FOR THE OPERATION, CARE AND INSPECTION OF BOILERS. United Nations publication, Sales No. E.72.II.F.21. Price $US 1.50. Available in English.
11. PROCEEDINGS OF THE TWELFTH SESSION OF THE SUB-COMMITTEE ON ENERGY RESOURCES AND ELECTRIC POWER. United Nations publication, Sales No. E.74.II.F.14. Price $US 12.00. Available in English.
12. URBAN ELECTRIFICATION - PLANNING. United Nations publication, Sales No. E.75.II.F.6. Price $US 6.00. Available in English.
13. PROCEEDINGS OF THE INTERGOVERNMENTAL MEETING ON THE IMPACT OF THE CURRENT ENERGY CRISIS ON THE ECONOMY OF THE ESCAP REGION. United Nations publication, Sales No. E.75.II.F.7. Price $US 10.00. Available in English.
14. NATIONAL POWER GRIDS AND EXTRA-HIGH-VOLTAGE SYSTEMS IN THE ESCAP REGION. United Nations publication, Sales No. E.75.II.F.13. Price $US 4.00. Available in English.
15. PROCEEDINGS OF THE SECOND SESSION OF THE COMMITTEE ON NATURAL RESOURCES. United Nations publication, Sales No. E.76.II.F.11. Price $US 8.00. Available in English.
16. PROCEEDINGS OF THE MEETING OF THE EXPERT WORKING GROUP ON THE USE OF SOLAR AND WIND ENERGY. United Nations publication, Sales No. E.76.II.F.13. Price $US 9.00. Available in English.
17. PEAK LOAD COVERAGE WITH PARTICULAR REFERENCE TO GAS TURBINES AND HYDROELECTRIC PLANTS. United Nations publication, Sales No. E.77.II.F.19. Price $US 9.00. Available in English.
18. PROCEEDINGS OF THE SEMINAR AND STUDY TOUR ON ELECTRICITY DISTRIBUTION SYSTEMS IN URBAN AREAS AND THEIR INTEGRATION WITH TRANSMISSION SYSTEMS. United Nations publication, Sales No. E.78.II.F.8. Price $US 10.00. Available in English.
19. PROCEEDINGS OF THE WORKSHOP ON BIOGAS AND OTHER RURAL ENERGY RESOURCES AND THE ROVING SEMINAR ON RURAL ENERGY DEVELOPMENT. United Nations publication, Sales No. E.79.II.F.10. Price $US 10.00. Available in English.
20. PROCEEDINGS OF THE WORKING GROUP MEETING ON ENERGY PLANNING AND PROGRAMMING AND OF THE COMMITTEE ON NATURAL RESOURCES, FIFTH SESSION. United Nations publication, Sales No. E.79.II.F.11. Price $US 12.00. Available in English.
21. GUIDEBOOK ON BIOGAS DEVELOPMENT. United Nations publication, Sales No. E.80.II.F.10. Price $US 11.00. Available in English.
22. PROCEEDINGS OF THE WORKING GROUP MEETING ON EFFICIENCY AND CONSERVATION IN THE USE OF ENERGY. United Nations publication, Sales No. E.80.II.F.12. Price $US 11.00. Available in English.
23. STUDY ON OPTIMIZATION OF THE UTILIZATION OF ELECTRICITY GENERATING PLANTS. United Nations publication, Sales No. E.82.II.F.5. Price $US 8.00. Available in English.
24. PROCEEDINGS OF THE ESCAP/FAO/UNEP EXPERT GROUP MEETING ON FUELWOOD AND CHARCOAL. United Nations publication, Sales No. E.82.II.F.10. Price $US 11.00. Available in English.
25. PROCEEDINGS OF THE COMMITTEE ON NATURAL RESOURCES, EIGHTH SESSION AND OF THE REGIONAL EXPERT GROUP MEETING ON THE FOLLOW-UP OF THE NAIROBI PROGRAMME OF ACTION ON NEW AND RENEWABLE SOURCES OF ENERGY. United Nations publication, Sales No. E.83.II.F.8. Price $US 19.00. Available in English.
26. FUELS FOR THE TRANSPORT SECTOR: COMPRESSED NATURAL GAS (CNG). United Nations publications, Sales No. E.84.II.F.5. Price $US 5.00. Available in English.

Note: Publication Nos. 1-10 were issued without an Energy Resources Development Series number.

كيفية الحصول على منشورات الامم المتحدة

يمكن الحصول على منشورات الامم المتحدة من المكتبات ودور التوزيع في جميع انحاء العالم . استعلم عنها من المكتبة التي تتعامل معها أو اكتب الى : الامم المتحدة ، قسم البيع في نيويورك او في جنيف .

如何购取联合国出版物

联合国出版物在全世界各地的书店和经售处均有发售。请向书店询问或写信到纽约或日内瓦的联合国销售组。

HOW TO OBTAIN UNITED NATIONS PUBLICATIONS

United Nations publications may be obtained from bookstores and distributors throughout the world. Consult your bookstore or write to: United Nations, Sales Section, New York or Geneva.

COMMENT SE PROCURER LES PUBLICATIONS DES NATIONS UNIES

Les publications des Nations Unies sont en vente dans les librairies et les agences dépositaires du monde entier. Informez-vous auprès de votre libraire ou adressez-vous à : Nations Unies, Section des ventes, New York ou Genève.

КАК ПОЛУЧИТЬ ИЗДАНИЯ ОРГАНИЗАЦИИ ОБЪЕДИНЕННЫХ НАЦИЙ

Издания Организации Объединенных Наций можно купить в книжных магазинах и агентствах во всех районах мира. Наводите справки об изданиях в вашем книжном магазине или пишите по адресу: Организация Объединенных Наций, Секция по продаже изданий, Нью-Йорк или Женева.

COMO CONSEGUIR PUBLICACIONES DE LAS NACIONES UNIDAS

Las publicaciones de las Naciones Unidas están en venta en librerías y casas distribuidoras en todas partes del mundo. Consulte a su librero o diríjase a: Naciones Unidas, Sección de Ventas, Nueva York o Ginebra.

Printed in Thailand
July 1984 – 2,825

Price: $US 17.50

United Nations Publication
Sales No.: E.84.II.F.14
ST/ESCAP/275