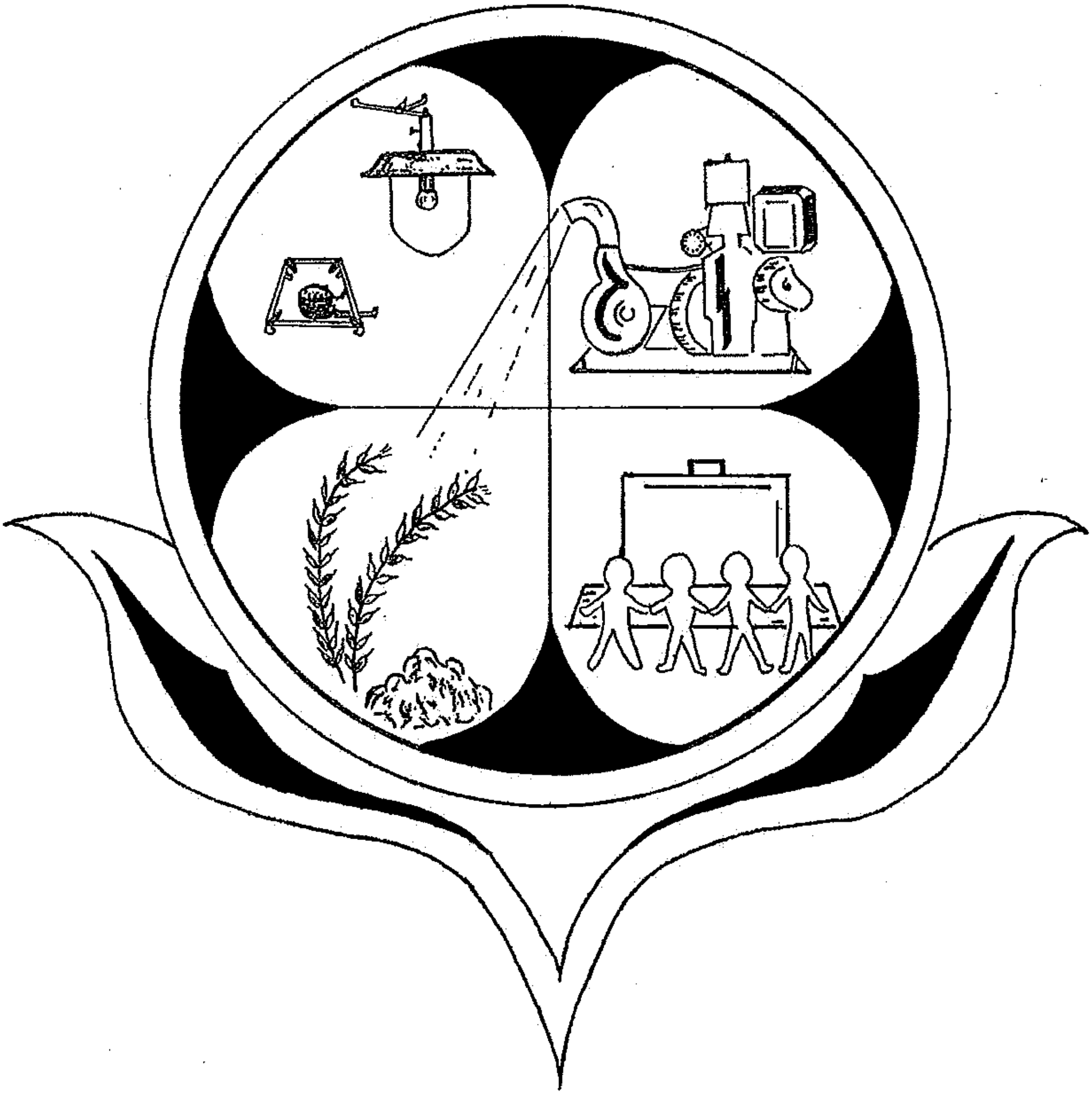
BIOGAS

Challenges And Experience From Nepal

Vol. I



United Mission To Nepal

BIOGAS

CHALLENGES AND EXPERIENCE FROM NEPAL
VOL. I

Authors:

John Finlay, Mamie M. Lau-Wong,
David Fulford, Andrew Bulmer

UNITED MISSION TO NEPAL

Cover design: by Mamie Lau-Wong

ABOUT THE AUTHORS

Andrew Bulmer, BA, General Arts from Durham University, U.K. After his studies he worked for 4 years in Orissa, India, with the village Reconstruction Organization which aimed to assist village communities after being devastated by cyclones. Since then he has been in Nepal, living largely in one community for over 4 years and involved in general development activities there, as well as being specifically concerned with assessing the effectiveness of community Biogas Systems.

John Finlay, C. Eng., MI Prod E., worked in the engineering industry in U.K. for 17 years in various positions including value analysis, and organization and method study. He has been working in Biogas research in the Development and Consulting Services since 1974, and has presented papers on this subject in various countries. He has also compiled and technically edited the United Nations book 'Guidebook on Biogas Development'. His particular concern has been reliable cattle dung biogas plants and accessories suitable for village use which are low cost but also efficient.

David Fulford, B. Sc., Physics from Bristol University, U.K. In previous assignments, he has worked as scientific officer at RAP, Farborough, researching on fuel system for aircraft. He was also research assistant at the University of Reading, where his interests were in the Humphrey Pump and development of appropriate technology for developing countries. After joining the Biogas programme at the Development and Consulting Services, he researches on the wet type gas meter and the Humphrey Pump. He has published various papers and reports in this field.

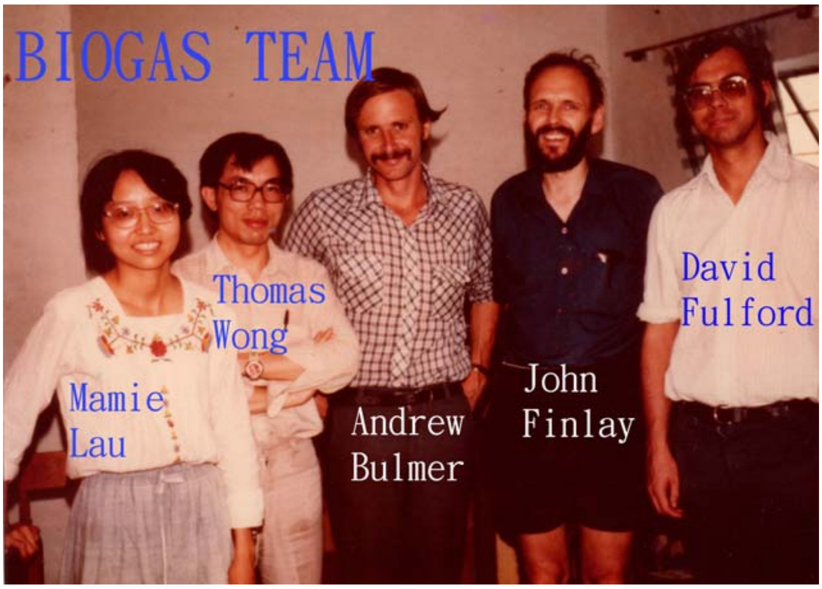
Mamie M. Lau-Wong, B. Sc., Ph.D., received her doctorate in Chemical Engineering at Cornell University, U.S.A., where she specialized in culturing aerobic and anaerobic micro-organisms for industrial purposes, and computer simulation of fermentation processes in living ruminants. As consultant to the Development and Consulting Services of the United Mission to Nepal, she has been engaged in Biogas research and training, presented papers in Biogas Conferences, and published various papers in this field. She is also involved in the production and field testing of nitrogen-fixing bacterial fertilizer for cereal crops.

Preface to the 2013 edition of
Biogas – Challenges and Experience from Nepal

With treasured memories, I embarked on preparing an electronic version (2013 edition) of this two-volume book as a tribute to two distinguished persons: Mr. John Finlay and Dr. Thomas KH Wong, who had served on the Biogas Team of the Development and Consulting Services (DCS) of the United Mission to Nepal (UMN).

Right after our marriage, Thomas and I set off for Nepal in January 1980. Our adventure began with an intensive and arduous 6-month study of the Nepali language that climaxed with the Village Stay. We soon joined the Biogas Team in Butwal in the southern Terai of Nepal. It comprised of five members, who enriched the Team with their diversified expertise and experience.

Photo taken at the DCS office in Butwal



The team leader John Finlay, being a ‘practical’ man, specialized in improving the building and design of biogas plants, gas stoves and lamps. Corrosion and leaking of the gas drum was a major problem of the Indian type design; whereas the Chinese dome design required good masonry skill that was hard to find. When we joined the team, John had started to experiment on the ‘plug -flow’ design (introduced by Prof. Jewell of Cornell University where I did my PhD), and developed it into what John called the ‘Tunnel Plant’, which was simpler to build and easier to maintain.

Dr. David Fulford, another senior member on the team, often impressed me with his burst of creative ideas and his passion for the Humphrey Pump. I still recall the occasions when we crossed streams and valleys on his motor bike to do trouble-shooting for biogas plants in the hills and villages.

Then there was Mr. Andrew Bulmer, whom I saw rarely as he stayed at the Madhubasa village for developing a community biogas plant there. Being patient and courteous, Andrew was ideal for this job.

Now Thomas, with his expertise in finance and operational management, served as consultant and director on the Board of the Gobar Gas tatha Krishi Yantra Bikash Pvt. Company (in short, the Gobar Gas Company), set up jointly by the UMN and the Nepali Government back in 1977. The capital costs of the plants were subsidized by the Agricultural Development Bank of Nepal with grants from agencies like UNDP.

Gobar Gas Company staff

Thomas later became the Assistant Economic Development Secretary of the UMN.

Meanwhile, after setting up a research laboratory at the Gobar Gas Company, I recruited and trained up the Research Scientist, Mr. Govinda Devkota. As gas production drops with surrounding temperature, research areas have included methods and devices to enhance gas production in cold climates. I also performed economic and financial analysis of biogas systems, and compared them for different scenarios: cooking, lighting, as well as income generating activities such as using biogas for milling, hulling and irrigation.

By 1987, over 2000 plants had been built by the Gobar Gas Company. The seeds that our Team planted flourished, as other biogas companies and international projects have sprung up since then. By 2011, some 250,000 plants had been installed, benefiting over a million people across the country, and saving a colossal amount of fuel-wood and trees. Our pioneering efforts had helped to spark off the biogas industry in Nepal, and left a legacy that made biogas technology viable and accessible to the Nepali people, up to this very day.

This 2-volume manuscript, first published in 1985, is a comprehensive collection and record of the work, ideas, experience and drawings of the UMN Biogas Team. I hope the data, designs and methodologies will be useful to others working in this field.

January 2013

Dr. Mamie Lau-Wong
Co-author and currently Principal Officer
Environmental Protection Dept. of the Hong Kong Government

PREFACE

For the past 30 years, the United Mission to Nepal has sought to meet the basic needs of people in Nepal, related to the areas of medical, educational and economic development. Its personnel have come from many different lands with various qualifications and skills, working toward the enablement of people by offering opportunity and training. There has been a mutual learning and sharing experience, resulting in projects and programmes which emphasise service towards others and the equitable sharing of benefits among the less advantaged and privileged.

Biogas is one area of the development and sharing of appropriate technology which is geared to making renewable energy resources available to those who need them. For the past 7 years, the Development and Consulting Services of UMN, at Butwal, has assigned and supervised the research and development of improved biogas plants and appliances, striving to make this equipment more efficient, effective and economical. Design work and production of biogas plants and appliances have been closely monitored by DCS engineers and technicians in the laboratory and workshops, as well as in the field. Testing of the performance of installed biogas plants and related equipment has been oriented to the customers on the farms of Nepal and it has been carefully monitored to ensure not only quality control, but also quality of operation.

This book describes the concept, purposes, implementation, constant revision, and implications of the whole process and its history. Amply illustrated and informative, the book records the achievements (and failures) of a dedicated task force which has persisted in a quest for advancing a technology, despite limited facilities. They have also gone beyond the mere mechanics and technicalities to address the economic, social and management aspects of biogas technology in the context of Nepal as a culture and society seeking development goals.

May I take the opportunity to commend the authors of this material for so ably documenting the biogas story and for the untiring efforts they have made. Commended also are the Tradesmen and Technicians of Nepal, without whose help much would have not been accomplished. This book is a testimonial to a joint venture of Nepali and Expatriate Cooperation at DCS in Butwal.

Kathmandu
January 1984

Al Schlorholtz
Economic Development Secretary
United Mission to Nepal.

ACKNOWLEDGEMENT

Since its commencement in 1974, the biogas research, development, and extension work undertaken at the Development and Consulting Services has been financially supported by three agencies:

The United States Agency for International Development (Grant No. : 498-0251 (357-0139) (OPG) Nepal).

The Mennonite Central Committee, U.S.A., and

The Canadian High Commission Small project Fund.

We would like to express our grateful appreciation to their assistance.

Written materials and diagrams used in Ch, 2, 5, 6, 7 and 9 in Vol. I are partly based on the "Guidebook on Biogas Development" published by the United Nations Economic and Socia1 Commission for Asia and the Pacific. Their permission for the use of the material is gratefully acknowledged.

Besides the four authors, significant research and deve1oplment were accomplished by Mr. Nick Peters. He pioneered in adapting the concrete dome p1ant for Nepal and developing the plastering system for making the dome gas tight.

Last but not least, credit goes to the staff of the Gobar Gas tatha Krishi Yantra Bikash Private Ltd., and to the many other Nepalis and expatriates whose cooperation has contributed considerably to this work.

* * * * * * * * *

Each chapter in this book represents the opinion of its individual author, and it may not necessarily reflect the opinion of the United Mission to Nepal or the other authors.

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BIOGAS RESEARCH AND DEVELOPMENT PUBLICATIONS AND DRAWINGS

Available at the Development and Consulting Services, or the EDB Service Office, United Mission to Nepal, P.O. Box 126, Kathmandu, Nepal.

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Springfield, Virginia, 22161, U.S.A.
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PB85 - 195477	Lau-Wong, M. (1984). The Development of Biogas in Nepal.
<u>Paper Series</u> :	Lau-Wong, M. (1985). Studies on the Dynamics of Biogas Processes. No. 1 - 5. (1) Modelling of Biogas Processes. (2) Analysis of the Kinetic Data of 3 Plant Designs Installed in Nepal and the Effect of Retention Time & Temperature. (3) The Effect of Slurry Moisture Content. (4) The Effect of Pressure on Gas production. (5) Prediction and Optimization. **?fld^p Clorj** 22/1985 Editor: BORDA, Bremem Overseas and Development Association, Bahnhofsplatz 13,D-2800 Bremen 1, Federal Republic of Germany Lau-Wong, M. (1986). The Economics of Biogas Systems - Summary. BIOGAS (Nepal) Newsletter, Number 22 Feb 1986.

DRAWINGS

Floating Steel Drum Design				Drawing No.
(Nominal Gas Production) :	100cft	200cft	350cft	500cft
Gas plant construction - straight type	D221/1	D228/0	D241/1	D161/1
Gas plant construction - taper type	D225/0	D220/0	D239/1	D169/1
Gas Holder manufacturing details	D163/0	D164/0	D240/0	D256/1
Concrete floor construction - straight	-	-	-	D168/1
Concrete floor construction - taper type	D124/1	D125/1	-	D170/1
Water (condensate) removing device for gas pipes	D329/1	D329/2	D332/2	D332/2

Special Night Soil Plant, 350cft

Gas plant construction - straight type	D231/1
Gas holder manufacturing details	D230/0
Night soil plant site layout	2000-142/3

Fixed Concrete Dome Design

(Digester volume, m^3) :	10	15	20	--->50 (not yet tested)
Gas plant	D333/1	D334/1	D336/1	D335/1
Concrete dome construction templates	D338/2	all same as 10 m^3		
Agitator (slurry mixer) manufacturing details	D337/2	D337/2	D337/2	-

Extended concrete dome gas plant

Gas plant	2000-143/1
Steel moulds	2000-144/1

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'Biogas -- Challenges and Experience from Nepal' comprises two volumes : Vol. I is a practical guide for field workers, whereas Vol. II includes more theory and research work.
The authors of each chapter are listed below.

Cover design: by Mamie Lau-Wong

Volume I

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LIST OF DRAWINGS

EXPLANATIONS

The notation used in the drawings and equations in this book follows international practice as far as possible. Almost all dimensions are shown in millimetres, with a gap between the metres and the millimetres, ie. 1,570. A few dimensions (such as for GI pipe) are in inches, shown as: in or ".

Areas are in square millimetres: mm^2, or in square metres: m^2. 1 m^2 = 1,000,000 or 10^6 mm^2. 1 hectare of land area = 10,000 or $10^4 m^2$.

Volumes are in cubic millimetres: mm^3, or in litres: l. 1 l = 1,000,000 or 10^6 mm^2, or in cubic metres: m^3. 1 m^3 = 10^3 l.

Mass is given in kg, or tonnes (1 tonne = 1,000 kg.)
Flow rate is given in lit/min or m^3/sec. $1m^3$/sec = 60,000 lit/min.

Dimensions for masonry are shown rounded to the nearest 10 mm (1,570), which implies that the tolerance is: ± 5 mm. Dimensions for machined parts, such as for gas stoves, are shown rounded to the nearest 1 mm (52), implying a tolerance of ± 0.5 mm. Some dimensions are shown to the nearest 0.1 mm (12.3), implying a tolerance of ± 0.05 mm. Tolerance are not usually shown in drawings, but can be inferred from the way in which the dimensions are written.

When a drawing is of the outside of an object, in elevation, only the outline is drawn. If an object is shown in section, to reveal internal details, the sectioned parts are shaded to indicate the material from which they are made. A key is given in Figure E.1.

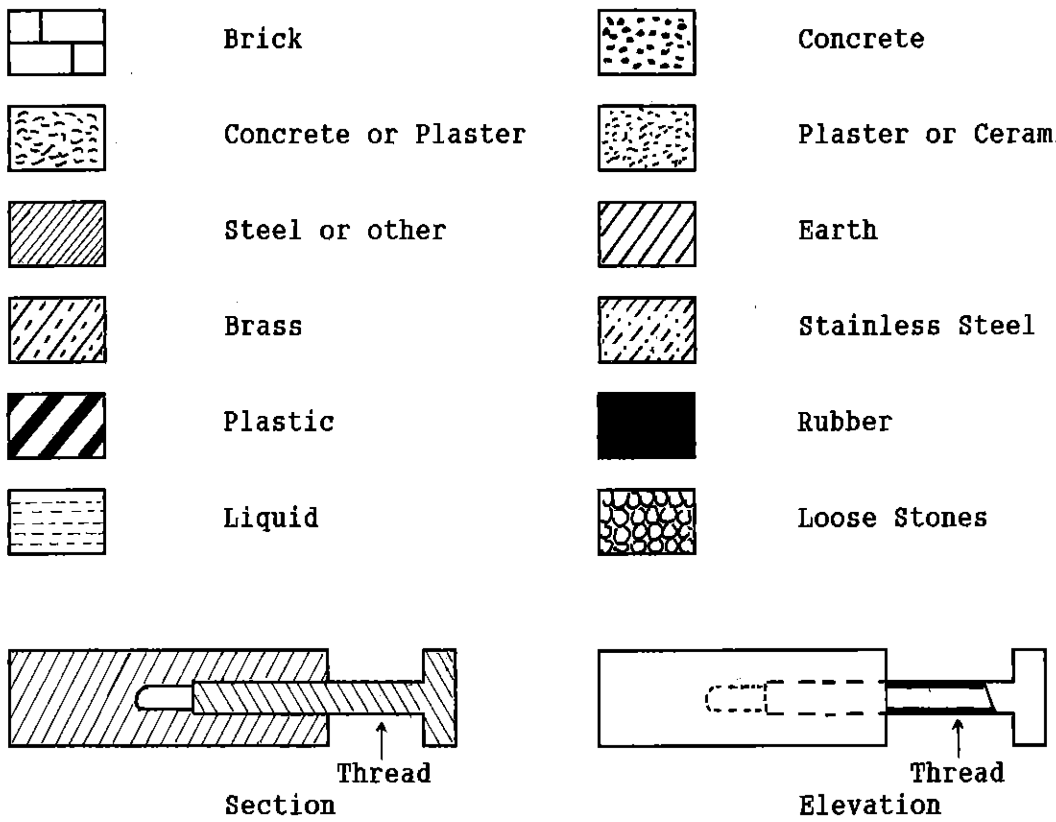


Fig. E.1 <u>A Key to the Shading of Different Materials Used in Drawings: How to Screw Threads also Indicated</u>

Letter	Meaning		Units	Chap.
a	Atmospheric Pressure	10330	kg/mm^2	6
A_o	Area of an orifice		m^2	7
A	Area of a flame port or pipe fitting		m^2	7
pc	Gas production per kg. volatile solids		m^3/kg	5
C_d	Discharge Coefficient of an orifice		-	7
C_g	Calorific Value of biogas	5.14	kCal/l	7
d	Proportion of dry matter in feedstock		%	5
d_o	Diameter of an orifice		mm	7
d_t	Diameter of a throat		mm	7
D	Diameter of a pipe (see ID, OD, O)		m	6
f	Fraction of volatile solids in feedstock		-	5
f	Friction factor for fluid flow in a pipe		-	6
g	Acceleration due to gravity	9.81	m/sec^2	8
H	Height to which water is pumped		m	8
H	Heat supplied by a burner		kW	7
H_a	Heat available from a burner		kW	7
I	Area of land to be irrigated		ha	8
ID	Internal Diameter of a pipe or biogas plant		m	
k	Reaction constant for the production of biogas		day^{-1}	5
k	Constant related to the smoothness of a pipe		-	6
K	Pressure loss coefficient for fittings		-	8
L	Length of pipe through which fluid flows		m	6
m	Mass of feedstock put daily in a biogas plant		kg/day	5
M	Molecular weight of biogas	27.351	kg/mole	6
n	Number of hours/day a pump is used		hr/day	8
O	Diameter (internal or external)		m	
OD	Outside Diameter of a pipe or biogas plant		m	

Table E.1 <u>List of Variables Used in Book</u>

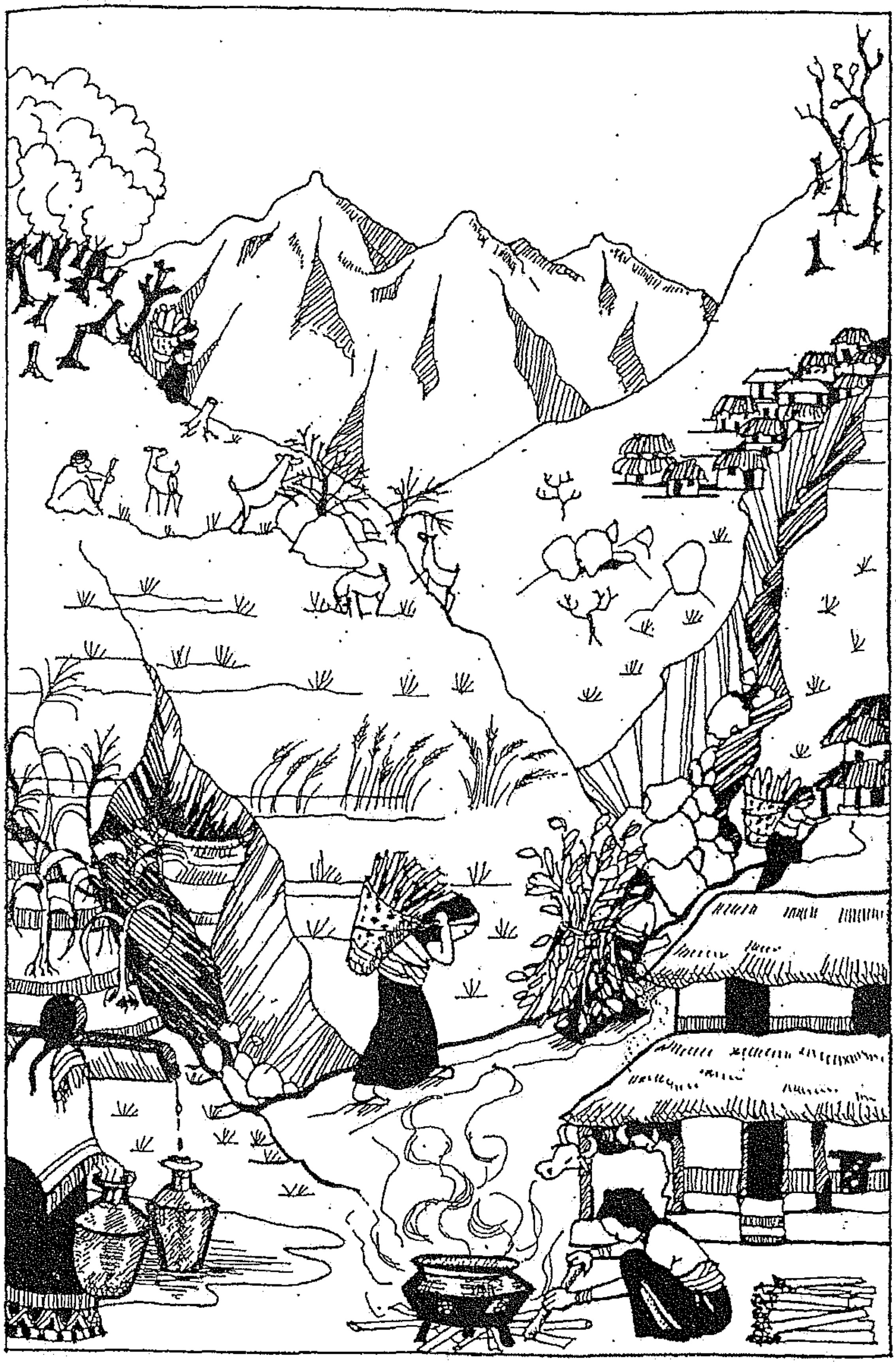
Letter		Meaning		Units	Chap.
	p	Pressure of biogas		mm WG	6
p		Pressure of biogas		kg/mm^2	6
	P	Power requirement for pumping water		HP,kW	8
Q		Flow rate of a fluid along a pipe		m^3/sec	6
	Q	Flow rate of a fluid along a pipe		l/min	6
q		Pressure function		-	6
	r	Entrainment ratio for a biogas burner		-	7
R		Retention time for slurry in a biogas plant		day	5
	R_e	Reynold's number - measure of fluid flow		-	6
R		Gas Constant	8314	J/kg/°K	6
	s	Specific gravity of biogas	0.94	-	7
s		Scale factor - used with nomograph		-	6
	S	Feedstock concentration in a biogas plant		kg/m^3	5
T		Absolute temperature (°C + 273)		°K	6
	t	Time for biogas to leak from a pipe		min	6
u		Velocity of a fluid in a pipe		m/sec	6
	v	Volume of slurry daily input in a biogas plant		m^3/day	5
v_g		Fluid velocity through a flame port		m/sec	7
	v'	Rate of loss of biogas through a leak		l/min	6
V		Internal volume of biogas plant		m^3	5
	V	Internal volume of a pipe		lit	6
V_w		Working volume of a displacement digester		m^3	
VS		Volatile solids in feedstock		kg	
	w	Depth of water in an irrigated field		mm	8
W		Volume of water available each day by pumping		m^3/day	8
	W	Wobbe number of biogas	27.7	kJ/l	7
WG		Water guage - a measure of gas pressure		mm	6

Table E.1 List of Variables Used in Book (cont.)

Letter	Meaning			Units	Chap.
p	(delta)	difference between of gas pressure		mm WG	6
n	(eta)	Efficiency of a biogas burner		-	7
n	(eta)	Efficiency of a water pump		-	8
o	(theta)	Angle of opening of gas valve		o	8
u	(mu)	Viscosity of biogas	$1.297x10^{-5}$	kg/m/s	6
	(pi)		3.14159	-	
p	(rho)	Density of biogas	1.0994	kg/m^3	6
p	(rho)	Density of water	1.0	kg/l	8
0	(phi)	Diameter (Internal or External)		m,mm	

Table E.1 List of Variables Used in Book (cont.)

Various other letters : A to Z are also used to indicate linear dimensions (see Tables : 2.2, 2.3, 2.5, 3.2, 4.1, 4.2, 6.12).



1. The Crisis in Nepal

Chapter 1 USEFULNESS OF BIOGAS TECHNOLOGY D. Fulford

1.1 Introduction

The need for alternative sources of energy to those commonly used at present, such as petroleum oils or wood fuel, is now recognised by many people, especially those in the poorer countries of the world. The high increases in the price of oil-based fuels over the last decade has meant that a large proportion of the Gross National Product (GNP) of most non-oil producing Third World countries is being spent on these fuels. Energy is required to help the people of these countries to develop, but

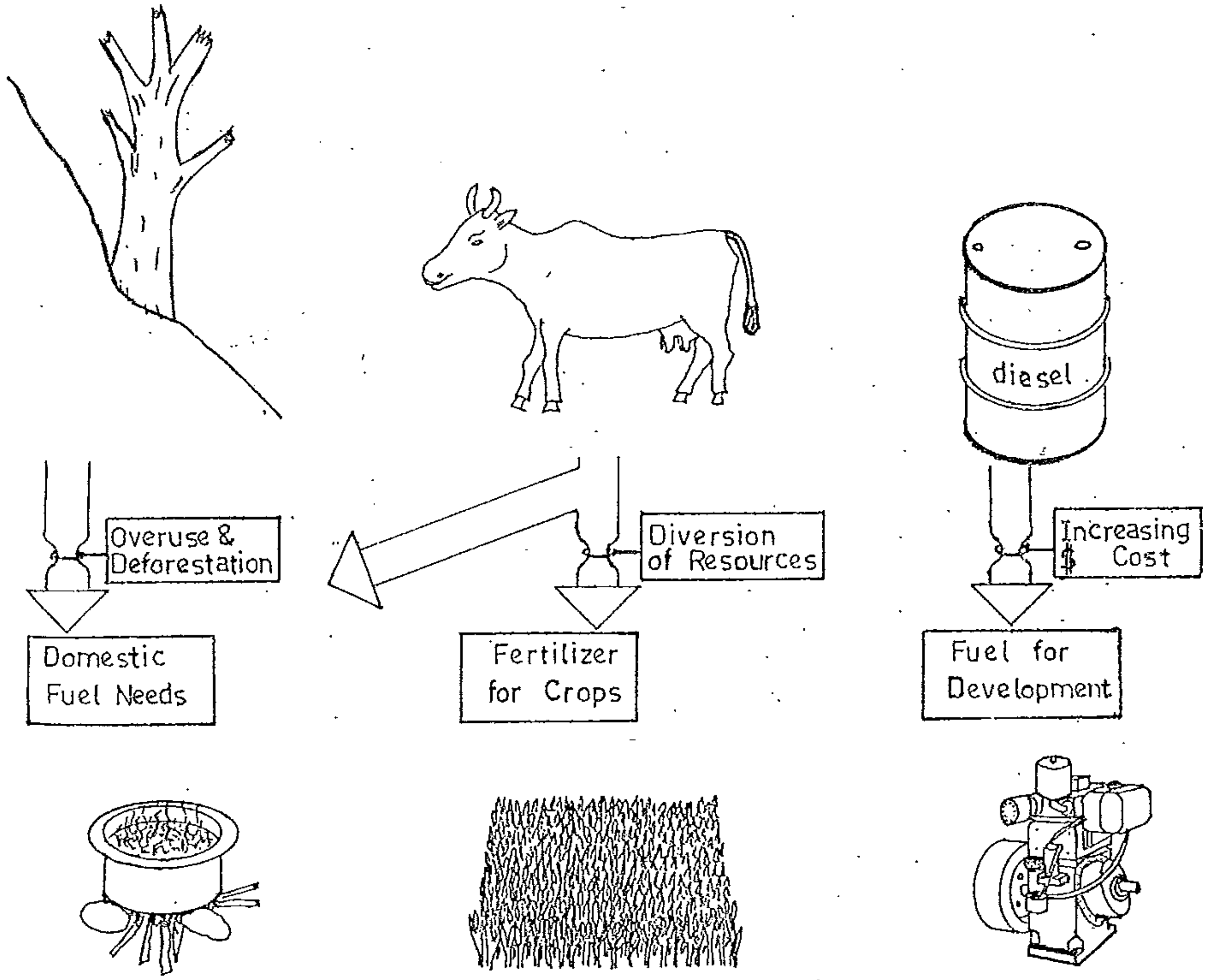


Figure 1.1 The Energy Resource Problem

neither the majority of the people nor the national economies of these countries can now afford to buy more oil-based fuels to form the basis for development.

A fuel crisis also exists in the supply of traditional sources of energy. Increasing population pressures mean that wood fuel from trees in most parts of the world is now being used faster than it can replace itself by natural growth (Agarwal, 1983). This demand for wood, coupled with commercial exploitation of trees for construction, pulping and other uses, means that forests are being destroyed at a high rate. Poor people lose out in two ways: not only cannot they develop, because of the high cost of petroleum fuels, but their traditional life style is also threatened as wood fuel becomes less availabale.

As population increase, more food must be grown, and more land used for agriculture. More fertilizer must be used to maintain the fertility of the soil. These demands make the fuel problem even worse, as now agricultural land must come from the forests. As wood becomes less

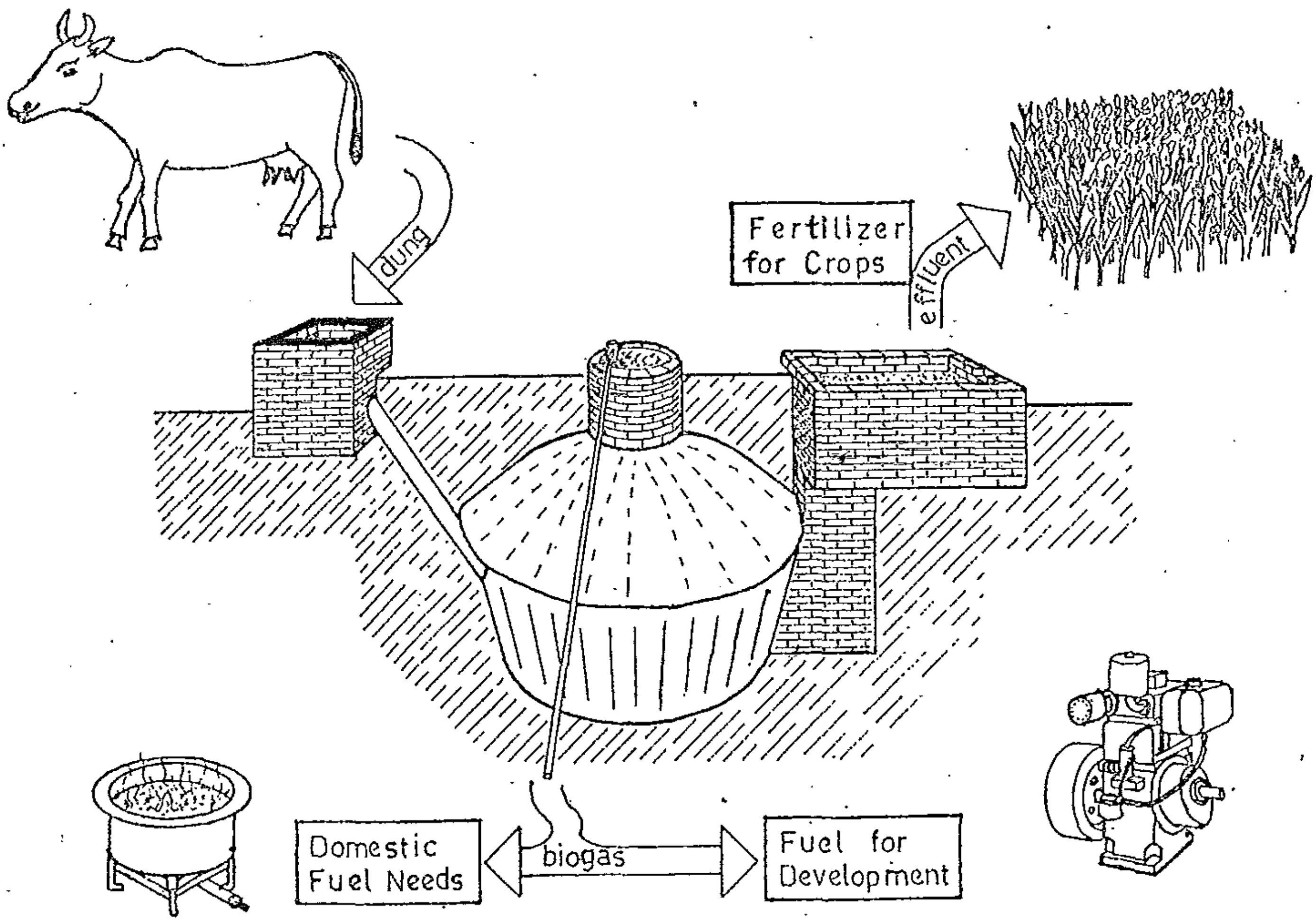


Figure 1.2 Use of Biogas Technology

available, people turn to other fuels, such as dried cattle dung and crop wastes, which could have been composted to give fertilizer. These fuels are also very inefficient, giving a poor smoky flame.

All these problems are present in Nepal, which is one of the poorest countries of the world. They are more complex here, because of the geographical and socio-economic position of the country. Import of petroleum oils is expensive and difficult, as Nepal is land-locked and a terrain of steep rugged hills, with few roads, making transport a problem. As forests are cleared, for wood fuel and cultivation, the steep slopes become unstable; top-soil is washed away in the monsoon rains and landslides destroy land, crops and homes. Increased water run-off on deforested slopes means floods further down-stream in the monsoon and less water absorbed and stored underground to supply springs and streams for the dry season. A natural cycle of flood and drought is intensified. People are not only short of fuel and food, but water also.

There is no easy solution to these complex problems. However, biogas is one technology that might provide the basis for a partial answer. A biogas plant can provide a good, efficient fuel, and also a well compostsed fertilizer from the same source of animal dung and crop residues. If biogas could be widely used in Nepal, and in countries in a similar position, people could use their dung and crop wastes for fuel, in a way that would not deny their land fertilizer. Properly used, biogas would not only help people overcome problems caused by wood fuel shortage, but it could also provide energy for development. Biogas can be used to run cottage industries and other money earning activities.

The work of spreading a new technology, such as biogas, so that it can be widely used in a country such as Nepal, involves many different activities. Decelopment and Consulting Services of the United Mission to Nepal has been involved in this work since 1974, in both extension and in developing improved biogas technologies, and this book is a sharing of our experience.

1.2 Biogas Process

When a cow eats grass, it digests the food in its gut, after breaking it up with its teeth. The process of digestion, the breaking up of complex food-stuffs into simpler chemicals, is assisted by a population of bacteria that live in the cow's gut. Some of these bacteria are 'methanogens', which turn certain of these chemicals into gases, such as biogas. Some of these bacteria are excreted with the dung, and can continue the process of digestion if given the right conditions: similar to those in a cow's gut. If light and air are excluded and they are kept at a warm temperature (between 20°C and 40°), the bacteria will make biogas until their food (the substrate) is used up.

These conditions can be met in a hole in the ground, lined with brick or cement, to keep the mixture from leaking out, with a suitable arrangement for collecting the biogas. The correct temperature will only be found in tropical or sub-tropical areas, unless some system is used to heat the mixture of dung, foodstuffs and water (called a slurry) and to prevent heat loss.

Cattle dung, containing the right bacteria to give biogas, is the most commonly used feedstock. In India and Nepal, biogas is called 'gobar gas', as 'gobar' is the Nepali, and Hindi, word for cow dung, and it also has a special significance in the Hindu religion.

Other feedstocks can be used to produce biogas. Pig dung is also good, although it may not contain the correct bacteria. A 'starter', slurry from a working biogas plant, is required to start a new biogas plant using other feedstocks (Maramba, 1978). Chicken dung is also a good feedstock, although a large number of birds are required to obtain adequate dung (Table 1.1).

The raw material, from which dung is composed, is grass and other vegetable matter, so more gas could be obtained by adding undigested plant material to the biogas plant (up to 80% per kg more: FAO 40). However, plant material contains lignin, a tough woody material that the bacteria cannot easily digest. If the vegetable matter is eaten by an animal, it is broken up mechanically by the teeth, and chemically by the action of acids and enzymes in the animal's gut. Some animals, such as horses and elephants, are less good at breaking down the lignin, so their dung, too, contains more woody fibrous material. These fibres can cause blockages and other problems within the digester. Some plants such as water hyacinth, have little lignin, so are good feedstocks for biogas plants.

Dung from goats and sheep are rich in nutrients, but it is in the form of pellets that must be broken up mechanically before they can be used in a biogas plant. There are few reports of the use of such dung in biogas plants, probably because these animals roam freely and the dung is difficult to collect.

Anaerobic digestion (without air) can also be usefully used with wastes such as sewerage and effluents from industries that process plant and animal products. Such feedstocks usually have particular problems of their own and we have not had experience of them in Nepal.

Table 1.1 Gas Production for Different Dungs
(Notes : (1)- Maramba, (2)- NAS, (3)- Makhajani)

Animal	Dung/Unit kg/day	Biogas/Unit litres/day	Total Solid%	Volatile Solid%	Carbon %	Nitrog. %	C/N
Cow	14	400-480	16-20	77	36	1.8	20 (1)
Pig	5	280-350	25	80	38	2.8	14 (1)
Chicken	7.5	420-510	48	77	56	3.7	10 (1)
Human	0.2	11- 14	15-20	90	48	7.1	7 (1, 2&3)

1.3 Uses of the Fuel Gas

Biogas is a mixture of methane (50% to 70%) and carbon dioxide (50% to 30%), with small amounts of other gases, such as hydrogen sulphide, which causes the gas to smell. The methane is a fuel, and burns with a blue flame, but the carbon dioxide acts only as a dilutant. The gas is slightly acidic, if mixed with water, and can be corrosive. The relative proportions of the gases depend on the feedstock for the plant and the exact population of the bacteria in it. The properties of biogas are given in Table 1.2.

Table 1.2 Properties of Biogas
(Pritchard, Perry, Weast, Watson House)

Biogas, assumed to be 58% Methane (CH_4), 42% Carbon Dioxide (CO_2), saturated with water vapour at 30°C and standard pressure.		
Calorific Value	5.14 kCal/lit.	(4.8 to 6.2 range)
Effective Molecular Weight	27.351	(24 to 29)
Density	1.0994 kg/m^3	(.96 to 1.17)
Specific Gravity (Air 30°C)	0.94	(.82 to 1.00)
Viscosity	$1.297x10^{-5} kg.s^{-1}.m^{-1}$	
Air to Fuel Ratio	5.5 : 1 (15% biogas) Stochiometric	
Flammability Limits	9% to 17% biogas in air	
Wobbe Number	27.7 kJ/litre	

The main use of biogas, at present, is for domestic purposes, such as cooking and lighting. Biogas can be used in suitably designed burners to give a clean, smokeless, blue flame, which is ideal for cooking. Biogas can also be used in specially designed lights, similar to 'Petromax' or other kerosene pressure lamps.

Biogas is a high-grade fuel, which means that it can be used in internal combustion engines. It is possible to use it in adapted petrol (gasoline) engines, with a spark plug to ignite the mixture. It is more usual to use it in "dual-fuel" engines, which are adapted diesel engines that still use 20% diesel, along with 80% biogas, to provide ignition. Biogas engines that still use 20% diesel, along with 80% biogas, to provide ignition. Biogas engines are usually stationary, used to drive equipment other than vehicles, as it is very difficult to store in a small space. It cannot be liquified in the same way as LPG, so it must be kept under low pressure in large balloons, or compressed to a high pressure to be kept in cylinders. Both have been done (FAO 41, Meynell) but not in Nepal.

There are many other possible uses for biogas. In Nepal, it has been used to run a refrigerator, of the absorbtion type, (Biogas, Nepal 5) and to heat an iron for pressing clothes. Larger sized biogas plants have been used elsewhere in small commercial operations, such as in processing animal products (Maramba, 1978), in distilling alchohol (FAO 41) and in drying crops, such as tobacco (UNIDO, 1980).

1.4 Use of the Slurry

Nutrients are needed by all living creatures. In a well designed farming system, much of the nutrients from plants eaten by animals and people are returned to the soil in dung. These nutrients are absorbed by the plants through their roots, so they must be soluble in water. Dung contains many plant nutrients, but it is only partly digested, and too concentrated to be used directly on the land. It is usually composted in some way, to allow micro-organisms (bacteria and fungi) to continue the process of digestion.

Anaerobic digestion in a biogas plant performs some of the functions of a compost pit, in that it breaks down the plant materials into simple chemicals that can be absorbed by the plants. However, it also concentrates the plant nutrients, so the effluent slurry must be diluted in some way. It also contains hydrogen sulphide, which is toxic to plants (Maramba, 1978).

In Nepal, the usual practice is to collect the biogas effluent into pits and allow it to dry. The toxic substances evaporate. The dried manure is then spread on the fields. Biogas effluent is free from odour, while a similar pile of raw cow-dung smells strongly. It does not give a good environment for flies to breed (Sathainathan, 1975). Anaerobic digestion also decimates populations of pathogenic bacteria and parasites in the dung. Some pathogens die quickly (McGarry et al, 1978), while others are reduced, but not destroyed (Hobson et al, 1979). Drying the effluent should complete the destruction.

However, drying the slurry means that plant nutrients, such as nitrogen are lost by evaporation into the air, and by leaching, as water drains from the slurry into the soil. The loss of nitrogen from dried slurry is 7% to 15% (Idnani, 1974), as opposed to 20% to 45% from a pile of raw cow dung (Yawalker et al, 1977). The sun drying of slurry takes up a lot of space, and is less effective in the monsoon season.

Digested slurry can also be introduced into irrigation canals, so the water washes it to the land (Biogas Nepal 13). In China, the slurry is sometimes sprayed directly onto the fields (FAO 41). The water dilutes the slurry and carries it to the crops and also reduces the toxicity of the hydrogen sulphide (Maramba, 1978). This approach means that slurry does not need to be stored, but it is only useful if the biogas plant is close to an irrigation canal. One problem, noticed in Nepal, is that more slurry is deposited near the mounth of the canal than the other side of the fields.

The slurry can also be added to dry plant material, such as straw or leaves (Idnani, 1974; Sathainathan, 1975). The dry material absorbs the water and plant nutrients and accelerates the drying.

The fertilizer value of the slurry, when it is treated in any of these ways, is reported to be good. One farmer in Nepal claims to be saving 80% of the area that he puts on his crops. Other places report an increase in crop production of 13% after biogas slurry was used on the fields (FAO 41).

Other uses of the slurry include putting it into ponds as feed for algae, water hyacinth, fish or ducks; using it in hydroponics, where plants are grown in a nutrient rich solution on a gravel bed; or even using it as a feed supplement for pigs and chickens, as it contains vitamins and growth promoting agents (Maramba, 1978).

1.5 Advantages and Disadvantages of Biogas

The primary advantage of biogas technology is that it can produce both a high grade fuel and a good manure from the same input of animal dung and crop residues. The spread of biogas technology in a country such as Nepal would have advantageous effects on local families, on communities and on the national level.

On the Family Level:

The immediate benefactors, when a family sets up a biogas plant, are the women, who do the cooking (Bulmer and Schlorholtz, 1979). When cooking fuel is available by just turning a tap and lighting a match, women prefer it to gathering wood, cutting it into pieces, lighting a fire and constantly attending it. A wood or cow dung cake fire is smokey, blackening the cooking pots, the kitchen and the cook's clothes and skin. Smoke also affects the eyes and lungs, causing irritation and making them more liable to disease. These things do not happen with biogas, so the women become more healthy and have much more time to look after themselves and the rest of their family.

One possible disadvantage of biogas is that insects can infest the roof beams and thatch of traditional houses, as they are not kept away by the wood smoke.

The value of the fertilizer is another advantage of biogas. In China, biogas plants are regarded as 'miniature manure plants' (FAO 40). The lack of smell and the lack of flies round the slurry are also benefits, as well as the decimation of pathogenic organisms.

Gas lights also help families who live away from electric light. Children can study in the evening, so literacy is improved; people could work at weaving or other cottage industries; people go to bed later, so biogas lights might have an effect on the birth rate.

The major disadvantage of a biogas plant for a family is the high capital cost for a poor family. The majority of people in Nepal could not afford to pay the cost of a plant (about Rs. 9,000; $690, for a small family plant in 1982). Assistance in the form of loans and subsidies is available, but the purchase of a biogas unit is still a large undertaking for a poor man.

Also a poor farmer has to find enough feedstock for the plant. If the plant is fed on cattle dung, a family requires dung from 4 to 6 cattle, which is more than most people own. If the owner of the biogas plant cleans his plant out regularly, he can also use crop residues and plant material, but this is not common in Nepal.

Other problems are the need for water, with which to mix the slurry, and the reduction of biogas production in cold weather.

On Community Level:

More people can benefit from biogas technology by setting up a community biogas plant, in which the cost of the plant and the task of supplying feedstock is shared among a group of poor villagers. The capital cost per volume of gas produced is reduced and the biogas plant can be used as a focus for development within a village or community.

Working together in the setting-up and running of a plant, villagers will build up a spirit of cooperation and unity. While this type of communal activity is difficult to start in Nepal, the Small Farmers' Development Programme (SFDP) has shown that it is possible, and can be successful (FFHC/AD' SFDU, FAO, 1977). Particular needs are for the people to be properly motivated, so they understand exactly what is expected from them and exactly how each will benefit. (RAFE 36).

A larger sized community biogas plant can be used to drive engines for an income earning activity. Engines can be used to drive grain mills and irrigation pumps, both of which can make a good profit for the owners. Biogas engines can also be used to generate electrcity, although this is not usually economically justified on a small scale. An 'add-on' electric generator to an engine used for another purpose could be used to provide lights for a village, especially as electric lights are far more efficient than gas ones. Village-based development activities attract young people in the villages and encourage them to stay at home rather than migrating to towns and cities to seek jobs.

Latrines can be attatched to biogas plants. While this is technically possible with a family sized unit, cultural factors suggest that it is easier to do in a community plant, especially if it is being used to run engines rather than cook food. Use of latrines with a biogas plant will improve sanitation and village health.

The disadvantages of a community plant arise if the members of the community fall out and disagree. This has happened in Nepal (Bulmer 1980) and India (Agarwal, 1983; Roy, 1981) and the plants have become an expensive liability. Careful preparation, teaching and testing of the community is essential, even before the plant is built, if these problems are to be avoided.

On National Level:

Biogas offers an alternative energy resource to wood fuel and petroleum oils. In the Nepali year 2031 (1974/75), the people of Nepal used a total of 6,530,000 metric tonnes of fuel wood (ERDG, 1976), mainly for domestic purposes, such as cooking and heating: an average of 550kg per person per year. Wood fuel is being used faster than it can grow: only 35% of the wood used in one mountain area of Nepal was estimated to have been replaced by natural growth in 1974 (SATA, 1977). The net loss of wood from the area per year was about 1.2%, which is steadily increasing, as the population grows, and stock wood, from which new wood can grow, is lost. Under these conditions, the whole forest cover will be lost in 40 years or less. Present estimates suggest that only 10 years remain before Nepal becomes a treeless desert.

In 1974/75, only 1.5% of domestic fuel was composed of dung and crop residues. However, as wood fuel becomes less, people will turn to these fuels, depriving their land of much needed fertilizer.

Also in 1974/75, 28,712,000 litres of petroleum fuel of all types was used in Nepal (ERDG, 1976). In 1970/71, the value of fuel oil imports was Rs. 71,733,000 ($6,030,000) (HMG/CBS). The cattle population in the same year was estimated as 10,010,000, producing 27,724,000 metric tonnes of fresh dung per year (ERDG, 1976). If all this dung could be used to produce biogas, the total theoretical yield would be about 1,136,000,000 cu.m This could, in principle, replace 4,806,000 tonnes of fuel wood, or 3/4 of all the fuel wood used in Nepal. Alternatively, it could be used to replace 433,000,000 litres of diesel, about 15 times Nepal's requirement in 1970/71. The value of this replaced oil would be over 2 billion rupees or about $700 million.

Of course, all this dung could not be used to make biogas; much is dropped directly on the land as cattle go out to forage for food. Even if 40% could be used, biogas technology could have an important impact on the economy of Nepal. If the dung from other animals, such as pigs, and human faeces and crop residues could be used as well, the potential impact of biogas technology would be even greater.

Biogas can replace wood fuel; if this can happen on a large enough scale trees and forests can be conserved. If forests were allowed to regrow on the steep mountain slopes of Nepal, then the impending ecological disaster could be averted. His Majesty's Government of Nepal (HMG/N) does recognise this, and is considering giving subsidies to all people who will install a biogas plant in Nepal.

The main difficulty in the extension of biogas technology on a national scale is in the setting up of suitable organisations for construction, for funding loans and for the follow-up of people who have installed plants, so they can be trained in their use. Government bodies have many different priorities; the introduction of a new technology has to compete with many well-established concerns. However, despite such obstacles, the biogas extension programme in Nepal has become established and is growing steadily, if not as fast as was first hoped.

1.6 Biogas Plant Design Criteria

There are many different designs of biogas plants available worldwide (Maramba, Pyle, Jewell) and most will work. However, in choosing suitable designs for use in a developing country such as Nepal, certain criteria limit the number of types that can be considered suitable.

Underground designs, built in a hole in ground, are cheaper and easier to build. The soil itself can be used structurally, to support walls against the hydraulic and pneumatic pressures of the slurry and gas. Also, such plants are easier to insulate against cold weather. Inlet and outlet pipes should be straight, for easy cleaning and any effective design should be easy to clean out and empty, in case of problems such as scum formation.

Traditional building materials, such as mud and "lipnu" (mud mixed with cow dung), are not suitable for biogas plants, as water and gas leak through them. Wood is also not suitable, as it is very difficult to make gas tight and it can be destroyed by insects or rot. Materials such as brick and cement are expensive, so, while they must be used, the biogas plant design must be carefully made to minimise the quantity. Reinforced concrete is normally too expensive.

Since rubber and plastic must be imported into Nepal, they can be almost as expensive as the steel required to do a similar job. They can also be damaged by rodents and by sunlight and during transit by sharp objects. Even steel is not an ideal material, as it is also expensive and can be corroded by the biogas slurry. The designs used in Nepal are therefore constructed mainly with brick or stone masonry, or with cement plaster, using the sides of the underground hole for structural support. Three such dsigns are described in the following chapters.

Chapter 2. FLOATING STEEL DRUM DESIGN J. Finlay

2.1 Basic Design

The floating steel drum biogas plant was developed in India. When D.C.S. started its biogas work in 1974 this was the only known biogas plant design. After studying it at institutions and in villages in India it was accepted for use in Nepal. The slurry is kept in a masonary lined well like structure and the biogas collects in a steel drum which floats mouth downwards in the slurry (Fig. 2.1). As gas collects or is used, the gas holder floats up or down accordingly. The D.C.S. design has not altered the basic principle but there are significant differences in construction details. These changes have been made to simplify construction and reduce construction and plant maintenance costs.

There are two versions to the D.C.S. design. The straight design (Fig. 2.3 and 2.4) is mainly used where bricks are not available and stone masonry is used and/or the water table is low allowing a deep hole to be dug. The taper design (Fig. 2.5) is mainly used where bricks are available and especially if the water table is high because it needs a shallower hole. It is much cheaper than the alternative commonly recommended horizontal plant which requires reinforced concrete. Both designs use exactly the same amount of bricks, sand and cement and use identical gas holders. Of the two designs, the taper one is most commonly used in Nepal due to the high water table and availability of bricks in the plains where most plants are built. A major improvement has been to change the method of taking the gas from the gas holder. Commonly a flexible pipe is used to join the gas holder to the main gas pipe. This pipe degrades in sunlight, often leaks at the ends, collects concensate till the pipe blocks and it also prevents the free rotation of the drum, which may be necessary for the mixing of the slurry.

The D.C.S. design (Fig. 2.2) allows the gas to be removed via the central guide pipe. It thus eliminates what was a major maintenance problem as well as a rust problem on the central guide because it is now closed to the atmosphere. It also enables the drum to be freely rotated for breaking up of scum. This design has been used exclusively in Nepal since 1976 and is very successful.

2.2 Sizes of Plant

From the beginning D.C.S. decided not to build any plants smaller than the SD100 because it was economically unattractive. For the sake of standardization it was decided to have four sizes (SD100, SD200, SD350 and SD500) producing nominally 100, 200, 350, and 500 cu.ft. (2.8, 5.6, 9.9 and 14.1m^3) of biogas per day. No larger plants were built because the required drum would become very heavy necessitating truck access to the site and also lifting equipment. The SD200 size is the most popular size in Nepal.

Under Nepali conditions of cooking two main meals plus lighting in the evening, it has been found that drums holding about two thirds of the daily gas production are suitable. In designing digester volumes and using available information at that time it was assumed that 1 kg cattle dung mixed one to one with water gave 37 litres of gas, held at a temperate temperature for 50 days. The digester volume was made a bit larger to allow for any unmoving dead volumes of slurry forming inside the digester. Subsequent research (Vol. II chap. 5) has shown that the gas availability is very temperature sensitive, so that the nominal daily gas production is rather meaningless. The characteristics of the various sizes of plant and realistic daily gas production at different slurry temperatures is given in table 2:1. Under local conditions the slurry temperature for most of the year is around 25°C.

Table 2.1 Characteristics of Floating Steel Drum Design
Input: Cattle dung mixed with water at 1:1 ratio

Plant type	SD100	SD200	SD350	SD500
Digester volume m^3	7.1	13.0	24.3	34.0
Gasholder voluem m^3	1.7	3.4	6.0	8.5
Input dung per day kg	60	120	210	300
Theoretical retention time days	59	54	58	57
Realistic retention time days	50	50	50	50
Nominal gas production/day, m^3	2.8	5.6	9.9	14.1
Realistic gas production per day m^3 at				
Slurry temp. 30.1°C	2.7	5.3	9.3	13.3
Slurry temp. 25°C	1.7	3.4	5.9	8.4
slurry temp. 20.3°C	1.3	2.5	4.4	6.3

2.3 Construction Details for Floating Steel Drum Designs

Detailed drawings are given in Figures 2.3, 2.4 and 2.5. The dimensions indicated by letters are given in Table 2.2 for the straight type and in Table 2.3 for the taper type. Material quantities for all drum plants are given in Table 2.4. Building materials are common to all plants. Details are given in Chapter 5.

2.4 Digester Floor

Having built hundreds of these plants, our experience is that a concrete floor is hardly ever necessary. Masonry floors are much lower cost and quite adequate in almost all cases. If the ground condition at the bottom of the pit is poor, i.e. muddy or soft sand, then a layer of broken bricks or stones much be pounded in until the ground is firm. The masonry floor can be built on top of this. Alternatively, a concrete floor can be laid.

The floor should be reasonably level. Bricks are laid on edge (not on their face) as in fig. 2.6. This method given sufficient strength because the weight of the walls is not significantly greater than the weight of soil removed.

Table 2.2 Dimensions of Drum Plants - Straight Type (Figure 2.3 and 2.4)

Dimension (millimetres)	Ident.	SD100	SD200	SD300	SD500
Depth of Digester	A	3620	4630	4930	5540
Deflector ledge to top	B	1050	1270	1270	1500
Depth Lower Section	D	2570	3360	3660	4040
Diameter of Pit	E	1600	2000	2600	3590
Diameter at Ledge	F	1300	1700	2300	2600
Diameter of Hole	H	2060	2460	3060	3360
Inlet Pipe Length	I	3800	4800	5000	5800
Outlet Pipe Length	J	-	4600	4900	5500
Pipe Opening from Wall	M	700	400	400	690
Mixing Pit Length & Breadth	P	610 x 460	700	1000	-*
Deflector Ledge to inlet	R	1200	1470	1470	1700
Deflector Ledge to outlet	S	950	1170	1170	1400
Depth of hole	T	3390	4400	4700	5310

* Note: The SD500 size uses a mixing machine (dimensions in chapter 6)

Table 2.3 Dimensions of Drum Plants - Taper Type (Figure 2.5)

Dimension (millimetres)	Ident.	SD100	SD200	SD300	SD500
Depth of Digester	A	2520	3090	3300	3770
Deflector ledge to top	B	1030	1270	1270	1500
Depth Taper Section	C	910	910	1220	1220
Depth Lower Section	D	580	910	810	1050
Diameter of Pit	E	1600	2000	2600	2900
Diameter at Ledge	F	1300	1700	2300	2600
Diameter of Lower Section	G	2500	2900	3900	4230
Diameter of Hole	H	2960	3360	4360	4690
Inlet Pipe Length	I	2320	2940	3150	4000
Outlet Pipe Length	J	2170	2740	2950	3370
Mixing Pit Depth	K	410	460	460	-*
Mixing Pit Length	P	460	600	850	-
Mixing Pit Breadth	Q	610	810	1200	-
Deflector Ledge to inlet	R	1180	1470	1470	1700
Deflector Ledge to outlet	S	930	1170	1170	1350
Depth of hole	T	2300	2850	3070	3540

* Note: The SD500 size uses a mixing machine (dimensions in chapter 6)

Table 2.4 Material Quantities for Drum Plants

Plant type	SD100	SD200	SD350	SD500
Cement kg	450	800	1,150	1,550
Sand m^3	2.20	3.86	5.52	7.50
Bricks	3,000	5,000	7,500	10,000
Cement Pipe (ST)(m)	3.8	9.4	9.9	11.3
(Tp)(m)	4.6	5.7	6.1	7.4

2.5 Side Walls

The side walls are circular and they are quick and easy to build using a building gauge (Fig. 2.7). The gauge is marked to indicate the different radio used in the plant (E/2, F/2, G/2). The partition wall can be completed after the gauge is removed, or alternatively it can be built slightly off centre.

It is essential to backfill the space between the walls and the sides of the hole with dug out earth after each 300 mm of wall has been built. The earth must be rammed thoroughly into place with a piece of wood and water can be added to compact the soil. A major reason for biogas plant walls breaking is that this backfilling job has not been done properly.

Normally digester walls are not built more than 350 mm above ground level. In certain cases, such as if the water table is very high, the plant must protrude more than this out of the ground. The brickwork must then be strengthened by tightly tying 3 mm wire round every second course of bricks, and plastering over it to prevent rusting (Fig. 2.8). Earth must be backfilled to more than 1 metre around the bricks, at deflector ledge level. A disadvantage of this approach is that the input dung and water must be lifted up to put them in the plant.

2.6 Partition Walls

Central dividing walls are commonly used in most plants, except SD100 straight type. The wall is designed to control the flow of the slurry, but some tests on SD100 taper type and SD200 straight types, with and without partition walls indicates no noticeable difference in gas production.

As the wall only controls the flow of slurry, it requires no structural strength, so a half-brick wall (120 mm) is used. It is built to the top level of the deflector ledge.

2.7 Deflector Ledge

This ledge deflects gas produced at the sides of the digester into the gas holder. A plant without this ledge would lose about 10% gas, or more in the case of taper type plants. The ledge is made to protrude about 100 mm inside the gas holder circumference and should be made flat. It can be used as a convenient datum from which to make several important measurements.

(i) From top of ledge to tope of digester pit walls: the height of the sides of the gas holder plus 25 - 100 mm.

(ii) From top of ledge to mouth of inlet pipe: the height of the sides of the gas holder plus 175 - 300 mm. This gives sufficient head for the slurry to run quickly and easily into the digester.

(iii) From the top of the ledge to the mouth of the outlet pipe: the height of the sides of the gas holder minus 50 -'80mm. This avoids the slurry coming over the top of the digester. When the slurry enters the plant daily the level of the slurry in the digester rises quickly and then lowers slowly as the effluent comes out of the outlet.

2.8 Central Guide Pipe

The central guide must be vertical otherwise the gas holder may not move up and down freely. It is held in position by two cross supports made of steel rod which are cemented into the side walls.

A gap of 50mm is normal between the gas holder and the side walls. When building the walls above the deflector ledge it is helpful to use a measuring rod from the central guide to the walls in order to get the right radius. The length of the measuring rod is : radius of gas holder plus 50mm minus radius of central guide.

2.9 Inlet and Outlet

The lower end of the inlet and outlet pipes are placed about in the centre of their respective compartments (at a distance M away from the walls). This position is not vital but it is important that the slurry moves at the bottom of the digester and that dead volumes of unmoving slurry are not allowed to form.

The mouths of the pipes are set above the floor of the digester (350mm for the inlet pipe and 250mm for the outlet pipe). This facilitates the clearing of blockages by rodding and also provides some volume in case sand and stones etc get in the plant and build up over a period of years. The inlet height is higher than the outlet because it is more likely that stone sand etc will enter the plant by this pipe. Outlet pipes above ground level usually have bricks around them, to protect the cement pipe from accidental damage. The SD100 straight type plant has no outlet pipe, and the slurry overflows from a notch in the top of the digester wall (Fig. 2.3). Outlets usually have a channel running from them to nearby compost pits, slurry collection pits or irrigation channels.

2.10 Plastering

If the masonry work has been done well then there is no need to plaster the inside of the digester. If a plaster was used it would significantly reduce the volume of the digester and increase the cost. The slurry level will always be higher than the ground water level, therefore any water movement will be from the digester outwards. The fibre matter in cattle dung will enter and basically seal any small holes or cracks. It is quite common to put a thin plaster on the exposed masonry work. This is only for aecorative purposes.

2.11 Fabrication of Steel Gas Drum and Guide

The gas holder is a welded steel construction with a steel frame at the open end (Fig. 2.9 and 2.10). It can easily be made in a workshop with simple welding facilities.

2.12 Central Support

The design is detailed in Figures 2.9, 2.10, and dimensions given in Table 2.5. The length of pipe is about twice the drum side height to ensure proper support when the drum moves up and down. This guide pipe has a 25mm diameter, smaller than the pipe in which it fits in the drum. It was found that closer fits could prevent free movement due to scum accumulation. The pipe is held by two clamps on cross supports made from 16mm steel rod, bolted together with two bolts each. The ends of the cross supports are bent over to provide a good anchor in the sidewalls of the plant. The lower end of the pipe is closed and a socket is welded on near the bottom. The gas pipe is attached to this socket. This design has been trouble free.

2.13 Steel drum

In the centre of the drum is a guide pipe which rides on the central support. It is just over 1 1/2 times the height of the drum side and closed at the top end. Two slots 100 x 30 are made just below the roof of the drum to allow gas to pass. Holes are not used as these could get blocked with scum.

The top of the drum is coned shaped, about 1:10, to allow rain water to run off. The cone is made by making the top plate slightly larger in diameter than the diameter of the drum, cutting a "V" shaped notch from the side to the centre and pulling the sides of the "V" together and welding.

Scum breaker bars (Lenght L) are welded between the radial struts on the bottom frame and the top plate, at varying radii (R) from the central pipe. All drums are tested for leaks prior to painting by filling them with water. Any leaks must be welded.

2.14 Cleaning and Painting of Steel

The gas drum is made from mild steel. While it is easy to work and weld, it is subject to rust especially on the sides which dip in and out of the slurry twice a day. Good quality steel sheet should be used, as free as possible form rust, with no pitting or deep corrosion and it must be properly cleaned and painted. Hand cleaning, with wire brushes and sandpaper, is hardly adequate, although this system has been used due to the lack of an alternative. Ideally the finished gas drums should be

Table 2.5 Dimensions of Steel Drums

Dimension (millimetres)	Ident.	SD100	SD200	SD350	SD500
Diameter of Drum	N	1500	1880	2500	2800
Height of Drum Side	S	1000	1220	1220	1400
Height to Slot	S_1	950	1190	1220	1410
Height Centre Above Side	T	65	90	115	130
Diameter of Top Plate	X	1510	1890	2510	2810
Width of "V" Notch	Z	18	27	35	38
Drum Guide Pipe Length	U	1630	2000	2030	2330
Support Guide Pipe Length	V	1900	2280	2300	2600
Radius of Support Arms	Y	970	1150	1490	1650
Length of Support Arms	Y_1	910	1100	1440	1600
Length of Struts in Drum	W	700	890	1185	1335
Hole for Gas. (Socket Size)	O	27(½"GI)	33(¾"GI)	33(¾"GI)	38(1"GI)
Radius of Scum Breaker	R_1	140	130	1010	1190
Length of Scum Breaker	L_1	1050	1290	1200	1375
	R_2	560	385	220	270
	L_2	1015	1270	1275	1465
	R_3	280	640	615	730
	L_3	1040	1245	1235	1420
	R_4	420	255	485	575
	L_4	1025	1280	1250	1435
	R_5	-	510	875	1035
	L_5	-	1260	1210	1390
	R_6	-	765	90	115
	L_6	-	1230	1285	1475
	R_7	-	-	745	880
	L_7	-	-	1225	1405
	R_8	-	-	355	420
	L_8	-	-	1260	1450

sand blasted to remove all the the grease, rust or millscale (a black or dark blue oxide layer). This method should give a paint lifetime of three times longer than for hand cleaned steel.

After trying various paints it has been found that bituminous paints give the most effective protection to gas drums. Anti-saline metallic primer is used, which incorporates aluminium, with a dry film thickness of 30 microns (DFT) followed by one coat (100 microns DFT) of High Build Black paint (incorporating Bitumen and Phenolic resins). A second coat is applied after the drum has been transported to the site where it is to be used, to repair any scratches, and to increase the paint thickness. The paint is applied by brush, as it is too thick to be applied with an air spray gun. This type of paint must not be over thinned as too much thinner breaks down the paint an causes it to crack badly after drying for some time.

If available, a high pressure airless spray painting machine can be used. In this case a first coat of primer paint should be applied as a "mist coat", so thin that it can be seen through. This gives an excellent adhesion to the steel. It should be followed by a second coat (30 DFT) of primer. In Nepal drums are now sandlasted on the outer sides and then airless spray painted.

2.15 Maintaining Gas Holders

Rust is a serious problem and gas holders can rust out in a few years if not properly painted and maintained. It cannot be stressed too much that gas holders need to be painted yearly an more frequently if signs of rust are seen.

2.16 Practical Experience of the Use of Steel Drum Plants

Three follow-up surveys have been done on the first 95 biogas plants built to the SD100 taper design in Nepal. Most of these early plants used a flexible plastic pipe to remove the gas.

On the basis of these surveys four improvements were made.

1. The flexible plastic pipe was found to be a serious maintenance problem. In all plants built afterwards the gas was removed through the central guide pipe, the method described in this chapter. This has overcome the problem.

2. Rusting on the gasholder. This was due to rather badly rusted sheet steel being used, combined with lack of proper cleaning and inappropriate paint. Most drums were showing signs of corrosion after six months. Better quality sheet was used for new plants and also a more appropriate paint. Currently drums are grit blasted on the outer sides and airless spray painted with bituminous paint as specified above.

3. A few of the brick digester pits had cracked. The cause was loose backfilling between the side walls and the hole. When the soil became wet in the monsoon season it settled. The plants were repaired and the necessity of proper backfilling should be emphasised to the masons.

4. Farmers complained of lack of gas especially in the cold season. Following research it is now possible to give a realistic estimate of gas production from cattle dung plants under different conditions (Vol. II chap. 3) and to recommend ways of improving gas production (chap. 10).

2.17 Gas Pressure in Drum

Biogas appliances are usually designed for a gas pressure of 70 to 90 mm water gauge (WG). This pressure is provided by the weight of the drum pressing on the area it covers which is its cross sectional area. Weights can be added to the drum if the pressure is too low. The method of measuring gas pressure is given in chapter 6. The pressure from any drum of known weight (either by calculation or actual weighing) is obtained from the formular

$$\text{Gas Pressure} = \frac{\text{weight of drum (kg)}}{\text{cross section area (m}^2\text{)}} = \text{mm WG}$$

If the pressure is too low and weights need to be added it can be calculated from the formula.

$$\text{Weight} = \text{Cross sectional area (m}^2\text{)} \times \text{required increase in pressure (mm WG)} = \text{Kg}$$

2.18 Night Soil Gas Plant

One night soil (human wastes) gas plant suitable for daily use by 350 people in an institution was built in Western Nepal. The plant was a specially modified floating steel drum design (Figure 2.11).

Digester design:

The waste products per day per person using the system was assumed to be 2 litres including flush water and was expected to produce 28 litres of gas. (The toilets were a dry tupe washed out twice daily). The means that the digester has to be considerably larger than the size of a cattle dung plant designed to produce the same amount of gas. Further, because the plant was in a cool place the residency was increased from 30 to 60 days.

Digester capacity 330 people x 2 litres per day person x 60 days = 42 m^3.

The gas holder was designed to fit into a water filled annular slot. This water seal was for odour and fly control and to protect the steel gas holder from rust as night soil is more corrosive than cattle dung.

Digester construction:

This was similar to a castle dung plant with a few changes as given below.

Digester walls:

These were not plastered but this was a mistake because, unlike cattle dung slurry, there are no fibres to fill up pores in the brickwork and the input is very watery.

Inlet pipe:

The mouth of this was 300mm above floor level so as to provide extra accomodation for any sand, soil or stones which might get into the plant.

Annular slot:

It proved difficult to make this slot water tight. Eventually it was plastered using a mixture of cement and acrylic plastic emulsion. The method was identical to that used for making fixed concrete domes gas tight. Water has to be added during the dry season to make up for evaporation losses. Oil can be poured on the surface to stop mosquitos breeding.

Gas holder:

This had to be specially designed because of the annular slot. it also had many mixin bars because the night soil slurry tends to form a thick scum which needs to be broken up by rotating the gas holder.

The expected daily gas production was 350 people x 28 l. per person = 9.6 m^3

The gas holder was made to hold a voluem of 6.1 m^3.

Drains from Latrines:

Channels 150 wide and 230 deep and sloped at 1:70 worked well. They were covered by bricks. Normal 100 m pipe was unsatisfactory and blocked frequently.

Mixing Tank:

This was made to the same principle as the cattle dung mixing machine. Night soil and flush water ran into the mixing tank which was designed to hold the daily input. At the entrance a large heavy steel mesh basket was fitted to collect any cloths, corn cobs etc. This proved effective. A two level overflow was also used. The lower half, fitted with heavy coarse steel mesh allowed excess liquid to pass while withholding floating sewerage. Should this block up, the upper section became operative which allowed everything to pass while controlling where it went. The sand and gravel collecting channel worked well and collected a surprising amount of material.

The night soil slurry is much more corrosive on the steel parts of the mixing machine than is cattle dung. Probably bituminous paint should have been used instead of red oxide paint.

Spent slurry:

This is grey in colour, odourless and does not attract flies. Having been digested it is much safer to work with than raw night soil as a high percentage of bacteria are killed in the digester.

Gas:

This burns in the same way as gas produced in a cattle dung plant but it has a stronger hydrogen sulphide odour prior to burning.

Starting up the plant:

Before feeding in night soil one truck load of cattle dung mixed with water was put in the plant. This was to establish the right bacteria in the plant.

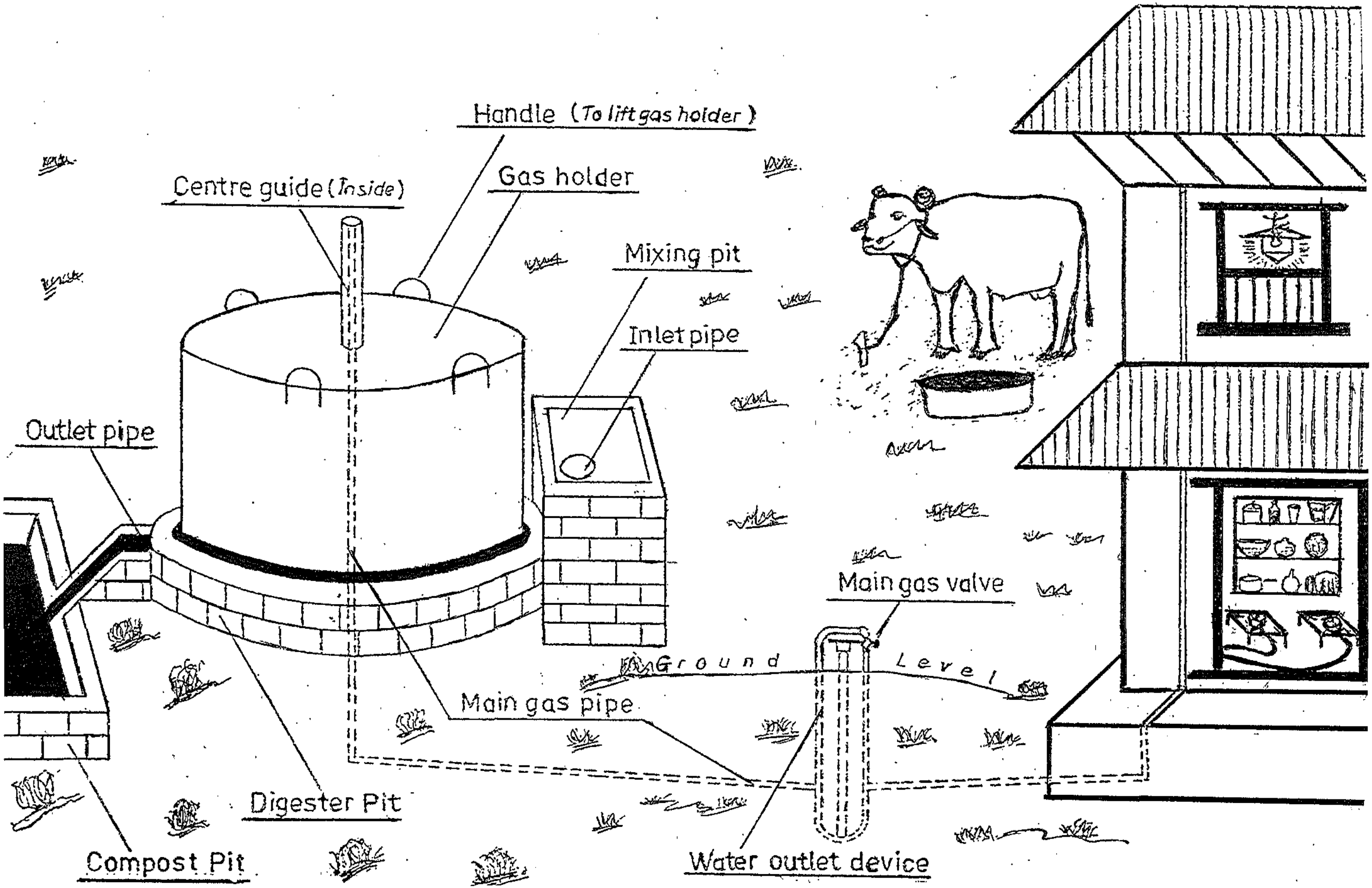


Figure 2.1 Floating Steel Drum Gas Plant (Janak Nepal)

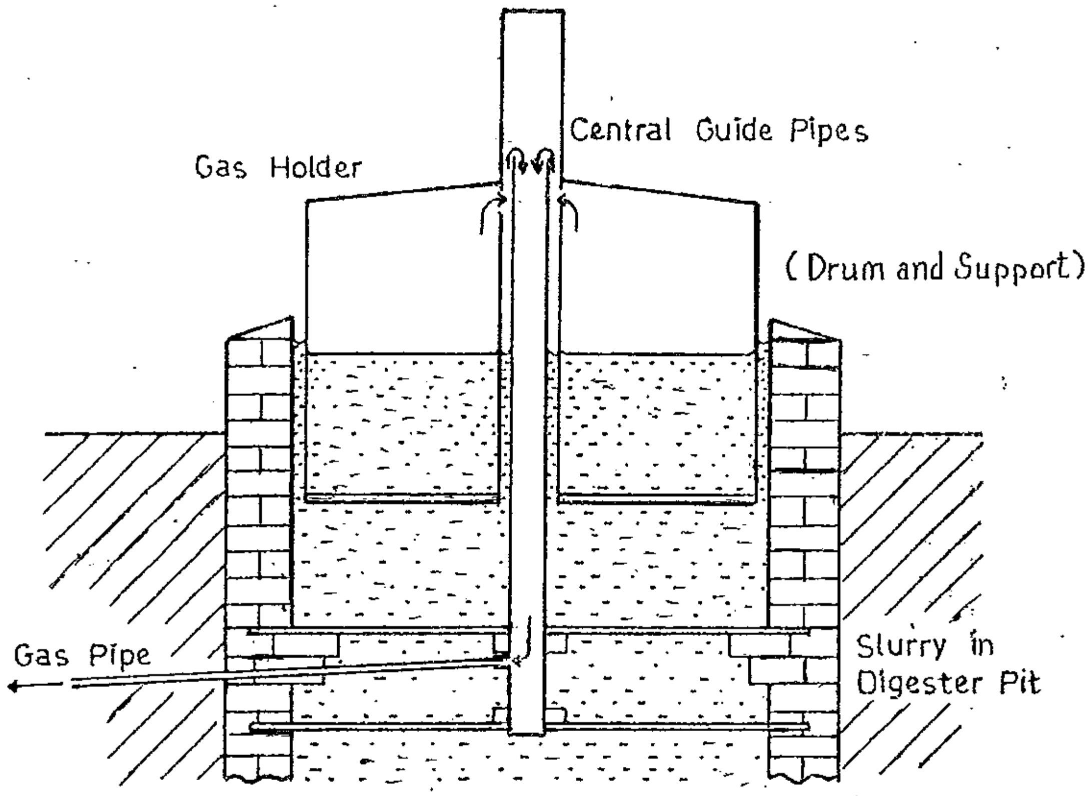


Figure 2.2 <u>Gas Removal System Using the Central Guide Pipes</u>

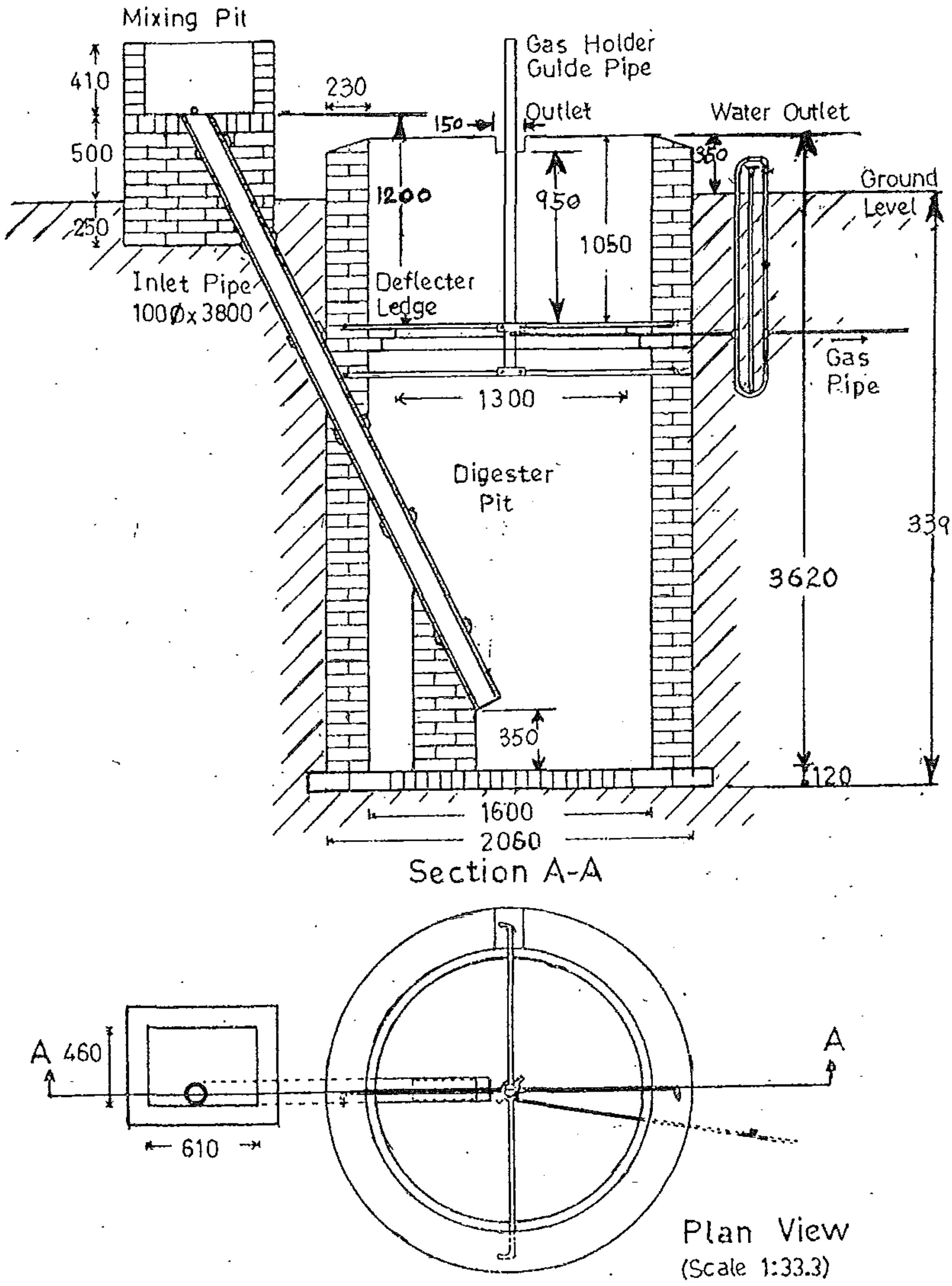


Figure 2.3 Floating Drum Design SD100 (Straight Type)

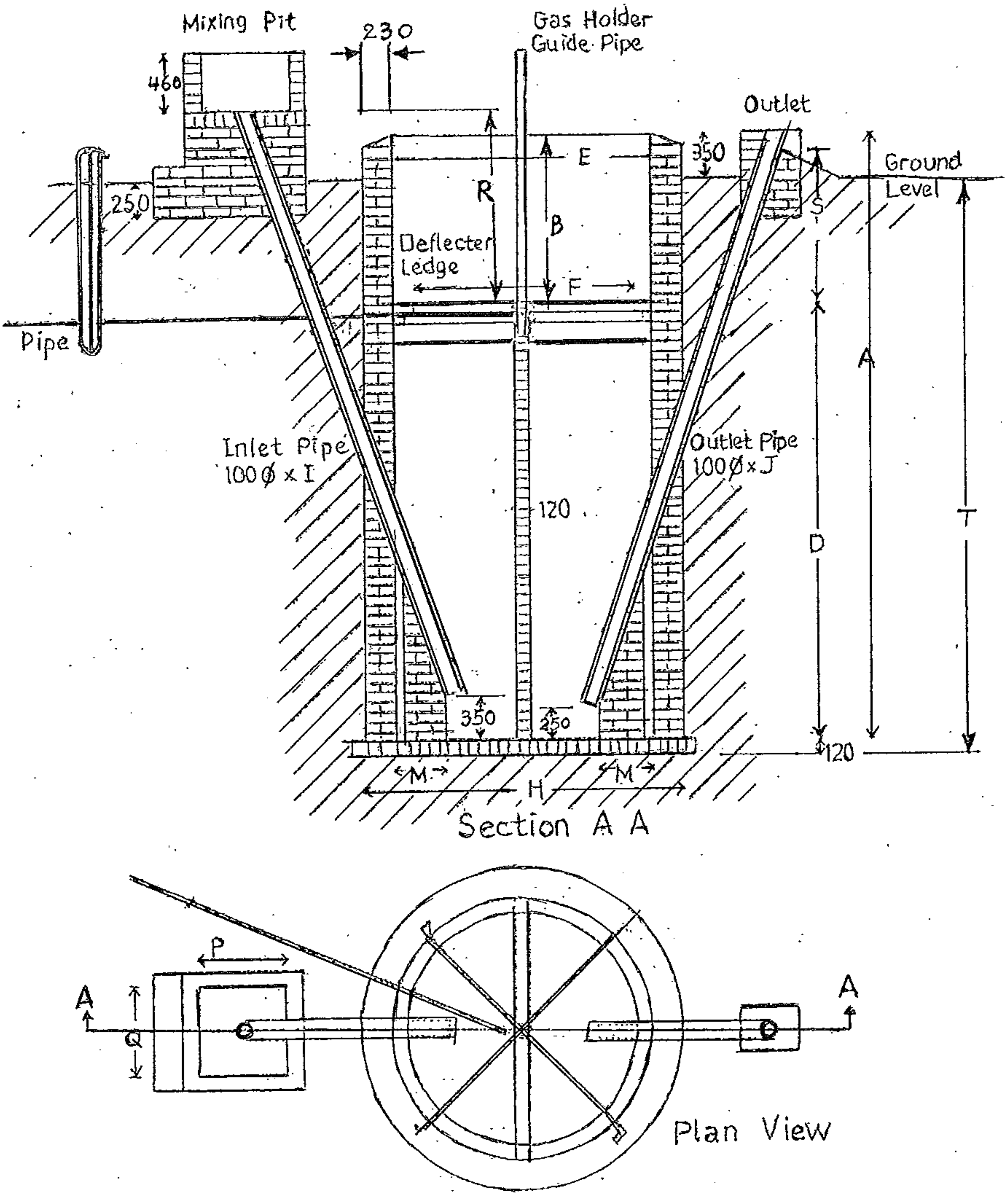
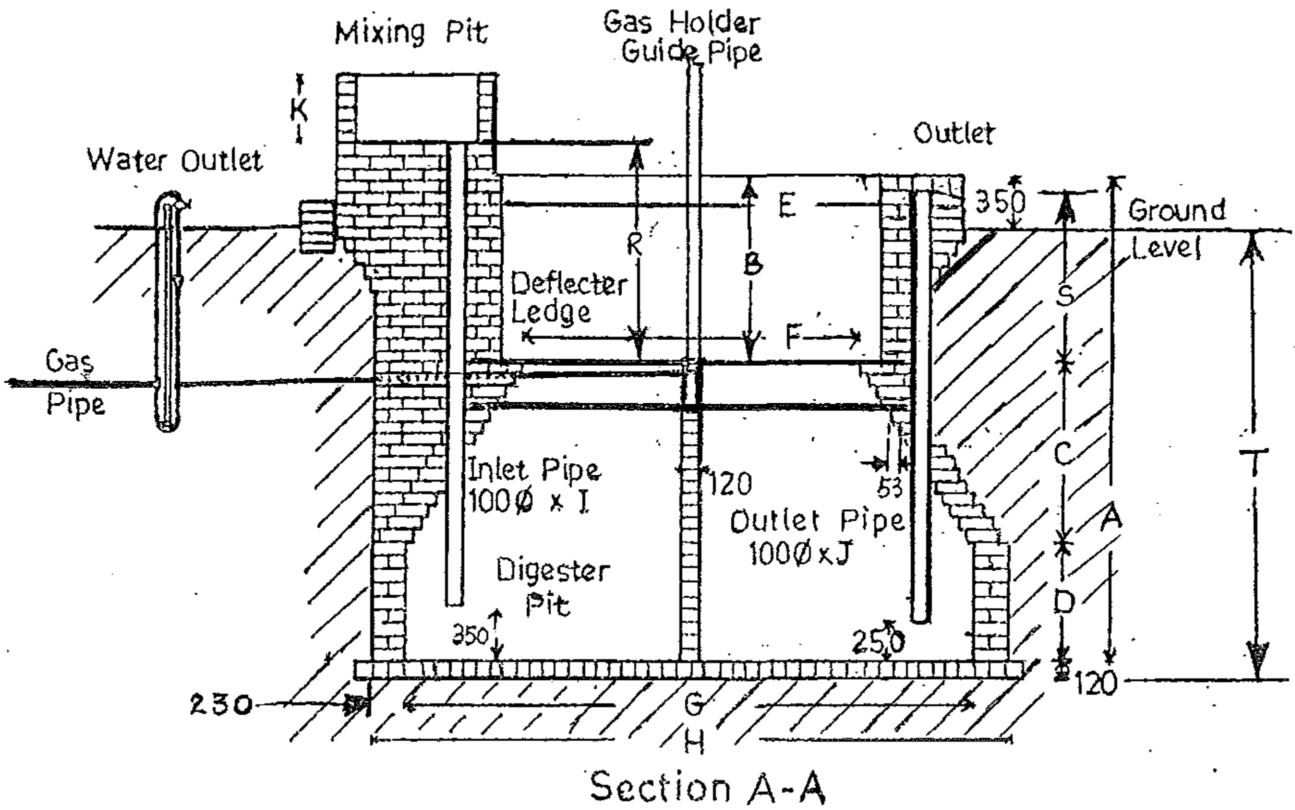


Figure 2.4 <u>Floating Drum Design SD200, 350 & 500 (Straight Type)</u>



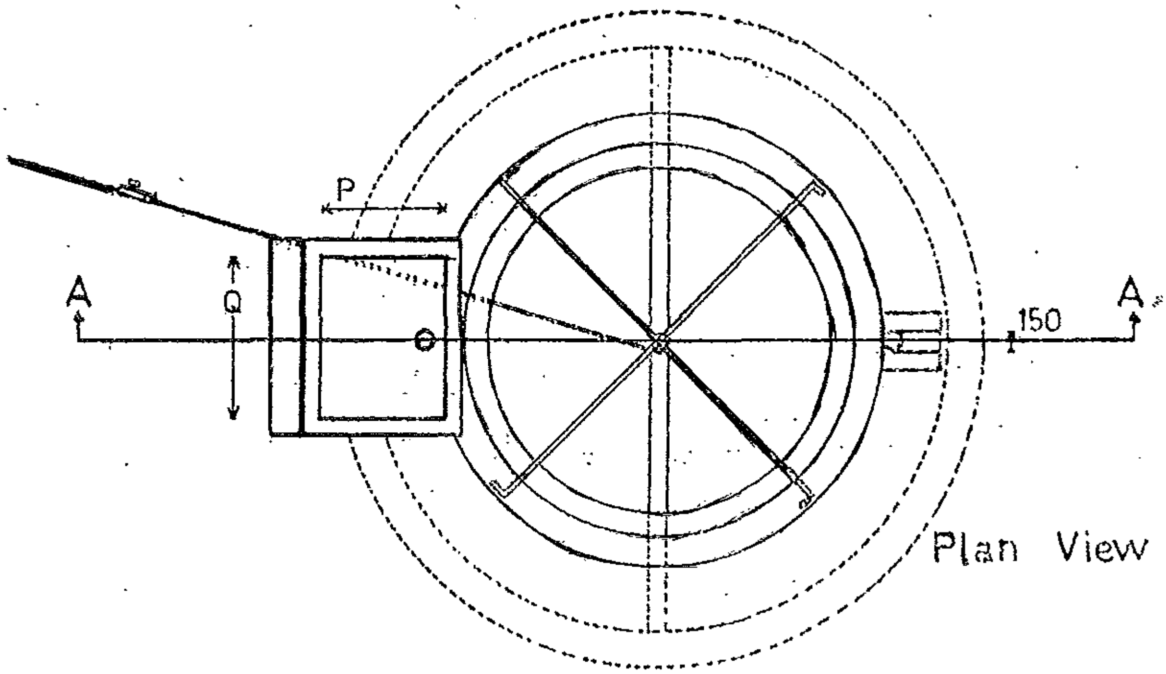


Figure 2.5 <u>Floating Drum Design SD100, 200, 350 & 500 (Taper)</u>

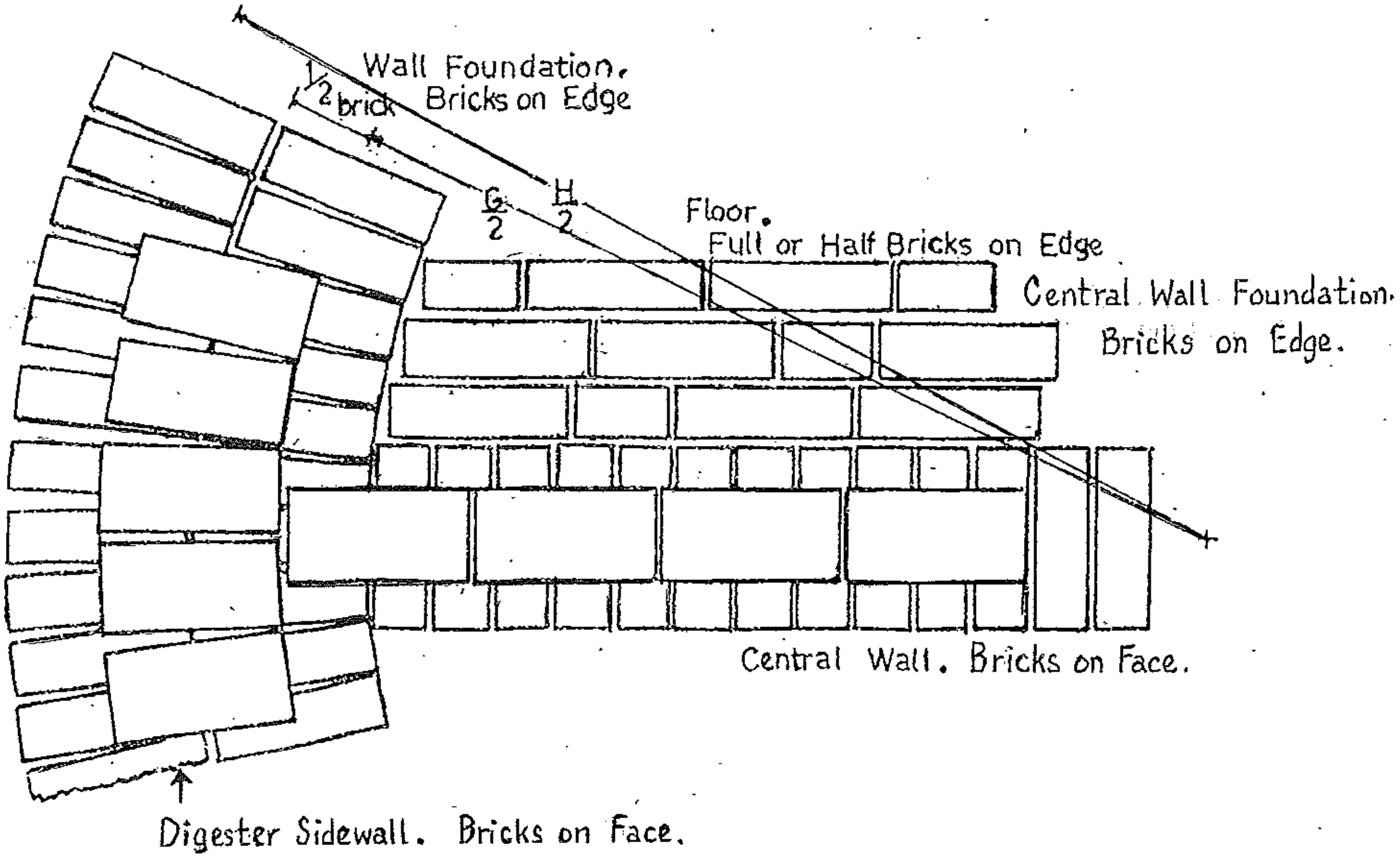


Figure 2.6 Layout of Bricks for the Floor of Drum Plants

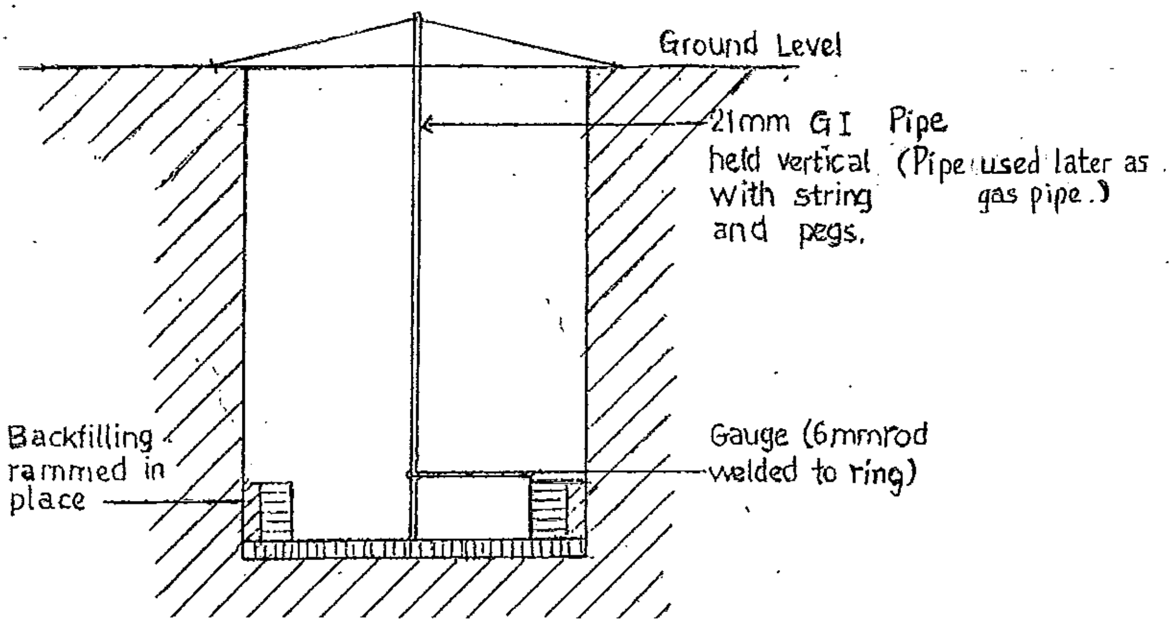


Figure 2.7 Building Gauge used to Ensure Circular Walls

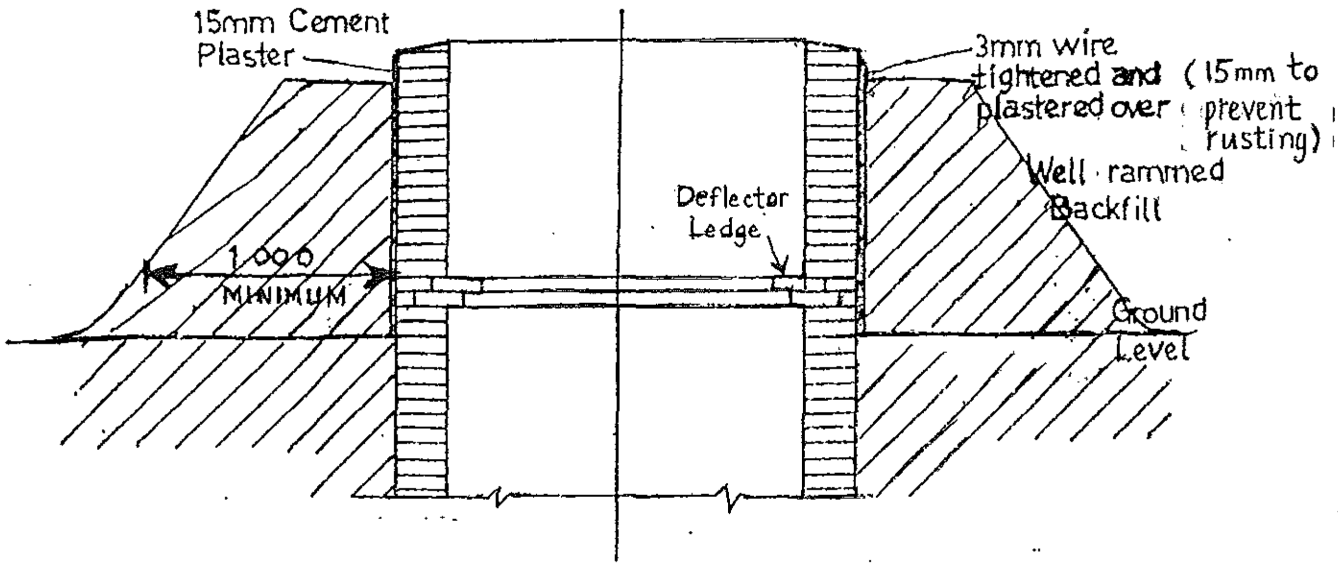


Figure 2.8 Method for Strengthening Brickwork above Ground Level
(United Nations ESCAP)

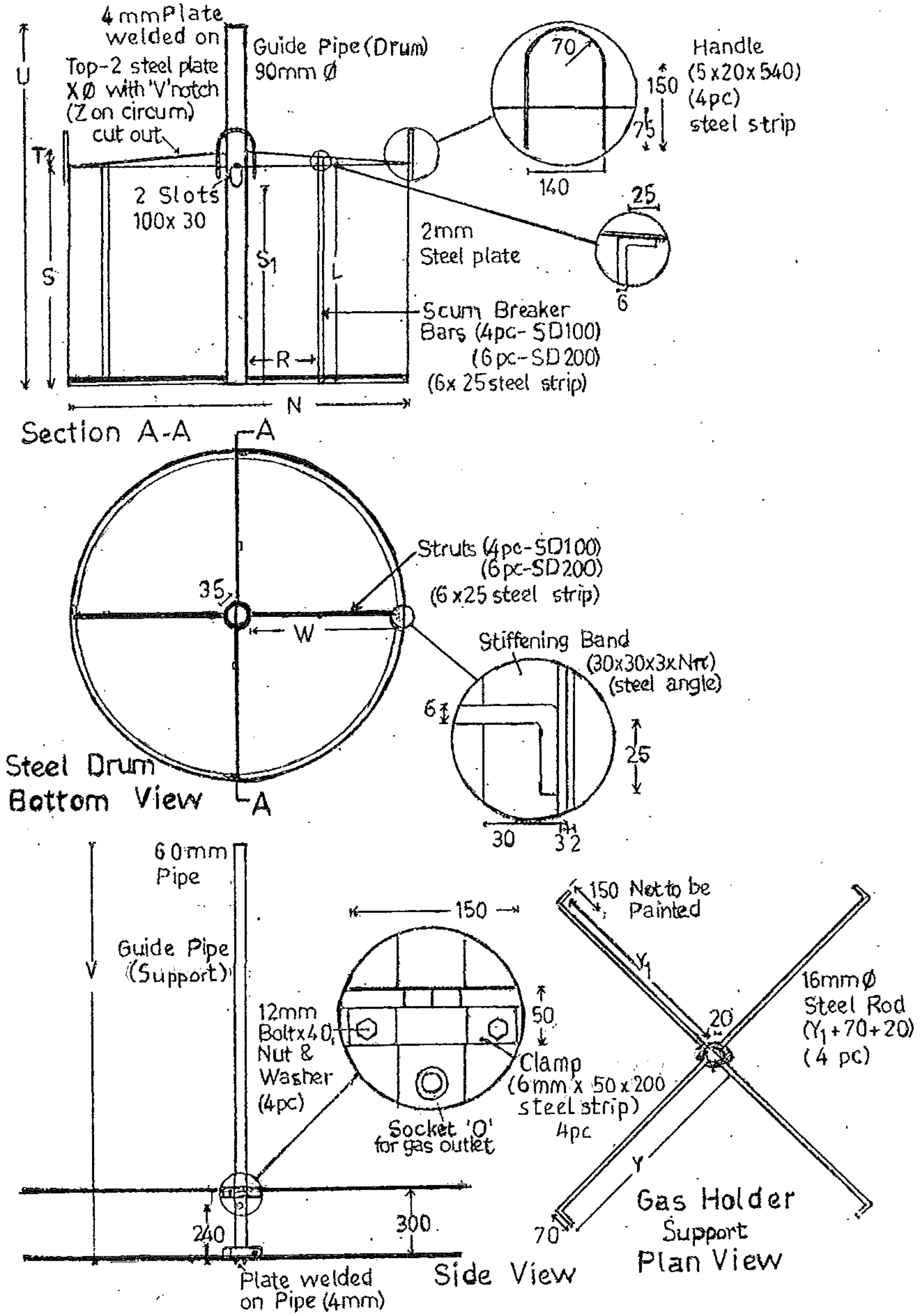


Figure 2.9 Gas Holder for SD100 & 200

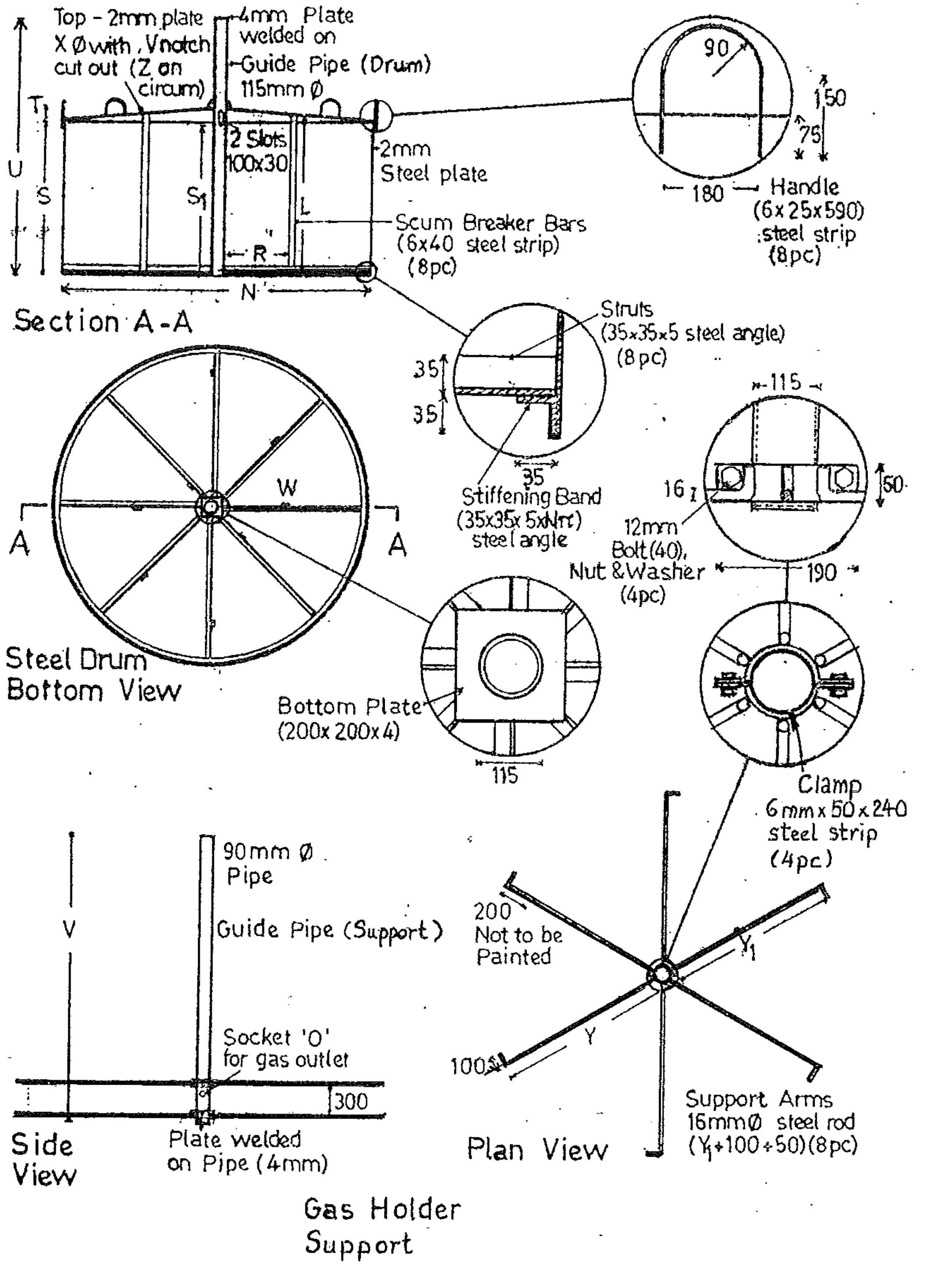


Figure 2.10 Gas Holder for SD350 & 500

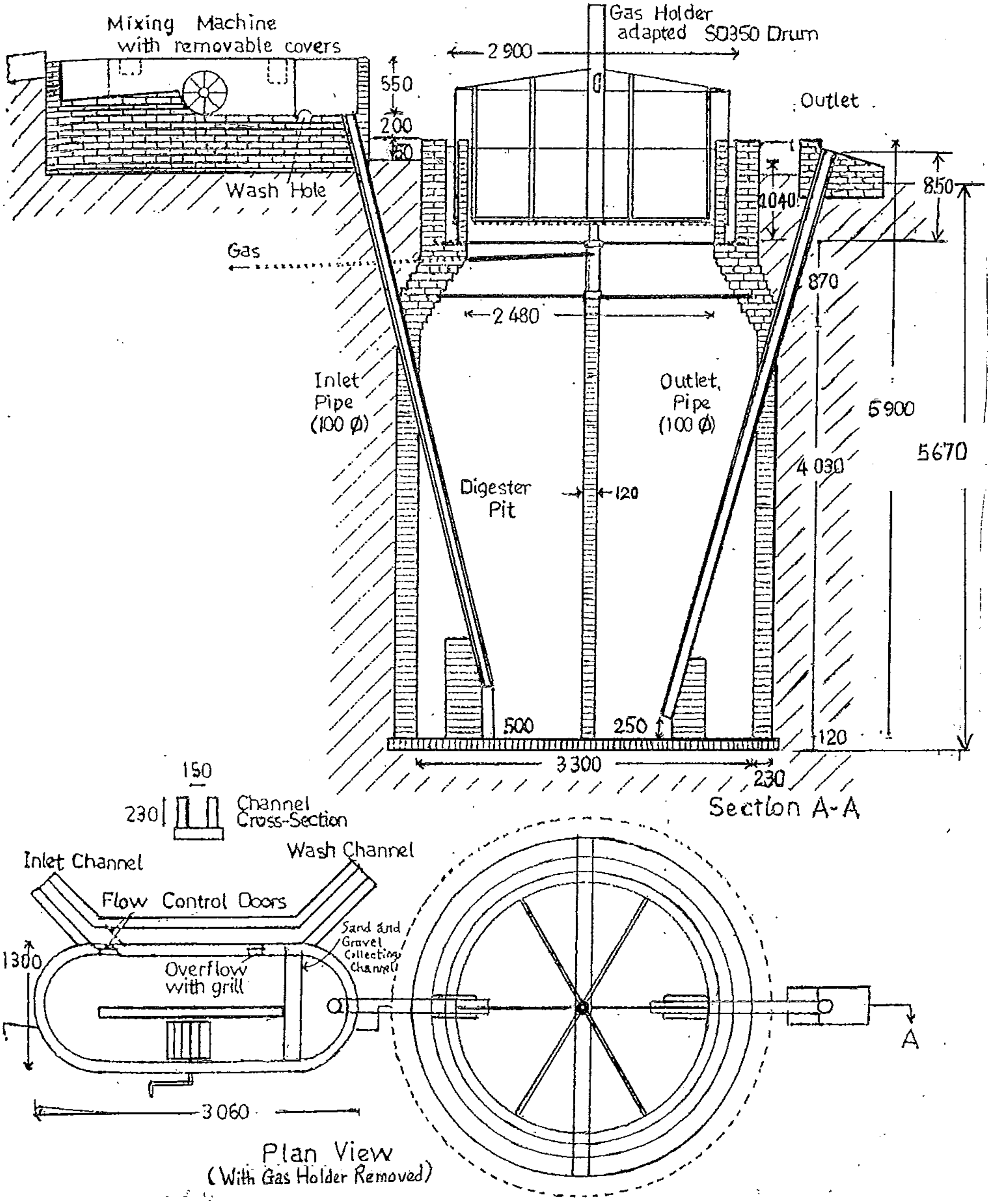


Figure 2.11 Night Soil Gas Plant

Chapter 3 FIXED CONCRETE DOME DESIGN D. Fulford

3.1 Characteristics of Design

The dome design consists of an underground digester pit with a concrete dome-shaped cover over it, to collect the biogas as it is given off by the slurry. The enclosed chamber is lined with concrete plaster and is all underground. The design used by DCS is an adaptation of a design developed originally in China (SPIIBD, 1978; van Buran, 1976) and it uses the 'displacement principle' of operation. A second pit, called the 'slurry reservoir' is built above and to the side of the digester pit and is open to atmospheric pressure. The concrete dome is fixed, so it cannot move up or down as gas collects; instead the slurry in the digester pit is forced up into the slurry reservoir, as the biogas collects under pressure (Figure 3.1). As the biogas is used from under the concrete dome, the slurry flows bac from the reservoir to replace it.

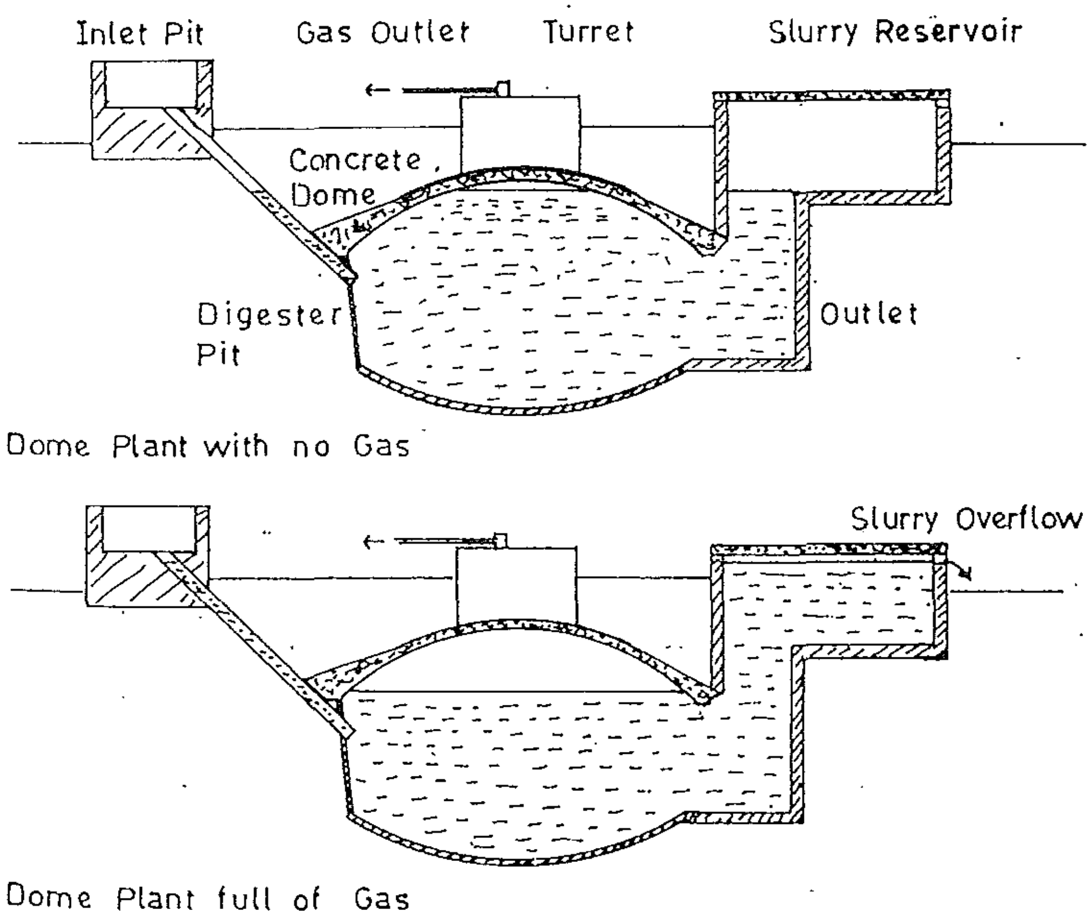


Figure 3.1 Displacement Principle of Operation of Dome Plant - Gas collects under the dome and forces the slurry into the reservoir. As gas is used, the slurry flows back into the digester pit.

The version of this design developed in DCS is made of concrete, with a minimum of reinforcement steel in it. Brick or stone masonry is only used for the inlet pit and slurry reservoir. As there is a high gas pressure under the dome, when it is full of gas (up to 1.2 metres water guage, 1200 kg/m²), the whole dome must be covered with a minimum of 0.8 metres of soil to hold it down. A central turret of brick or stone filled with soil also acts as a weight, as well as supporting a gas outlet pipe and a scum breaker. Access to the digester pit during construction, and also if the pit needs cleaning out at any time, is from the side, through the slurry reservoir and outlet. For safety, nobody should enter the pit until every trace of cow dung has been washed out of the pit and the remaining biogas has been flushed out, as it is possible to be suffocated by biogas in the pit.

The two key features of the DCS version of the Dome Design are the way the dome is built and the way it is sealed. The dome is made by casting it over a mud mould, before the digester pit is dug away underneath. The dome is sealed with a cement plaster coat with an acrylic plastic emulsion paint mixed in it. This design has proved very successful in Nepal, both technically and commercially. The commercial price is about 20% cheaper than the steel drum design and the farmers seem to like it. Because both the digester pit and the gas dome are underground, it is better insulated than the steel drum design, so gas production in the cold weather is greater. Further insulation, in the form of straw or compost can easily be added. The DCS design includes a scum breaker, fitted through a pipe in the centre of the dome. This item is not essential, and can be left out, but it may allow the farmers to clean out their plants less often, if they allow too much straw and other vegetable matter that can form a scum to be added to the slurry.

A disadvantage of this design is the increase and variable pressure of the gas in the gas dome. As the gas forces the slurry into the reservoir, the gas pressure increases from a few millimetres up to 1200 mm (WG). This high pressure makes it more difficult to seal gas pipes against leaks and can also cause certain gas valves to leak. It also means that gas burners and gas lights must be carefully controlled, as the gas flow through the jets is increased by up to 4 times. The high pressure has one advantage, as the loss of pressure as the gas flows down gas lines is far less important. Smaller sized gas pipes may be used with this design of plant.

The construction of this design of digester is also more difficult than for other types, as it requires people with good skills in plastering cement. If the cement plaster work is done badly, then gas or slurry can leak from the plant, thus reducing its efficiency.

At present, three sizes of this design are being made commercially in Nepal: CP10, CP15, and CP20, where the numbers refer to the nominal total digester pit volume in cubic metres (Table 3.1). The CP10 size produces enough gas for the cooking and lighting needs of a family of 7 people, and requires dung from 4 to 6 cattle. Two CP20 plants can supply enough gas to run a 5HP engine for 6 hours a day.

Table 3.1 Characteristics of Concrete Dome Design

Plant Type	Vol. m³ Digester	Dome	Total	Working	Input Dung,kg	Retention Time,day	Gas Production m³
CP10	7.3	3.3	10.6	9.0	60	75	1.84
CP15	9.7	5.6	15.3	12.5	90	69	2.69
CP20	14.1	5.6	19.7	16.9	120	70	3.61

Notes: The 'Working Volume' is the mean volume of slurry in the digester pit (taken over the daily variations). The Input is taken as cattle dung mixed 1:1 with water. The Gas Production is taken at 25°C (based on Ch.5).

3.2 Construction Details for Fixed Concrete Dome Design

Detailed drawings for the Fixed Concrete Dome design are given in Figures 3.2 to 3.6 inclusive. The drawings apply to all three sizes of plant, but are only to scale for the CP10 size. The values for the dimensions indicated by letters and numbers in the drawings are given in Table 3.2 and the quantities of materials used are shown in Table 3.3.

3.3 Site Preparation

The site for the biogas plant is roughly cleared and levelled. The positions for the digester pit, inlet pit an reservoir are defined. The centre of the dome is located and a circle, diameter D_1, is marked on the ground, using string and sticks. Two pegs are placed in the ground, about 0.6 metres from the edge of the circle, so that the string tied between the pegs passes over the centre of the circle. This string defines a datum line from which measurements may be taken. It should be checked with a level to ensure it is horizontal.

A hole is dug, within the circle, diameter D_1, to a depth H_1. In the centre of this hole a second pilot hole is dug, of diameter 1.5 m or more, and of depth H_2 or more. This hole eases the work of excavation of the digester pit later on, and also allows the condition of the soil to be checked: to see if there are large stones, or to see if the water table is too high.

3.4 Making the Dome

The concrete dome is cast over a mud mould. The pilot hole is covered with boards and brances and mud is piled over. The pipe for the scum breaker is placed in th exact centre of the mould. The edges of the hole are cut away, and mud is packed onto the central mound, until the steel template will fit into the hole. The template is attached to the central pipe with string, and rotated round it to define the shape of the mould. The template should just pass under the datum string and should be regularly checked with a plumbline or level to ensure that it is square.

An important part is the edge of the mould, where the concrete dome rests on the soil. The edge of the dome is thickened to form a 'collar'; the weight of the dome, and the earth fill above it, is taken by this collar as it rests on the earth foundation. The soil in this area

Table 3.2 Dimensions of Different Dome Plants

Item	Dimension (millimetres)	Ident.	CP10	CP15	CP20
Concrete Dome	Outside Depth	H_1	800	920	920
	Inside Diameter	D_1	3 100	4 000	4 000
	Radius of Spherical Seg.	R_1	2 000	2 800	2 800
	Included Angle (°)		101° 36'	91° 10'	91° 10'
	Thickness of Shell	t_1	60	80	80
	Width of Collar	t_2	190	230	230
	Height of Collar	t_3	160	190	190
	Length of Collar	l_1	800	1 000	1 000
Turret	Height of Turret	T_1	750	750	850
	Diameter of Turret	T_2	750	1 000	1 000
	Length of Gas Outlet	T_3	900	900	1 000
Slurry Inlet	Inside Length Sides	I	1 200	1 500	1 700
	Length Cement Pipe	L_1	2 500	3 000	3 000
Digester Pit	Depth of Conical Sectn	H_2	780	270	785
	Depth Spherical Segment	H_3	580	1 090	875
	Radius Spherical Seg.	R_2	2 100	2 200	2 500
	Diameter of Inside	D_2	2 900	3 800	3 800
Slurry Outlet & Reservoir	Overflow to Datum	G_1	240	160	120
	Datum to Floor	G_2	560	680	630
	Floor to Base Outlet	G_3	1 060	630	1 195
	Inside Length Reservoir	S_1	1 800	2 480	2 640
	Inside Breadth Reserv.	S_2	1 250	1 250	1 760
	Length & Breadth Outlet		600	600	600
Template	Diameter of Guide Pipe	d_1	42	42	48
Scum Breaker	Length Outside Pipe	J_1	1 870	1 990	2 080
	Length Inside Pipe	J_4	1 950	2 070	2 160
	Base to Rider	J_2	630	740	740
	Length Bottom Blade	J_3	1 400	1 490	1 800
	Length End Piece	J_5	0	0	100
	Radius of Top Blade	R_3	1 980	1 980	2 480
	Diameter Inside Pipe (OD)	c_1	27	27	33
	Diameter Outside Pipe	c_2	33	33	42
	Diameter Rider	c_3	48	48	48
	Diameter Steel Stud	c_4	20	20	25

Table 3.3 Material Quantities for Different Dome Plants

CP 10 Size	Cement kg	(bags)	Sand lit	(bags)	Aggregate lit	(bags)	Bricks nos.
Concrete in Dome (1:3:3)	260	(5 1/2)	500	(15)	500	(15)	-
Plastering	260	(5 1/2)	600	(18)	-		-
Brick Masonry	120	(2 1/2)	460	(14)	-		1300
Concrete Covers	50	(1)	70	(2)	140	(4)	-
Total for basic plant	690	(14 1/2)	1630	(49)	640	(19)	1300
(Extra to Plaster Outlet	50	(1)	160	(5)			)
(Extra for Support Legs	20	(1/2)	60	(2)			150)
Cement Pipe	2.5	metres					
Steel Rod (6mm)	40	metres					
Acrylic Emulsion Paint	2	litres					
Scum Breaker							
Gas Outlet Piping							
CP 15 Size							
Concrete in Dome (1:3:3)	500	(11)	1100	(32)	1100	(32)	-
Plastering	360	(8)	750	(22)	-		-
Brick Masonry	140	(3)	540	(16)	-		1500
Concrete Covers	70	(1 1/2)	100	(3)	200	(6)	-
Total for basic plant	1070	(23 1/2)	2500	(73)	1300	(38)	1500
(Extra to Plaster Bricks	50	(1)	160	(5)			)
(Extra for Support Legs	20	(1/2)	60	(2)			150)
Cement Pipe	2.5	metres					
Steel Rod (6mm)	50	metres					
Acrylic Emulsion Paint	3	litres					
Scum Breaker							
Gas Outlet Piping							
CP 20 Size							
Concrete in Dome (1:3:3)	500	(11)	1100	(32)	1100	(32)	-
Plastering	420	(9)	900	(26)	-		-
Brick Masonry	170	(4)	680	(20)	-		1900
Concrete Covers	90	(2)	140	(4)	200	(8)	-
Total for basic plant	1180	(26)	2820	(82)	1300	(40)	1900
(Extra to Plaster Bricks	70	(1 1/2)	250	(8)			)
(Extra for Support Legs	40	(1)	200	(6)			300)
Cement Pipe	3.0	metres					
Steel Rod (6mm)	75	metres					
Acrylic Emulsion Paint	3.0	litres					
Scum Breaker							
Gas Outlet Piping							

Notes: If wooden covers are used rather than concrete over the slurry reservoir, then only 5 metres of 6mm steel rod are required. Plastering of the bricks in the slurry outlet and reservoir is only required if the outside soil is porous. If stone masonry is used, double the cement and sand quantities in line : 3 of each section.

should be disturbed as little as possible as the shape is cut, and it should be packed as hard as possible to form a firm foundation.

The dome shaped mould should be shaped carefully according to the template and packed hard to form a smooth segment of a sphere. When it is complete, it is covered with a thin layer of fine sand and the template removed. The gas outlet pipe should be put in place and held upright with a pole or rope across the top of the pit. The 0.1 m (6mm) studs on both the gas outlet and scum breaker pipes should lie just above the mould, so they are covered completely with concrete, when it is applied.

The concrete dome should be cast at one time and within one day, so all the materials must be prepared and ready. Enough labourers must be available to mix the concrete and trowel it in place. A mixture of 1 part cement, 3 parts sand and 3 parts aggregate (small stones, 5 to 25 mm diameter) is used, with as little water as possible to make a workable mix (Table 3.3). Reinforcement rods (1.4 Metres long, 6 mm thick) are placed in the edge of the dome, over the outlet, next to where the slurry reservoir is to be built. The concrete is trowelled to the shape shown in Figure 3.2 and compacted. It is left to dry for 7 days before it is disturbed. It must be damp by covering it with sacking which is wetted regularly, so the concrete cures properly.

3.5 Inlet Pit, Turret and Gas Outlet

While the dome is curing, other work can be started. The inlet pit is built; a hole is dug beside the dome into which a length of asbestos/ cement pipe is placed, which takes the slurry into the digester pit. The inlet pit itself is built of brick or stone masonry on a simple foundation. It is a square of sides: I, with the end of the inlet pipe to one end of the square. The inside of the square is filled up with stones or rubble to floor level, which is at least 0.5 metres above datum. The floor is paved with bricks or concrete and plastered, so that slurry can be mixed in the pit and pushed down and the pipe into the concrete cast into a suitable shape.

A brick or stone turret is built on top of the dome, to support the gas outlet and scum breaker pipes. When the plant is completed, this turret is filled with stone, rubble and earth and closed with a layer of concrete (50 mm thick).

The pipe fitting can also be started, to take the gas from the plant to where it is needed. The pipeline should slope (1:100) towards a low point, where a water outlet device is fitted. A small brick-lined pit can be made to allow easy access to it (Figure 3.6).

3.6 Digging and Plastering the Digester Pit

A pit for the slurry outlet is dug beside the dome, to a depth G_2+G_3 below the datum. Once the dome concrete is set,excavation of the digester pit can begin, soil being removed via the slurry outlet pit, must be taken not to undercut the edge of the dome while digging. A pipe can be lowered through the scum breaker pipe to act as a centre from which the radius ($D_1/2$) can be measured, with a string or tape, at a depth H_2

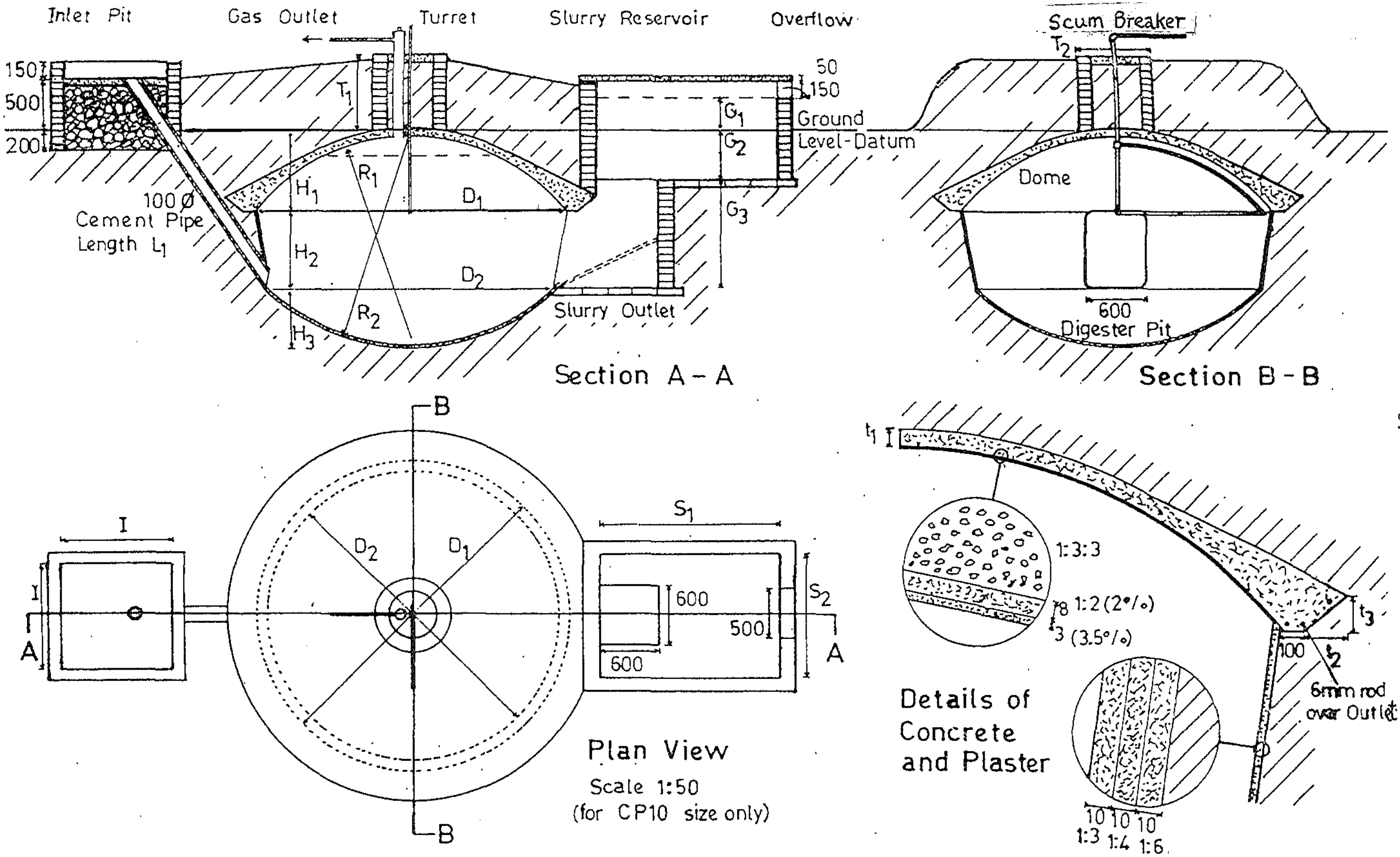


Figure 3.2 Fixed Concrete Dome Design: Construction Drawings

DJF/DCS

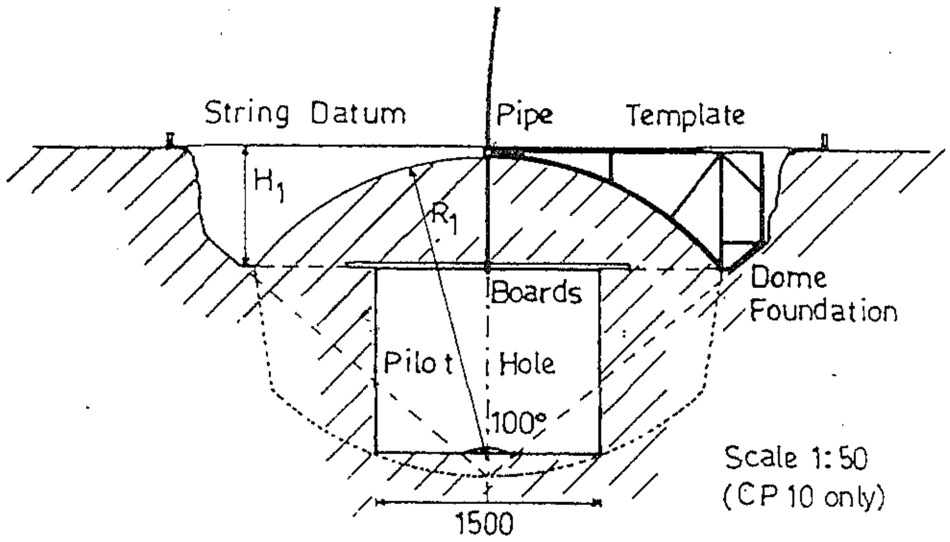


Figure 3.3 Mud Mould for Dome

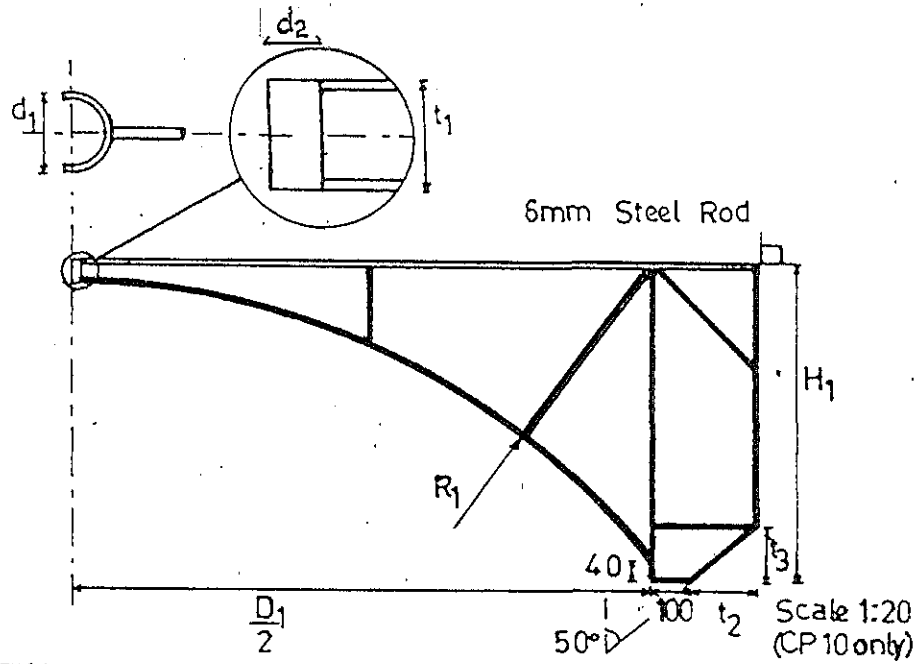


Figure 3.4 Steel Template

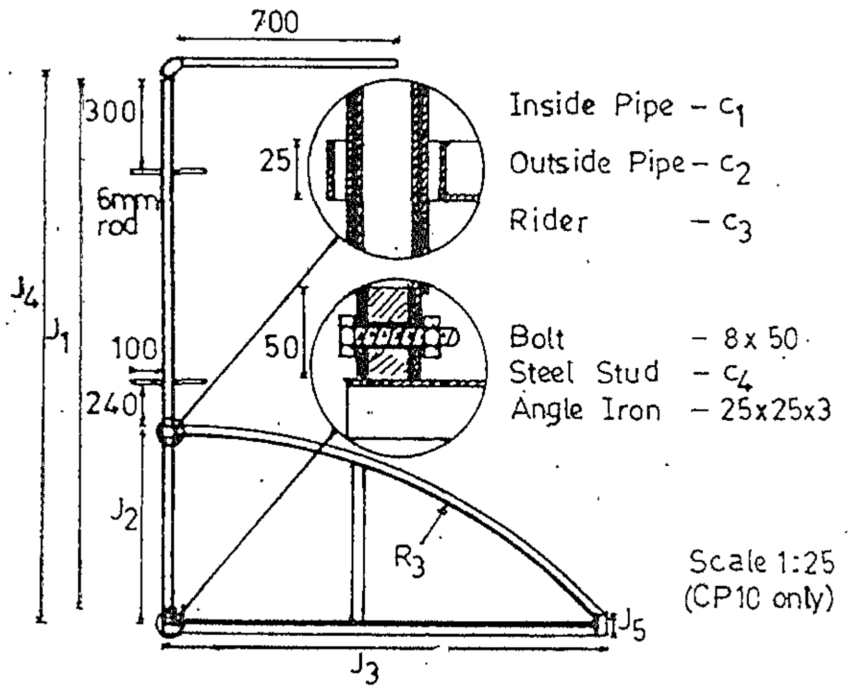


Figure 3.5 Scum Breaker

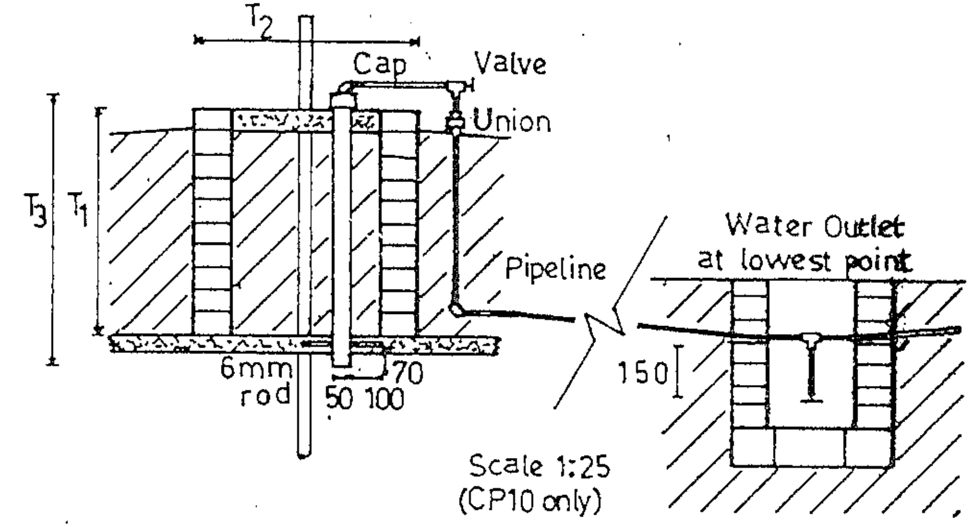


Figure 3.6 Gas Outlet and Pipeline

DJF/DCS

below the end of the fixed gas outlet pipe. The concave shape of the floor can be defined by a length of string, tied to the top of the scum breaker pipe, as it goes into the dome. The string is of length R_2, and the earth is cut away until this string can be held taut over the whole floor area.

If the soil is loose and sandy, brick pillars can be made to help support the dome (5 for CP10 and 7 for CP15 and CP20 plants): one on either side of the outlet, the others spaced equally around the dome. Recesses are first dug, one at a time from the pilot hole to under the edge of the dome, and a brick pillar (height H_2) built up from the floor to the dome. When these 'legs' are complete, the rest of the digester can be excavated as usual.

The whole of the inside of the digester is lined with cement plaster, walls and floor. The plaster is usually applied in 3 coats, each of 10mm thick (CAI), using mixtures of 1:6, 1:4, 1:3 of cement and sand, for respective coats. As little water as possible should be used to give a workable mix. The plaster for each coat should be applied at one time, working from the inlet to the outlet round both walls and floor. If the first coat does not bind well to the wall, eg. if the soil is loose and sandy, it can be 'dashed' onto the wall, sharply throwing it from the trowel. Alternatively, wire mesh can be used to reinforce and bind it. Each coat should be allowed to cure for two days before the next is applied, and should not be allowed to dry out while it is curing. Other work, such as pipe fitting, can continue as the plaster cures.

3.7 Plastering the Dome

The inside of the dome is carefully cleaned of all mud and loose sand and scrubbed with a wire brush. It is also dampened by brushing on water . The surface of the dome is then sealed with two coats of cement plaster mixed with acrylic plastic emulsion paint. The first coat is a mix of 1 part cement with two parts sand with about 2% (by weight of cenent)paint. The water content should be limited to about 35% of the weight of the cement, and the morter should be very well mixed. This coat is of 8mm thickness and it should be allowed to cure for two days before the top coat is added. This coat is of pure cement mixed with 3.5% paint and 28% water. Both coats should be spread evenly over the whole inner surface of the dome to ensure a gas tight seal. Any remaining paint can be applied over the surface of this plaster, once it is cured.

3.8 Slurry Reservoir and Outlet

The slurry reservoir and outlet can be shaped and lined with brick or stone masonry while the plaster coats are drying. The outlet is 0.6 m^2 and the walls should blend in with the edges of the dome and the plastered walls of the digester pit. To save material on the CP20 plant, the outlet floor can be made on a slope (dotted lines in Figure 3.2), but steps should be made to ease access. The reservoir encloses a rectangle of sides S_1 and S_2 and the masonry floor is G_2 below the datum level. The walls are built up to a height of (G_1+0.15m) above the datum except for the slurry overflow. A large overflow gap is useful (eg. 0.15x0.5m) as the slurry can dry out and block it.

If the outside soil is porous, the slurry outlet and reservoir may need to be lined with cement plaster (10mm of 1:6 mix) to stop the slurry leaking out through the bricks. This type of leak should be self-sealing eventually, as the slurry dries out in the cracks and fills them.

3.9 Completing the Plant

The scum braker is put in place, with the inside pipe, with handle attached, lowered from above and bolted to the scum breaker arm inside the plant (Figure 3.5). The whole dome must be covered with soil, up to the level of the top of the turret in the centre. The weight of the soil counterbalances the pressure of the gas inside the dome. If adequate soil is used to cover the dome, it may break.

Covers must be made for the slurry reservoir, either from wood or reinforced concrete. If concrete is used, lengths of 6mm steel rod are arranged in a grid shape, equally spaced, in a shallow mould. This can be a trench in the ground (50mm deep). The concrete mix is 1:2:4, cement to sand to aggregate (stones 5 to 25mm). The covers can be made as several separate slabs to ease moving, and handles made from 6mm rod incorporated.

3.10 Fabrication of Plant Components

One advantage of the concrete dome digester is that very little of the plant has to be fabricated in a workshop and transported to the site. There are three items: the steel template, which is reusable for many plants, the gas outlet pipe and the scum breaker.

The steel template is made from 6mm rod (Figure 3.4) One rod is bent into a radius R_1, but the rest must be straight. The top corner must be accurately squared. As the frame is welded, care should be taken that it remains flat, and not twisted. A short section of pipe is chosen, to fit round the central pipe of the scum breaker.

The gas outlet pipe is made from 50mm 2 inch) diameter steel galvanised pipe (GI). Four 100mm stubs (of 6mm) steel rod, or other steel material, are welded, at right angles to each other onto the pipe near the lower end. These stubs will tie the gas outlet into the concrete dome. A screwed cap is provided at the other end, to provide access for cleaning. The 15mm (½ inch) GI pipe can be welded to the 50mm pipe, or to the cap. The former has proved more effective, as cast iron pipe fittings are difficult to weld. However, if brazing were used, the second method would be preferred.

The scum breaker is made from angle iron (25x25x3 mm) and GI pipes. The upper arm is bent to a radius (R_3) and welded to the lower arm (length J_3). A strut of angle or flat iron is welded between them. Only the lower arm is attached to the inner driving pipe (c_1), with a bolt, passing through the pipe and a stud on the arm. The upper arm is welded to a 'rider', a short length of GI pipe (c_3) that rides on the outside of the fixed pipe (c_2). The outside pipe has 8 studs welded to it, so it can tie into the cement dome and the concrete at the top of the turret. A handle is made from GI pipe (c_1), attached to the inner pipe by an 'elbow', and welded or brazed for strength.

3.11 Practical Experience of the Use of Dome Plants

Two follow-up surveys have been done on the first 11 plants built to this design in Nepal. A further 12 plants were included in the second survey, built since the first. The second survey included 16 CP10, 2 CP15 and 5 CP20 plants (3 of the latter on a government farm) (Devkota, 1982). All 23 plants were working, at the time of the second survey, when the first plant built was almost 3 years old, and the structure appeared to be in good condition. The major problem experienced by the plant owners were the leaks in the gas valves, which were not designed to use the greater pressures. No owner had any other problems with using their gas equipment at these greater pressures.

The scum breaker caused some complaints. People objected to gas and froth leaking from the pipe when the dome was full of gas. This was a deliberate feature of the original design, to act as a 'safety valve' when there was too much gas, but the pipe has been made longer to stop this happening. Gas can leak from the outlet pit, so a 'safety valve' is not needed. About half of the original (eleven) scum breakers were broken, but the owners could see little difference whether they were able to use them or not. The scum breakers were included because of reports (Fry, 1974) of scum build up, and of practical experience of similar problems with drum plants. However, they are not used in China despite the practice of adding large proportions of vegetable matter to the plants (FAO 41). Scum breakers may not really be necessary.

Some owners complained that the slurry did not come out of the overflow each day, despite adding slurry daily. The soil is very porous in the area where these plants were built, and the bricks were of lower quality so slurry could be leaking away underground, pushed by the high pressures in the plants. The inside of the slurry outlet and reservoirs of these plants need to be plastered.

To date (ie. Summer of 1983), about 300 biogas plants have been built to this design in Nepal, and most seem to be working well. There have been a few problems with individual plants, but the cause is usually traced to poor masonry work. The dome has rarely given trouble, although one or two have cracked, when poor quality cement (that had lain in the open for several months) was used. These were rebuilt. In one plant, the farmer added slurry before the dome was covered with soil, and the gas pressure pushed the dome out of the ground. Once the slurry had been removed, the dome could be pushed back into place, the cracks between the dome and the reservoir pit plastered over, and the plant was working as well as any other.

Other problems have been wrongly shaped domes, too small because the template had not been positioned properly, and too small digester pits because the masons had measurd them incorrectly. The present design has been slightly modified t allow these measurements to be made more easily. Good supervision and quality control are essential for the building of any design of biogas plant.

Chapter 4 TUNNEL DESIGN J. Finlay

4.1 Basic Design

The tunnel design of biogas plant was inspired by the work on plug flow trench reactors done at Cornell University (Jewell et al, 1980). It is different in that it is totally underground and includes gas storage using the displacement principle which means there is movement and mixing of the slurry in and out of the reservoir and therefore the plant is not strictly speaking a plug flow reactor.

From Figure 4.1 it will be seen that this underground masonary plant is shaped like a tunnel and hence its name. The slurry is fed in at one end and discharged at the opposite end. Gas is stored in the roof of the plant which is lined with plastic sheet and displaced slurry flows into a slurry reservoir at the overflow end of the plant.

The top of the tunnel is covered with soil to a minimum depth of 900 to provide the necessary weight to prevent the gas pressure breaking the tunnel roof when it is full of gas. The tunnel design has certain advantages over the Dome design. It is simpler to build and special skills for cement plastering are not required. It requires a shallower digester pit, so is useful where the water table is high, or where the ground is difficult to dig. It is of a modular type of construction, using pre-cast concrete sections, and so can be made to any size, by adding extra sections. Because of the ease of construction it is cheaper to produce.

Jewell's work suggested that a thicker slurry could be used in a plug flow reactor (Jewell et al, 1980b). Therefore less water would be required to mix with the cattle dung and the total digester volume could be reduced for the same amount of daily feed. Tests with the tunnel plant showed that slurries up to 14.5% total solids maximum (a ratio of 2 cattle dung to 1 water approx.) gave the same gas production as slurries of 9% total solids (1:1 dung : water ratio approx.). Subsequent research showed that the same appears to be true for the Dome and Drum plants too (see chapter 15). The tunnel design of plant has been in use in Nepal since 1980 and is proving to be reliable.

4.2 Plant Sizes

As it is well established that these plants run successfully with thicker slurries, all the figures regarding gas production are based on a cattle dung to water ratio of 2:1. This is different to both Drum and Displacement designs where a ratio of 1:1 has been used. It means a smaller digester volume is needed for the same gas production.

Due to the modular construction any size of plant can be built, by altering the length or by running two or more digesters in parallel. The depth of the plant could also be increased in order to increase the plant volume, provided the side walls are made strong enough. So far three sizes of tunnel plant have been made and a series of five standard sizes is planned. There are two designs of digester trench. A tapered trench (Figure 4.2), with the side walls made from cement mortar plastered onto soil (as in the dome plant), is suitable in places where the soil is of good quality. It is the most commonly used design. A brick lined rectangular trench (Figure 4.1) is more appropriate where the soil is sandy or loose. The cross-sectional area of the tunnel, with its arched roof, is about 1.10 sq.m. (trench 0.772 m^2, roof 0.330 m^2). The masonry lined trench has an area of 1.23 sq.m., but dead spots in the corners may reduce this. Each 1 meter length of tunnel plant, therefore, is assumed to have an effective volume of 1.10 cu.m.

The amount of gas that can be stored depends on the smaller volume of one of two things: either the volume of slurry stored in the reservoir which replaces the gas as it is used, or the volume under the plastic lined curved tunnel roof. In Table 4.1 the volume of slurry in the reservoir is used because this is the smaller of the two volumes. It allows about 65% of the daily gas production at 25°C to be stored. If a higher percentage needs to be stored then the reservoir can be extended. For each half meter addition length to the reservoir an extra $0.36m^3$ per metre length.

D.C.S. has made three sizes of plant. For simplicity, and because the basic design is not being altered at all, the sizes of those plants accepted and those planned to become standard are listed in Table 4.1.

4.3 Construction

Masonary: General information is given in Chapter 5.

Detailed drawings for the two types of tunnel plant are given in Figures 4.1 and 4.2. Figure 4.1 can be made to apply to all sizes of plant by altering the lengths of A, C, D and I as given in table 4.2. Material quantities are given in table 4.3.

4.4 Site Preparation and Trench

The site is roughly leveled and cleared.

A trench is dug width 1700 depth 600 and length C. A second trench is dug in the centre of the first 1370 wide and depth 900. The sides of this trench are straight. The floor is lined with bricks on their face and the side walls built up 800 as in Figure 4.1 section D.D. Care needs to be taken when backfilling not to push the walls inwards. The top of the walls should be reasonably level along the whole length of the plant. End walls are built at the same time. At the inlet end the 100 inlet pipe is set totally into the wall and its mouth opens 400 up from the floor to give space for stones etc., which might fall down the pipe (Figure 4.3). Four wooden blocks are set into the end wall for attaching the plastic to. The end wall arch above the blocks is plastered smooth to protect the plastic from getting punctured.

Using cement plaster for sides of trench:

A template (Figure 4.2) defines the shape of the trench. The ends of the template are placed on two bricks placed on either side. End walls are build of masonary (Figure 4.3) and bricks are laid along the sides as shown on Figure 4.2. These should be reasonably level along the whole length of the plant. The floor and sides should be plastered all at one time.

Table 4.1 Characteristics of Tunnel Plant designs
Input : cattle dung mixed 2:1 with water

Plant	TP6	TP8	TP10	TP15	TP20
Digester vol.m^3	4.2	5.8	6.9	10.4	13.9
Dome vol.m^3	1.8	2.5	3.0	4.5	5.9
Total vol.m^3	6.0	8.3	9.9	14.9	19.6
Gas storage* vol.m^3	1.1	1.4	1.8	2.8	3.6
Working vol.**m^3	5.5	7.6	9.0	13.5	18.0
Input Gung kg/day	60	80	100	150	200
Retention time days	61	63	60	60	60
Gas production per day m^3					
Slurry temp. 30.1°C	3.0	4.1	4.9	7.3	9.7
Slurry temp. 25°C	1.7	2.4	2.8	4.3	5.7
Slurry temp. 20.3°C	1.3	1.6	2.2	3.3	4.3

* This is controlled by the volume of displaced slurry which can be stored in the slurry reservoir.

** The "working volume" is the mean volume of slurry in the digester pit (taken over zero and maximum gas stored).

Table 4.2 Dimensions of Standard Tunnel Plants

Dimension (millimetres)	Ident.	TP6	TP8	TP10	TP15	TP20
Tunnel Length	A	5 500	7 500	9 000	13 500	18 000
Trench Length	C	6 500	8 500	10 000	14 500	19 000
Reservoir Length	D	1 500	2 000	2 500	4 000	5 000
Inlet Pit Length	I	1 100	1 400	1 800	2 650*	3 550

* Or use a Mixing Machine (Dimensions in Chapter 6)

Table 4.3 Material Quantities for Standard Tunnel Plants Using Cement Plastered Trench

Type of Plant	TP6	TP8	TP10	TP15	TP20
Cement* kg	300	400	450	600	800
Sand* m³	1.5	1.45	1.82	2.43	3.12
Bricks 230 x 120 x 75 (9" x 4 1/2" x 3")	1,200	1,500	1,700	2,300	2,900
Roof sections (including reservoir)	24	34	42	66	88
Plastic sheet m²	9.75	12.75	15	21.75	28.5
Inlet pipe (100 0) m	2	2	2	2	2
Gas outlet pipe	1	1	1	1	1
Reservoir cover	2	2	2	2	2
Partition piece	1	1	1	1	1

* Excluding requirement for pre-cast parts.

Materials for compoments per piece	Cement kg (litre)	Sand litre	Aggreg. litre	Red 6 m
Roof Section	5 (3.5)	7	14	-
Reservoir cover	10 (7.0)	15	30	9.3
Partition piece	10 (7.0)	13	27	5.1

4.5 Tunnel roof

The roof is built from precast concrete parts made in a mould (Figure 4.4). No reinforcing is used. As the plastic sheet is laid against the inside of the curve it means that this surface must be smooth. Each piece needs to be quality checked and repaired if necessary.

It is easy to place the roof pieces in position if there is one person on either side of the pit and one standing in the pit. A steel rod or wood pole helps lever the pieces into position. They are held there temporarily by pressing bricks between them and the sides of the hole and later on a permanent row of bricks is cemented in place.

If the plastic sheet is to be held in position by using tying strings then it is necessary to place five small spacers where the strings will go (e.g. twigs) (Figure 4.8) between each pair of roof pieces and at both ends.

A 95 Φ hole is cut in the roof to suit the gas outlet pipe. It is positioned on the centre line and close to where the wall for the inlet pipe will be built and to which the pipe will be attached. A new alternative system of removing the gas without cutting a hole is shown in Figure 4.10, it is cheaper and much simpler to install. Tests so far on this new system are positive.

The partition piece (Figure 4.5) is put in place, smooth face inwards and the wooden blocks at the bottom. On the inside of the plant all the levels between the roof pieces are filled in and made smooth and the joints on the outside closed with cement.

4.6 Slurry Reservoir

This is built the same width as the plant (1130). The length is made to suit the size of the plant and the amount of gas which is to be stored.

In the reservoir it is essential to have a fillet to give enough weight to the tunnel roof pieces to prevent them opening up when gas pressure is formed in the plant. This fillet must be keyed into the side walls using a row of bricks (Figure 4.1 section CC). The outlet level is 1100 above the bottom edge of the curved roof pieces. The opening is bell mouthed 45° to reduce blockages due to drying dung.

To reduce costs, curved roof pieces are used as a cover instead of flat ones except for 1000 which is necessary for access (Figure 4.6). Brick walls are built up 900 from the bottom of the tunnel roof pieces and the curved pieces placed on top. If any roof pieces get damaged in transit then they can be repaired and used for this cover. The flat roof pieces at the extreme end have a hole covered by a wooden cover. This is to facilitate removal of a bucket of slurry each day for feeding the new slurry with appropriate bacteria.

4.7 Slurry Inlet

The design of inlet pit shown is shallow with a large surface area so that slurry can be passively heated by solar energy in winter weather (refer Vol. 2 Ch. 6). Where this is not required the depth of the pit can be altered from 150 to 350 and the length shortened by about 70%.

The inlet is built the same width as the plant (1130). The extreme end wall is overhung in order that the inlet pipe can run straight into the digester. The length l is altered to suit the size of the plant and the daily input slurry volume. The depth is to allow 75 for the slurry and 75 to avoid spills when mixing.

4.8 Plastic Sheet Lining for Tunnel

Gas is stored in the roof of the tunnel using a plastic sheet 1500 wide x the length of the tunnel plus an extra 1000 for the ends. PVC 0.45mm thick has worked well and is reasonably easily obtainable because this thickness is used to cover seats. PVC or PVC based plastic is preferred because it is easy to repair or join using PVC glue. A high frequency PVC plastic welding machine is preferable for joins. Other people in Nepal are making tunnel plants using two thinner sheets (700 gauge) of polyethelene. It can be joined by hot plate welding. However, it cannot be glued, so puncture repair is almost impossible. It is readily available and low cost. If black plastic sheeting is used then it easily can be checked for punctures prior to installation by holding it up to the light. Care must be taken not to pierce or puncture the plastic when fitting it in place and the sheet should be laid on a mat, sacks or straw. It should not be walked on. Two methods of putting the plastic in place have been used.

4.9 Tying Strings

Plastic string, which does not rot when wet, is used to tie loops (Figure 4.7) previously welded onto the plastic sheet to wire retainer pieces through holes in the concrete roof pieces Figure 4.8. Five sets of loops are attached at 500 intervals. Five loops are made in each set to allow for misalignments. After fitting, and the holes through which the string pases are closed with cement. When this system is used it is necessary to fit the plastic sheet before the inlet and slurry reservoir are built, in order to get access.

4.10 Plastic Pipe

With this method the plastic sheet is supported from underneath by plastic pipes, which fit into the radial "V" grooves between each pair of concrete roof pieces (Figure 4.9). The pipe is low cost, 1/2" bore, stiff, black water pipe. The radial "V" grooves are not filled in but are made smooth using fine sand and cement to cover up any roughness which could puncture the sheet. This is important. The ends of the pipes have dowels put in them and are nailed into wooden blocks set into the walls immediately below the curved pieces.

Care must be taken at both ends of the plant as only a half "V" is formed by the roof piece. A full "V" can be formed by leaving a small gas of 10 - 15 mm between the end and the adjoining roof piece and using cement mortar to form the full "V".

4.11 Gas Outlet

The assembly of the gas outlet is given in Figure 4.10. The inside faces of both steel flanges must be machined and smooth.

The pipe is passed through the hole in the tunnel roof beside the inlet before the plastic sheet in installed. It is held in position with a clamp and 'J' bolts set into the wall of the inlet pit.

The plastic sheet is clamped between rubber gaskets (made from motor vehicle inner cubes) and steel flanges using brass bolts that fit into threaded holes between the rubber gaskets. After tightening up the loose flange, the centre hole is cut out the same size as the bore of the pipe to seal it and prevent slurry leaks which would otherwise occur.

4.12 Practical Experience with Tunnel Plant

Six plants, four of the TP8 size have been built for customers in Nepal. All have worked well for the 1 to 4 years they have been built. Experience with one plant shower the necessity for the fillet in the slurry reservoir to hold down the roof sections against the internal gas pressure. All holes in the tunnel roof need to be closed otherwise slurry will zone out under gas pressure.

Both systems described for holding the plastic sheet in place have been used but neither system is perfect. With the plastic pipe system care has to be taken to get the grooves smooth and to press the pipe tightly into position otherwise it can slip out sideways. The tying system works provided five ties are used. Three proved to be insufficient to hold the sheet close to the roof and slurry collected in pockets between the roof and sheet. Access to the outer surface of the roof pieces is needed. Over 70 experiments to find a suitable locally available glue to attach the sheet in place have been unsuccessful. Currently a new system to hold the plastic in place is being tried. A pair of half-inch water pipes are made into an 'H' shape but with two corss pieces which are made out of stiff (3.5 GI) wire. This frame is pressed upwards tightly against the plastic sheet and the four ends of the pipes rest on bricks protruding into the plant immediately below the arch. Pairs are set at 500 mm intervals and single wires used to connect the pairs (Figure 4.10). This system is the easiest to install. The gas outlet Figure 4.11 works well and no blockages have been reported. It is expensive to make and needs care in installation. The new system (Figure 4.12) is lower cost and much easier to install. It is being tested at present.

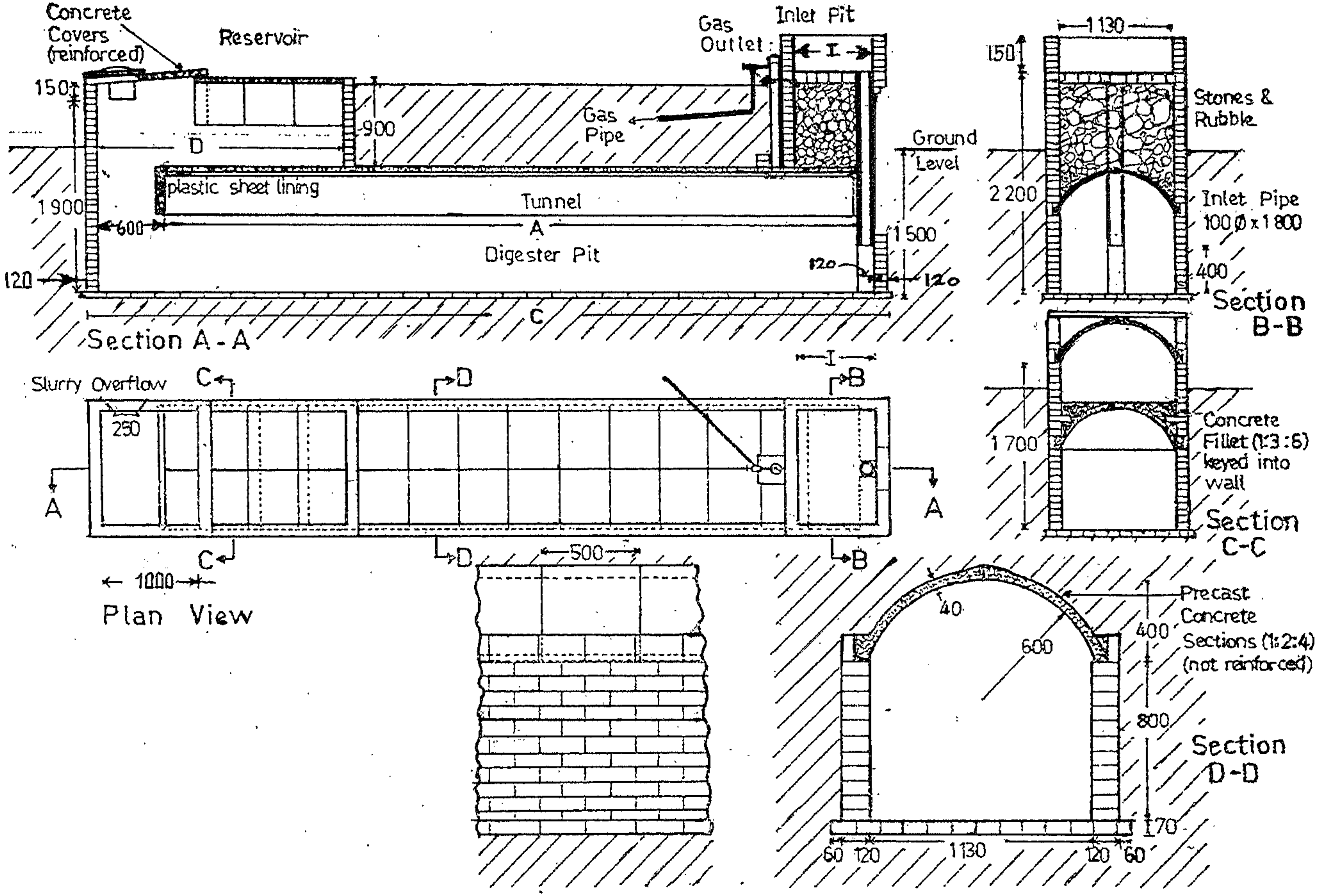


Figure 4.1 Tunnel-Plant Design (TP8)

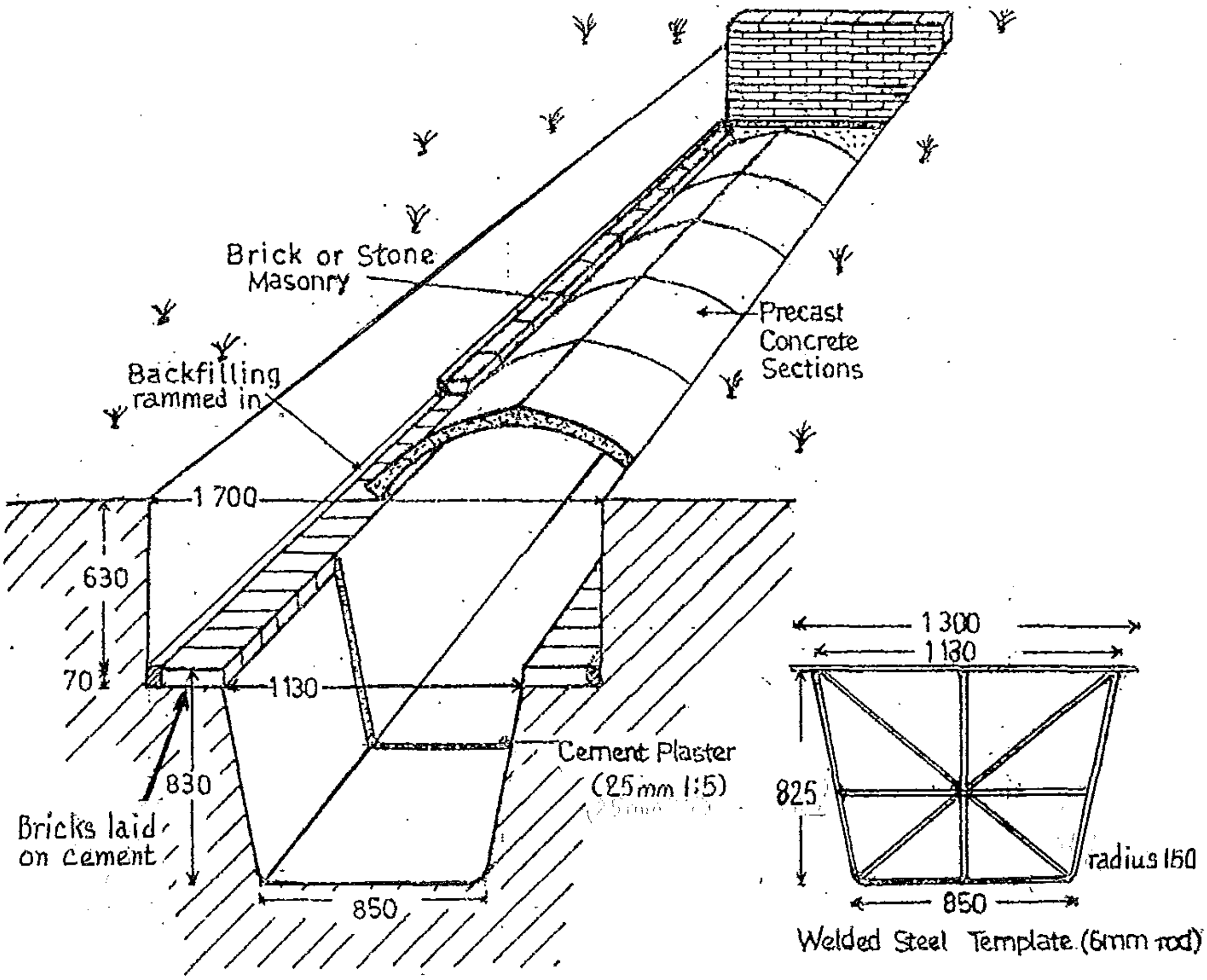


Fig. 4.2 <u>Tunnel Plant Design, with Plastered Trench</u>

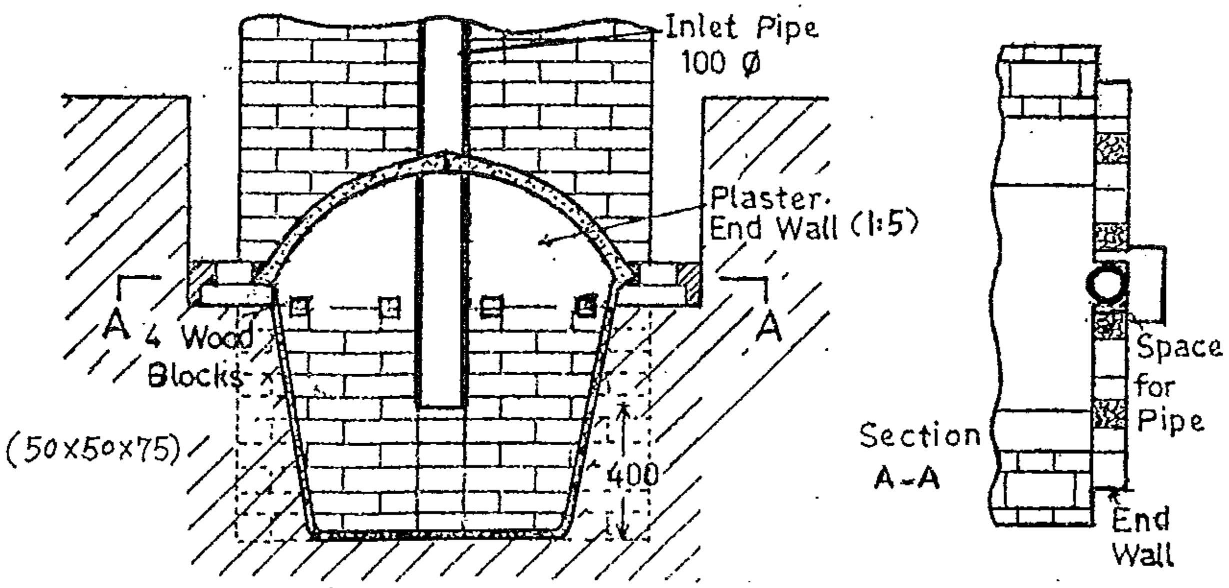


Fig. 4.3 Inlet End Wall for Tunnel PLant

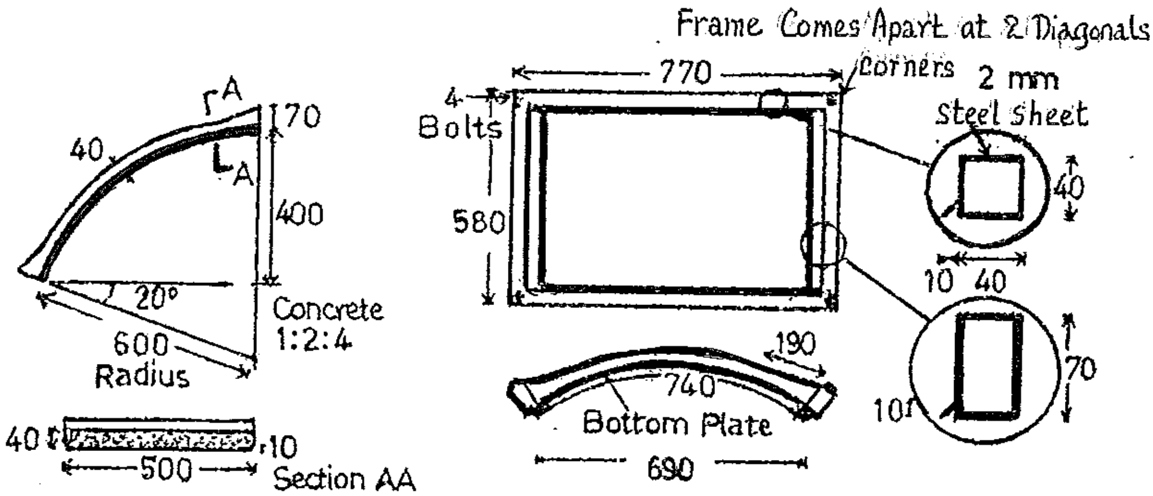


Fig. 4.4 Precast Concrete Arch Sections for Tunnel

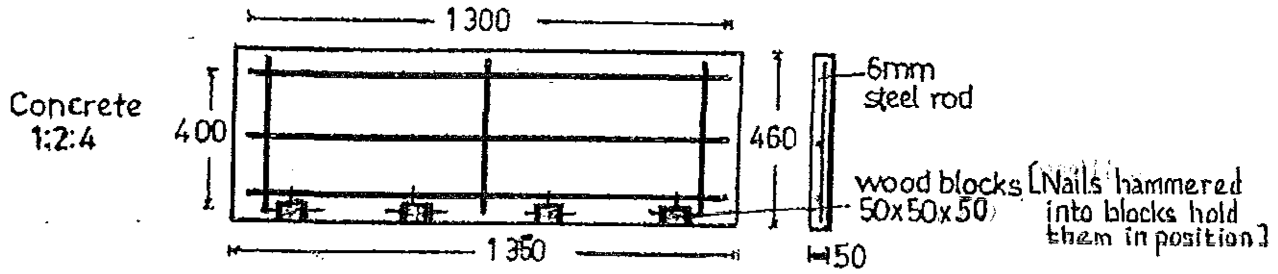


Fig. 4.5 Partition Piece for the Outlet End of the Tunnel

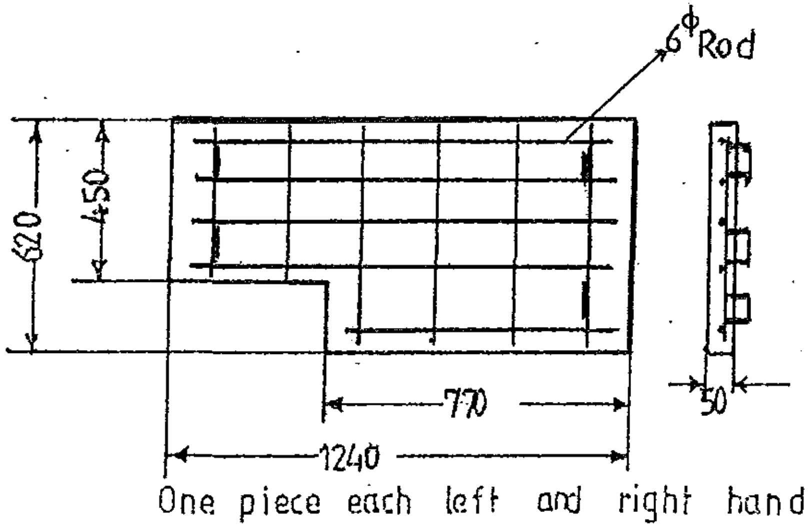


Fig. 4.6 Cover for Slurry Reservoir

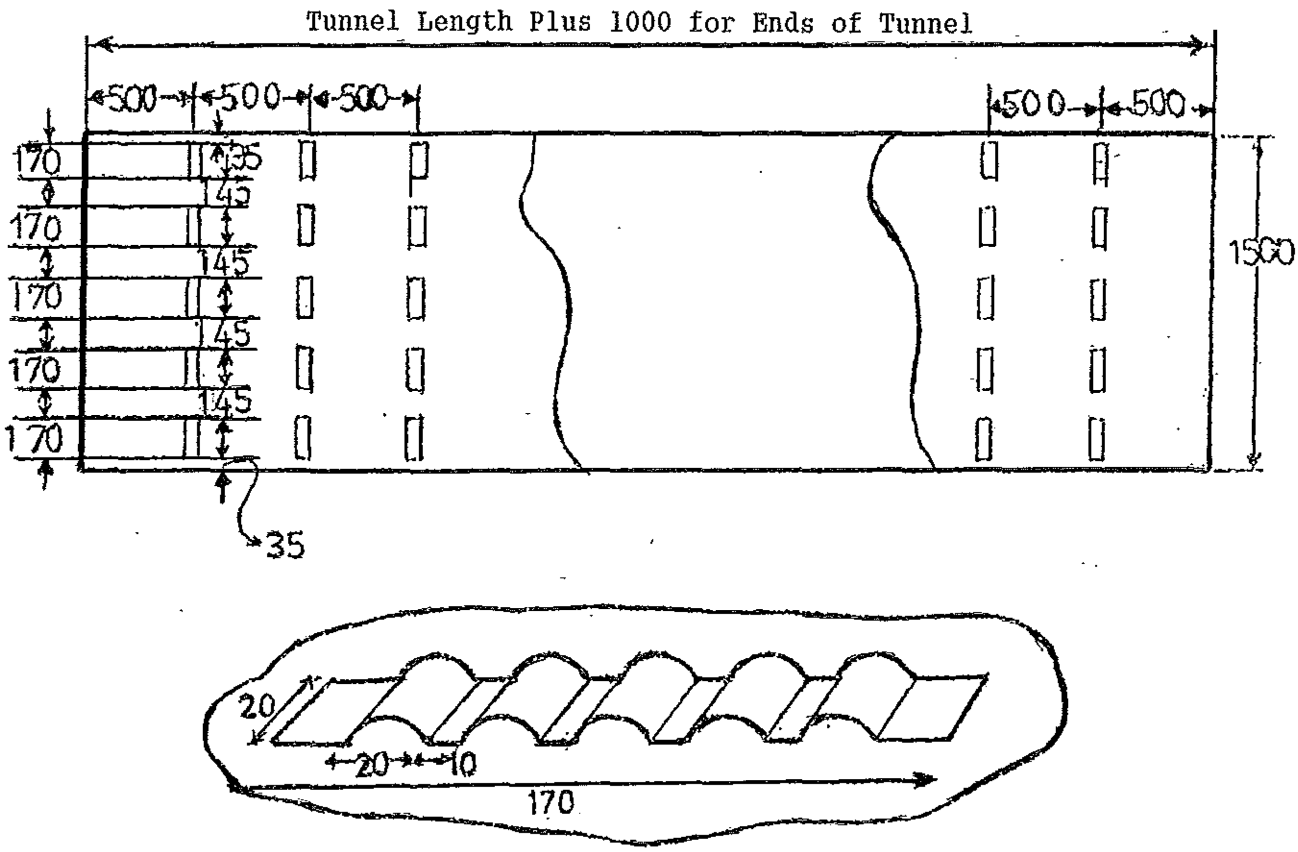


Fig. 4.7 Plastic Loops Welded onto Plastic Sheet

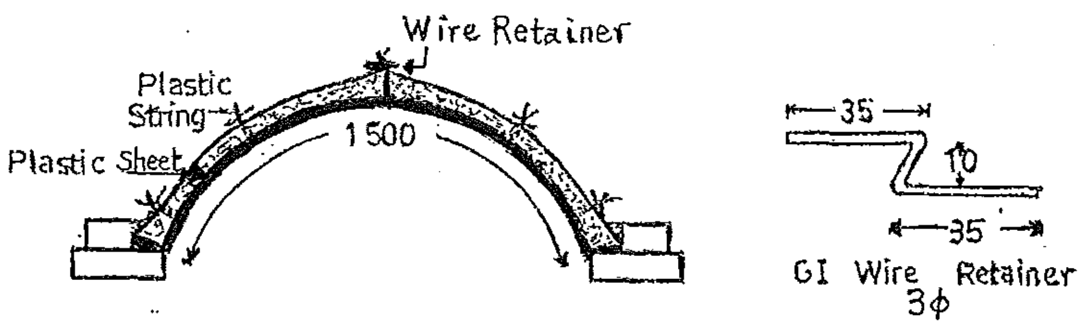


Fig. 4.8 Use of Tying Strings to Hold Plastic Sheet in Place

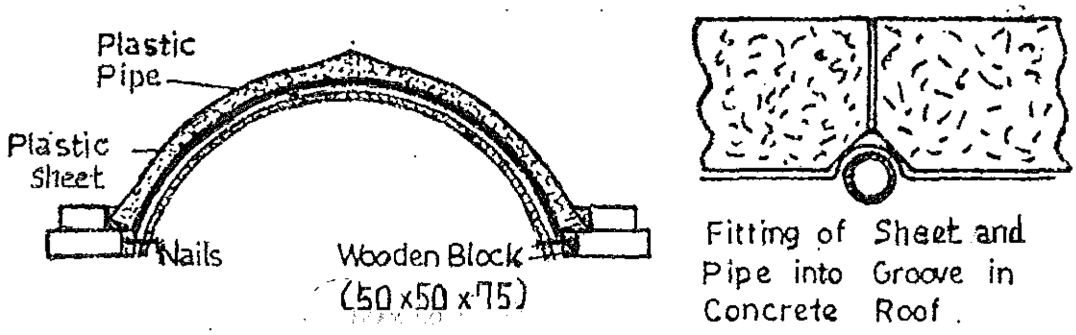


Fig. 4.9 Use of Plastic Pipe to Hold Plastic Sheet in Place

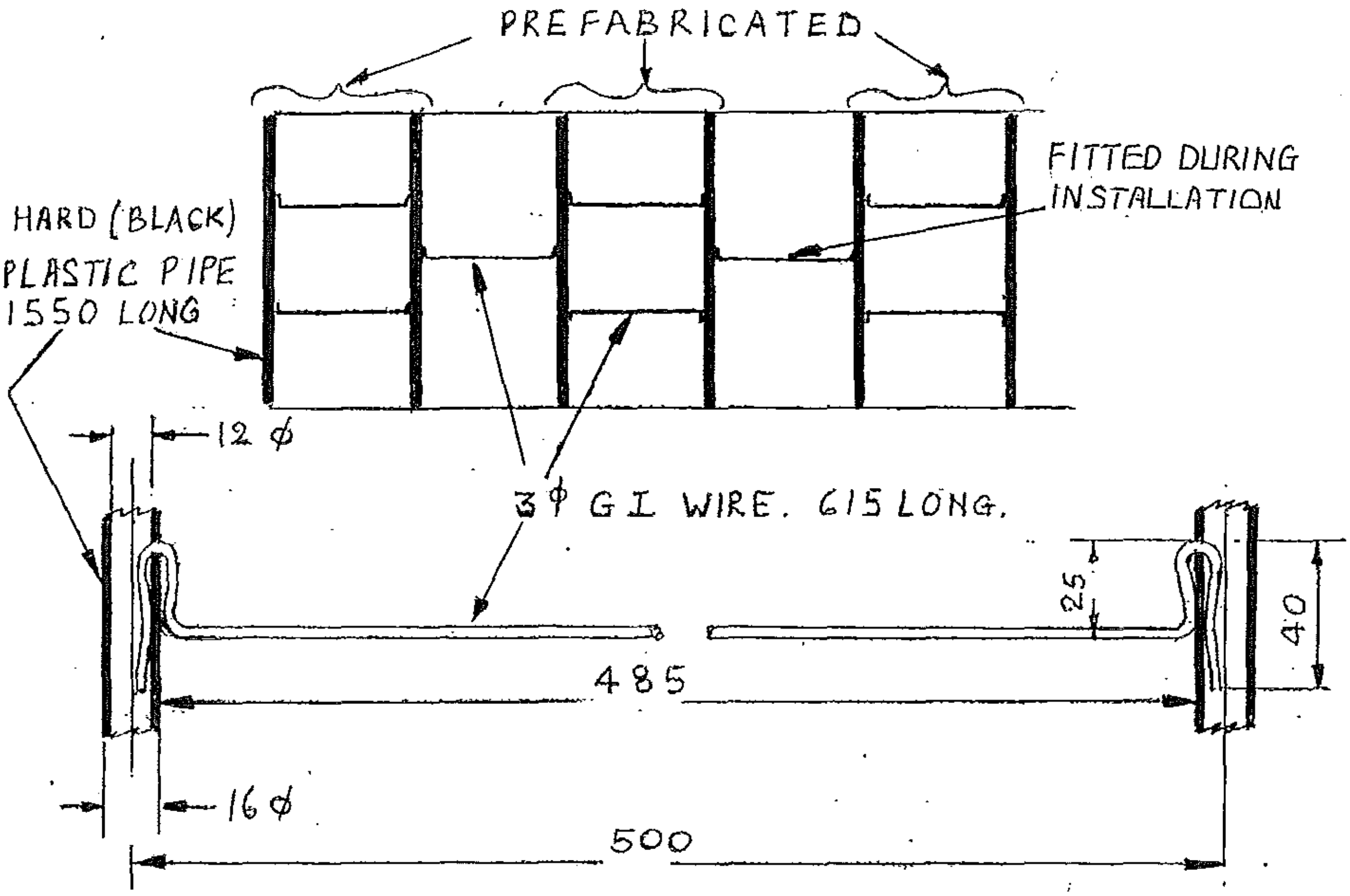


Fig. 4.10 Plastic Pipe and Wire Struts to Hold Plastic Sheet in Place

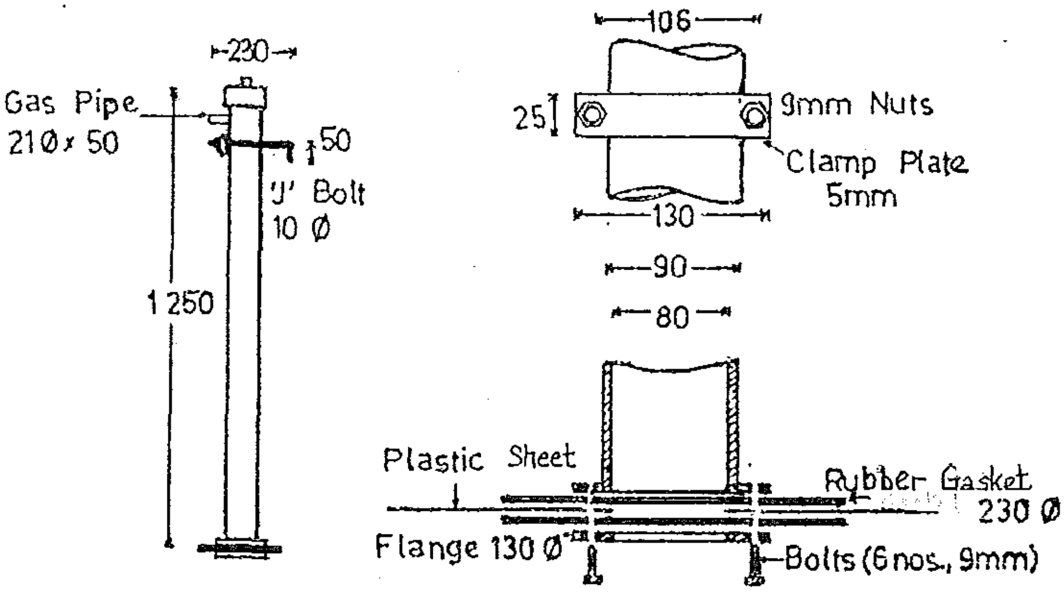


Fig. 4.11 Gas Outlet Pipe and Clamps

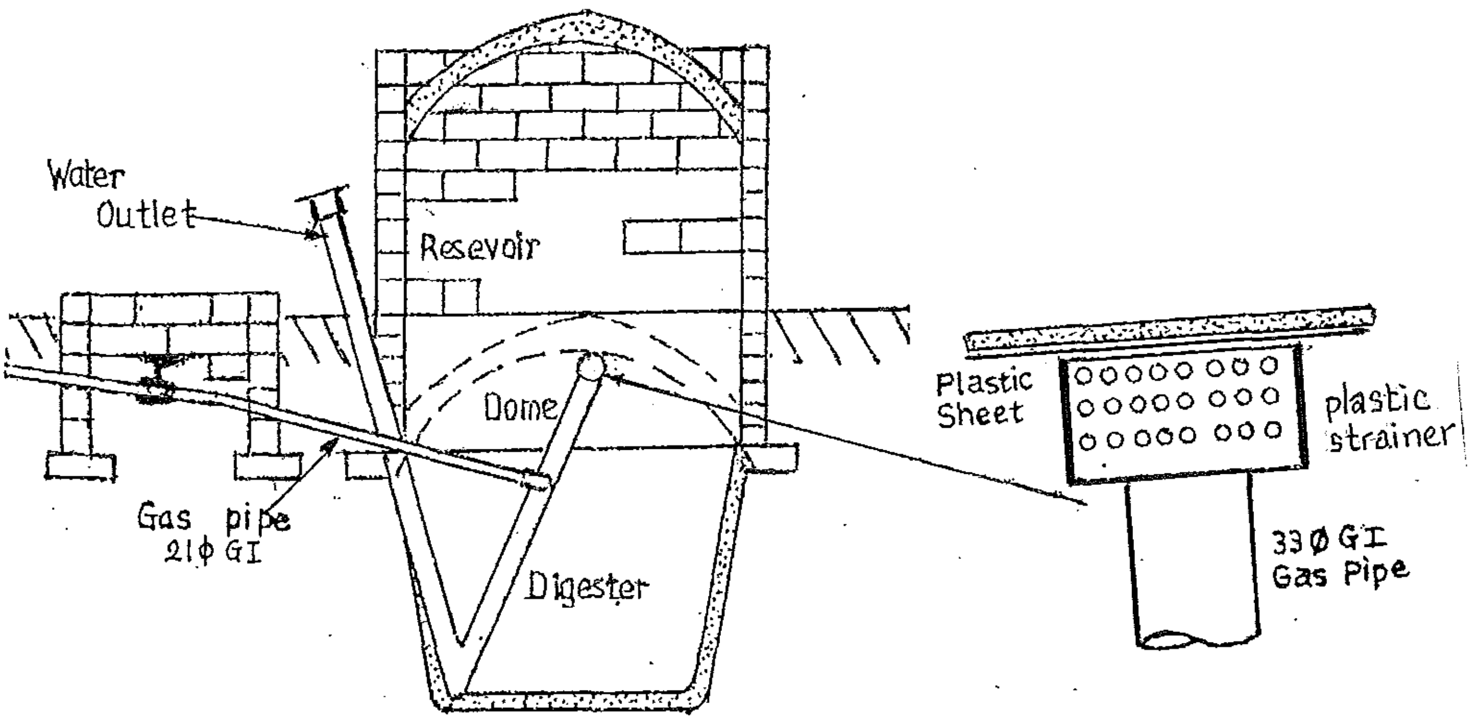


Fig. 4.12 Alternative Gas Outlet for Tunnel Plant

Chapter 5 SELECTION OF DESIGN, SIZE, MATERIALS AND SITE

J. Finlay, M. M. Lau-Wong

5.1 Designs

The aim in D.C.S. has been to make biogas plants that are low cost, but also efficient and maintenance free. Full details of the plants are given in Ch.2: Floating Steel Drum Plant, Ch.3: Cement Dome plant, and Ch.4: Tunnel Plant. All three designs have been thoroughly tested using cattle dung fed in daily.

The floating drum design was the best known when D.C.S. started its biogas work in 1974. The concrete dome plant was introduced with the aim of eliminating the expensive gas drums which were difficult to transport to remote sites and gave a serious rust problem. It was also cheaper.

Finally, the tunnel plant was introduced to further reduce the cost and also because it was easier to build, eliminated the need for high plastering skill and used a thicker slurry, and so required a smaller digester volume. Later research indicated that thicker slurry also could be used in all plants although in practice it is only used in the tunnel plant at present.

5.2 Advantages and Disadvantages of the Three Designs

Floating steel drum design

Advantages:
1. Simple to build
2. Constant low gas pressure
3. Something visibly impressive to show friends

Disadvantages:
1. Expensive
2. Rust problem on gas drum
3. Hard and expensive to transport gas drum off roads
4. Hard to insulate and therefore depressed gas production in winter

Special requirements:
Steel plates.

Concrete dome design

Advantages:
1. 20% cheaper than steel drum design (in Nepal)
2. Easy to transport anywhere
3. Easy to insulate

Disadvantages:
1. Varying gas pressure

Special requirements:
1. Acrylic Plastic Emulsion Paint

Tunnel Design

Advantages:
1. 20% cheaper than dome design (35% cheaper than steel drum design) in Nepal
2. Simple to build
3. Easy to insulate
4. Modular construction allows any size to be make
5. Pre-cast parts can be made and stocked during slack building seasons

Disadvantages:
1. Varying gas pressure
2. In remote areas pre-cast parts may need to be made on site.

Special requirements:

1. Strong plastic sheet
2. Plastic welder if sheets are too narrow
3. PVC plastic glue if PVC sheet is used

5.3 Choosing a Plant Design

When chossing the most appropriate design for any particular situation certain points need to be considered :-

1. Availability of construction materials and skills, especially those items listed above under special requirements.
2. Local cost of materials.
3. Transportation of materials.
4. Water table, i.e. can a deep hole be dug without water quickly filling the hole?
5. Feed material to be used. D.C.S.'s experience is almost exclusively with cattle dung. Other materials could be used such as :
   i) pig dung washed into the plant with a low percentage total solids necessitating a large volume and plastering the digester to avoid leakage.
   ii) corrosive slurries such as night soil.
   iii) vegetable matter which will need to be manually removed from the plant from time to time.

6. Air temperature and whether or not insulation is needed.

5.4 Selecting the Size of Plant

Plant size clarification:
In Asia two basic methods of classifying plant sizes are used :-

1) With floating steel drum design it is the nominal expected gas production per day in cubic feet. This is very misleading because gas production varys a great deal depending on several factors but especially daily slurry input (too often people put in too little) and slurry temperature (a reduction from 30°C to 20°C can reduce gas production by 50%).

2) With cement dome and tunnel designs it is the total volume of the digester under the gas storing roof.

These two system are not directly comparable. However, they can be compared once the volume of slurry in the digester is known (in the cement dome and tunnel plants it is the average amount of slurry over a day i.e. the total volume less the average amount of gas stored which is called the "working volume").

5.5 Factors Affecting Gas Plant Size

There are five main factors which affect gas plant sizes.

1. Amount of gas needed.

   It may not be possible to provide as much gas as desired but at least it is helpful to know how much is wanted!

   In Nepal it is customary to have two meals a day consisting of boiled rice, lentils and curried vegetables. There may also be an early morning and mid-afternoon snack. It has been found that under these circumstances, it takes 0.20 to 0.40m^3 gas per person per day. Lights require 0.15m^3 per hour but may consume up to 50% more if the gas pressure is high. Engines use a maximum of about 0.45m^3 horsepower per hour.

2. Amount of dung available per day.

   All too often there is less dung available than expected therefore it has been found essential to measure the dung for at least 3 days in order to get a fair idea of the amount of dung available. It can be weighed or its volume measured. One litre of dung well pressed down is almost exactly one kg in weight.

   A buffalo, which is stable bound, can be expected to provide about 15kg dung per day. A cow or ox, which is stable bound, can be expected to provide about 10kg dung per day.

   Having given these figures it is still very important to actually measure the dung at each proposed gas plant site because it can vary so much. Too little dung equals too little gas!

3. Temperature.

   Bacteria in gas plants are temperature sensitive and give reduced gas production at lower temperatures. Plants in the Southern plains of Nepal operate at temperatures ranging over the year from 30°C to 20°C. This affects gas production by about 50%. There are ways to increase the temperature which are given in Chapter 10.

4. Residency time.

   The residency time is the working volume of a plant divided by the daily input mixture of dung and water. The longer slurry is kept in a plant the more gas can be obtained from it, but as a slower rate per day after the first approximately 40 days. A longer residency implies a larger digester is needed and this in turn increases the cost.

5. Slurry thickness.

Up to the present time it has been normal practice for steel drum and concrete dome plants to be fed a slurry mixture of dung and water in the ratio of 1:1 giving a total solids (TS) concentration of 8 to 9%. In the tunnel plant a ratio of 2:1 (12-13% TS) has been used. This meant that a tunnel digester could be reduced in size by 25% and yet hold the same amount of solid matter.

However, research has shown (Vol. II Ch. 3) that slurry moisture between 6 and 14.3% has negligible effect on the rate of gas yield in any of the three designs of gas plant D.C.S. has used, so a thicker slurry can be used in any plant.

6. Cost.

The main controlling factor is the size of the digester which is affected by the slurry thickness used residency and of course the amount of gas required.

5.6 Gas Production Calculations

For theory refer Vol II Ch. 3.

Working volume of digester	: V M^3
Daily input volume of slurry	: F m^3
Daily input weight of wet dung	: Wg Kg
Proportion of dry matter in dung	: DM %
(For fresh cattle dung DM = 20% approximately)	
Retention time	: R days
Feedstock concentration	: So kg/m^3
Gas production per day at STP	: G m^3(STP)/day
Rate of gas production	: $r_g m^3$(STP)/kgm^3 day
Fraction of volitile solids in feedstock (constant)	: f
(For grass fed cattle and buffaloes f = 0.74)	

Retention time R is given by :

R = V/F and is usually between 40 and 140 days.

The feedstock concentration So is given by :

$So = \frac{Wg \times DM}{F}$ and is usually between 80 and 140 kg/m^3

The rate of gas production per day rg is obtained from the graph "Rate of gas production vs Retention time" (Figure 5.1) once the retention time has been worked out and the slurry temperature is known.

The gas production per day, G, at Standard Temperature and Pressure (STP) is given by:

$G = r_g S_o V F$ m^3 (STP)/day

The gas production per day at any temperature is given by G(STP) (273 + gas temperature °C)/273.

For example, to find the gas production at 25°C

$$G(25°C) = G(STP)\ (273 + 25)/273 = m^3\ (25°C)/day$$

When there are two unknowns, ie when trying to work out both the retention time and working volume, it can be done by superimposing a tracing of graph $r^g = Z/R$ (Fig. 5.2) on top of graph of rate of gas production versus retention time at different temperatures (Fig. 5.1). See Example 2.

Example 1. What is the gas production that can be expected from a TP10 tunnel plant under the following conditions?

Working volume 9.0 m^3
Cattle dung fed in daily 100 kg = 0.10 m^3
Slurry temperature 25°C
Dung water ratio 2:1

Retention time $R = V/F = 9.0/(0.10 + 0.05) = 60$ days

Feedstock concentration $S_o = W_g\ D_m/F = 100 \times 20 / (0.15 \times 100)$
$= 133.333$ kg/m^3

From the graph in Fig. 5.1, at retention time = 60 days and temperature = 25°C, the third unknown, rate of gas production can be found:

Rate of gas production = 0.0025 m^3 (STP)/kg m^3 day
Gas production per day $G = r_g\ S_o\ V\ f$
$= 0.0025 \times 133.333 \times 9.0 \times 0.74$
$=$ 2.22 m^3 (STP)/day

At 25°C

$$G_{25°C} = \frac{G_{STP}(273 + 25)}{273} = \frac{2.22 \times 298}{273}$$

$$= 2.42 m^3/day\ at\ 25°C$$

Gas Production at STP = 2.22 m^3
Gas Production at 25°C = 2.42 m^3

Example 2 A farmer requires gas to cook for a family of 5 and requires two lights. One will burn in the kitchen for one hour a day and the other will burn in the living quarters for three hours a day. He plans to use a plant with 2:1 dung water ratio. The average ground (and therefore slurry) temperature is about 27°C. He only has 50kg of dung available per day. What size of plant is required?

Gas requirement per day:

5 people @ 0.3m^3/person/day		= 1.5 m^3/day
4 hours of lighting @ 0.15m^3/hour		= 0.6 m^3/day
	Total	2.1 m^3/day

Feedstock concentration:

$$So = \frac{Wg\ DM}{F} = \frac{50 \times 20}{0.75 \times 100} = 133.333 \text{ kg/m}^3$$

Working Volume of digester:

$$V = FR \quad (\text{from formula } R = V/F)$$
$$= \underline{0.075\ R}$$

Gas Production per day at STP:

$$r_g = \frac{G}{So\ V\ F} \quad (\text{from } G = r^g\ So\ V\ F)$$

$$= \frac{1.9}{133.333 \times 0.075R \times 0.74}$$

$$= \frac{0.257}{R}\ m^3(STP)/kgm^3\ day = \frac{Z}{R}$$

Put tracing of the graph in Fig. 5.2 on top of the graph in Fig. 5.1 and match up the axis. Mark where the two graph lines cross.

Z = 0.257 is just above the 0.25 graph
27°C is proportionally between the 27.5°C and 25°C graphs.

Draw line down to Retention time R = 98 days

Working Volume of digester:

$$V = FR$$
$$= 0.075 \times 98 = \underline{7.35\ m^3}$$

The gas plant built should have a working digester volume of 7.35m³

From Table 5.1, SD100 = 7.1, CP10 = 9.0 and TP8 = 7.6. The decision as to which plant to build will depend on other factors previously discussed in this chapter such as building materials available and cost.

Table 5.1 Working volumes of standard size gas plants

	SD				CP			TP				
Plant type	100	200	350	500	10	15	20	6	8	10	15	20
Work. Vol.m³	7.1	13.0	24.0	34.0	9.0	12.8	17.4	5.5	7.6	9.0	13.5	18.0

5.7 Building Materials

This section covers the commonly used building materials used in the construction of the three types of plant described in this book. Special materials and construction details relating to a specific plant design are included in the respective chapter dealing with that plant.

Digesters and associated masonary work can be made out of any of the usual building materials except those which deteriorate with moisture (e.g. unburnt bricks, lime and mud mortar). Choice is normally a matter of what is available at the lowest cost.

- Bricks. These must be burnt. Unburnt bricks will deteriorate in the presence of the moisture in the slurry. Walls made of poorer quality bricks, which are both weaker and more porous, may need to be plastered on the inside faces.

- Building stones. The stones need to be free from soil. Stone walls tend to be up to twice the thickness of brick walls and require considerably more mortar.

- Sand. This must be clean and free from vegetable matter and mud etc. otherwise the cement mortar will be weak. Sand can be tested for cleanliness very easily. A bottle is filled with 1/3 and 2/3 water and then shaken. The mixture is allowed to settle until the water is clear. If the impurities (mud etc) form a layer more than 6% of the total height of the sand then it is necessary to wash the sand before using it. The sand is put in a container, e.g. a wheelbarrow, and water is flushed through it to wash away the impurities. Fine sand requires a higher cement to sand ratio to give a similar strength mortar.

- Gravel, broken stones. Since most of the concrete sections are only between 40 and 80mm thick the gravel or broken stones used as aggregate should be between 5 and 20mm in size. It should be screened by passing it through wire screens with the appropriate sized holes. It should be free from vegetable matter and soil etc.

- Cement. Ordinary Portland cement is quite satisfactory. Additives are not necessary. If the cement is stale, i.e. if it is lumpy, then it will be weaker and therefore extra should be added to the various mixes. Cement is usually packed in 50kg bags (35 litres). However, some bags, such as those made from jute sacking, tend to leak out the powder. They may only contain 45 or even 40 kg due to wastage in transit.

5.8 Construction Techniques

Cement mortar should be the same strength as the bricks or stones it binds together. A ratio of 1:6, cement to sand, is average, although the ratios may very from 1:9 to 1:4 depending on the quality of the sand and cement, and bricks or stones. Strickly speaking ratios are by dry weight but in villages this is impossible. In practice ratios are measured by volume and this is perfectly satisfactory.

Concrete used in the D.C.S. designs is normally a 1:2:4 mix of cement, sand and gravel, although a mix of 1:3:3 mix which gives a more compact mix is used for the concrete dome. Concrete must be carefully compacted to avoid air pockets (6% air voids in concrete means a 20% loss in strength - Merrit). The cement, sand and gravel must be thoroughly mixed and then the minimum amount of wate used to make it usable. It needs to be cured for at least 7 days before any load is put on lit by keeping it damp by covering with wet sacks or covering with water. Small sections such as tunnel roof pieces can be cured under water, in a pond or stream, after they have set for 24 hours.

Construction plaster : This is a 23 to 30mm plaster applied directly onto the soil for the walls and floor of both the cement dome and the tunnel plants. Well over 500 plants have been built using this method and so far there have been no reports of failure in this system of construction. The cement dome design calls for three layers each 10mm thick of 1:6, 1:4,, 1:3 cement sand mix. The tunnel plant calls for one 25mm layer 1:5.

5.9 Construction Features

There are several common construction features.

Inlet pit (Fig. 5.3) : This pit is required for the daily mixing of the dung with water. For convenience it is designed to hold the correct amount of daily slurry, with an additional 75 to 100mm in the height of the sides to prevent the slurry being spilt while it is being mixed. The inlet pipe is set in the floor and there must be no obstruction from any side wall which would prevent a pole or rod being pushed down the pipe in case of any blockages. A plug needs to be provided for the inlet pipe. Various things can be used such as a wood plug, a metal plate or a stone wrapped up in a piece of sack cloth. A removeable sieve can be fitted to the inlet pipe to prevent straw and lumps entering the digester. The floor of the pit is level. A hole in the side wall, fitted with a plug, is made to facilitate the washing out of the pit and removal of rainwater which could otherwise enter the plant and dilute the slurry. The inlet pit should not be built on soil that was replaced after construction because this may well sink in time and after rain and break the inlet pipe.

Traditional mixing pits are 400 to 500mm deep. However, shallower pits (150mm deep) have the advantage that the mixed slurry can be solar heated before being fed into the digester (refer Vol. II Ch.6) resulting in much higher gas production.

Inlet/Outlet pipes : Experience has shown that 100mm diamter pipes are the best for both inlet and outlet pipes. This is irrespective of plant size and whether 1:1 or 2:1 slurry ratio is used. Smaller pipes tend to have frequent blockages. Larger sizes add unnecessary expense. Any low cost pipe can be used, e.g. asbestos cement, concrete or burnt clay. It is essential that there are no bends in the pipes, as blockages easily occur in them.

Slurry Overflow : In some designs of biogas plant, the digested slurry leaves the plant through a gap in the top of the digester pit or slurry reservoir wall. This gap should be at least 150mm wide and be tapered away from the inside, like a bell mouth (Figure 5.3). This arrangement reduces the tendancy of the slurry to dry out and block the gap.

5.10 Slurry Mixing Tool

Many people in Nepal mix the input slurry by hand, as cattle dung is not considered obnoxious. This practice is not recommended, as dung often contains patenogenic bacteria. A slurry mixing tool (Fig. 5.4) has been designed, similar to a rake. The wire mesh at the end can be used to break up lumps of dung and also to trap straw and other material that may cause scum problems.

Slurry Mixing Machine : The mixing machine used in Nepal (Fig. 5.5, 5.6 and Table 5.2) is an adaptation of an Indian design (KVIC, 1972), which, in turn, is based on a machine used to break up pulp for paper making. The slurry flows around the trough, driven by a hand operated paddle wheel, which breaks up lumps as the paddles pass over a bar set in the floor. A coarse sieve removes straw and other large items.

The paddle wheel, of selded steel, is bolted onto a shaft of GI pipe. The beater bar is set in the floor with a gap of 10mm between it and the bottom of the paddle wheel. The shaft runs in hard wood bearings soaked in oil. The radius at the front of the paddle wheel can be easily made by attaching a piece of wood which protrudes 25mm to one of the paddle blades and using this as a guage. Covers are usually fitted over the paddle wheel to avoid splashing.

A channel can be made in the floor of the machine at the lowest point to collect sand etc., which can be removed via a 100 Φ hole in the wall. Plugs need to be provided for both this hole and the inlet pipe hole. The expense of a mixing machine is usually only justified for large plants. It is normally operated with all 1/2, 1/3 or 1/4 of the daily input slurry when filled to about the top of the slope beside the paddle wheel. Too much or too little slurry will make the machine difficult to operate.

Because the slurry in mixing machines is deep it cannot easily be heated using solar energy. Instead, the water used to make the slurry can be put in uncovered tins or buckets which are set in the sun from morning to mid-afternoon. Tests have shown that if this is done and there is no wind and the air temperature is in the region of 16° to 20°C then the water temperature will rise from about 15° to 25°C. This is a significant rise of 10°C which will increase the slurry temperature and result in increased gas production if it is done daily.

5.11 Addition of a Latrine.

In Nepal, it has so far been rarely acceptable to have a latrine attached to a biogas plant due to cultural reasons. However, where possible it should be encouraged as it is rich in nitrogen. A latrine can be easily fitted using a separate pipe which goes into digester near the inlet. It should be at least one third down the side of the plant (to save a lot of digging going deeper) and protrude at least 500mm into the plant to get the night soil and water mixed in with the slurry.

The base of the toilet must be at least as high as the floor of the inlet pit to allow easy flushing. Whether a water seal is used in the latrine or not, there must be some means of access for clearing the pipe to the digester in case of a blockage. This is important. To prevent too much water entering the plant the flush water should be restricted to one litre per usage. The floor of the latrine should slope away from the bowl to a drain hole in the wall, so that when cleaning the floor with water, any soil or sand brought in on the cleaner's feet and the cleaning water can get away without entering the digester.

With steel drum plants the total daily input from the latrine should not exceed 15 or 20% of the daily feed to the, otherwise the slurry may become too corrosive and rust out the steel drum rapidly.

If the outlet slurry from the gas plant appears to be thin due to dilution by flush water etc., in the latrine then this can be compensated by making the cattle dung slurry thicker. However, sufficient water must be added to make the cattle dung fluid and to break down all lumps.

5.12 Compost Pits or Slurry Collecting Tanks

Unless the old slurry (effluent) coming out of the plant is taken directly to the fields each day, e.g. by putting it into an irrigation canal, it must be stored until required. Compost pits or slurry collecting tanks are usually dug close to the plant so that the effluent can flow directly into them. Masonary sides to the pits are not essential but they do prevent weeds growing into the compost. For the sake of safety it is suggested that compost pits are not more then 800mm deep.

The volume of the pits should be sufficient to receive the amount of effluent put in per day multiplied by the number of days between emptying pits. The slurry volume will reduce as moisture evaporates or soaks into the ground and this can accommodate any compost materials such as animal bedding which may be added.

5.13 Selection of Gas Plant Site

Every gas plant site is different. Assuming the ground is suitable for digging a digester pit, a careful selection of the best site has to be made considering personal preference and technical points.

Technically, the selected site preferably should be :

1. Close to where the gas will be used since gas pipes are expensive.
2. Close to supply of dung and water to save carrying them.
3. Close to compost pit or slurry tank so that old slurry can slow there without handling.
4. At least 10 to 1 metres away from shallow wells to prevent contamination.
5. Some distance from any trees whose roots might grow into the digester and cause damage.
6. In the sun to keep the plant warm.
7. Protected from cold winds that cause heat loss.

8. Not liable to floods which could dilute the slurry and damage the plant.

An example of a selected site is given in Fig. 5.7.

Table 5.2 Materials for Standard Slurry Mixing Machine

Bricks	
Cement	
Sand	
Aggregate	
Paddle Wheel	Mild steel 3mm, 280 x 400Φ, 10 blades, 115 x 274
Beater Bar	Steel angle: 310 x 40 x 40 x 6
Shaft	GI Pipe: 630 x 27Φ
Bearings	2 nos. 2 blocks of wood: 110 x 200 x (50 + 100)
Bearing Covers	2 nos. 2.0mm steel, boxes: 110 x 200 x (125 to 150)
Bolts	4 nos. 360 x 12Φ, with anchor rods and nuts
Handle	305 x 40 x 6 steel bar, 130 x 20Φ rod, 115 x 27Φ GI pipe
Seive	Steel rod: 12Φ, 460 x 280, 6 rods x 7 rods lattice x 6Φ

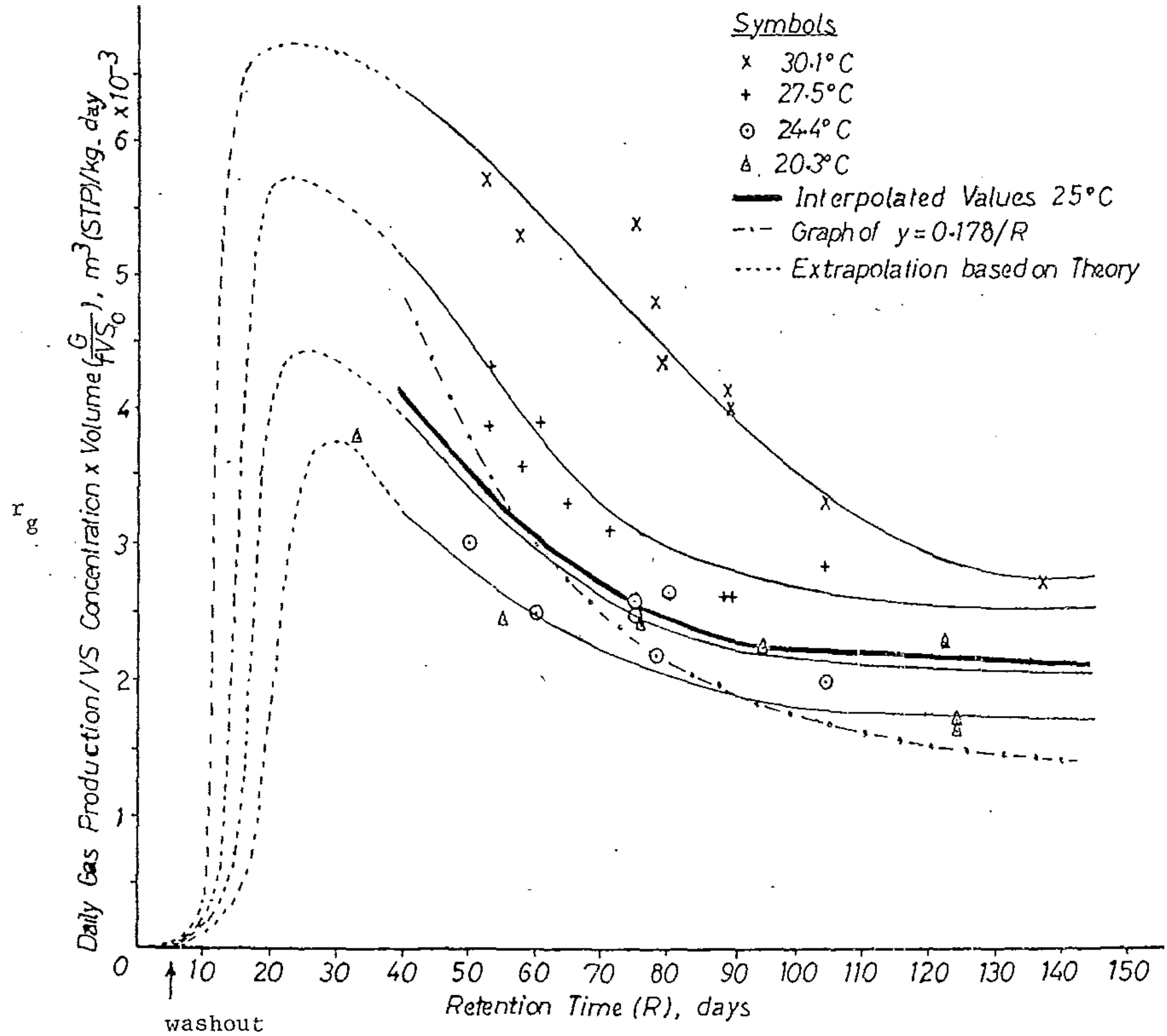


Fig. 5.1 Rate of Gas Production versus Retention Time
(Source: Vol.2 Ch.3, M. Lau-Wong)

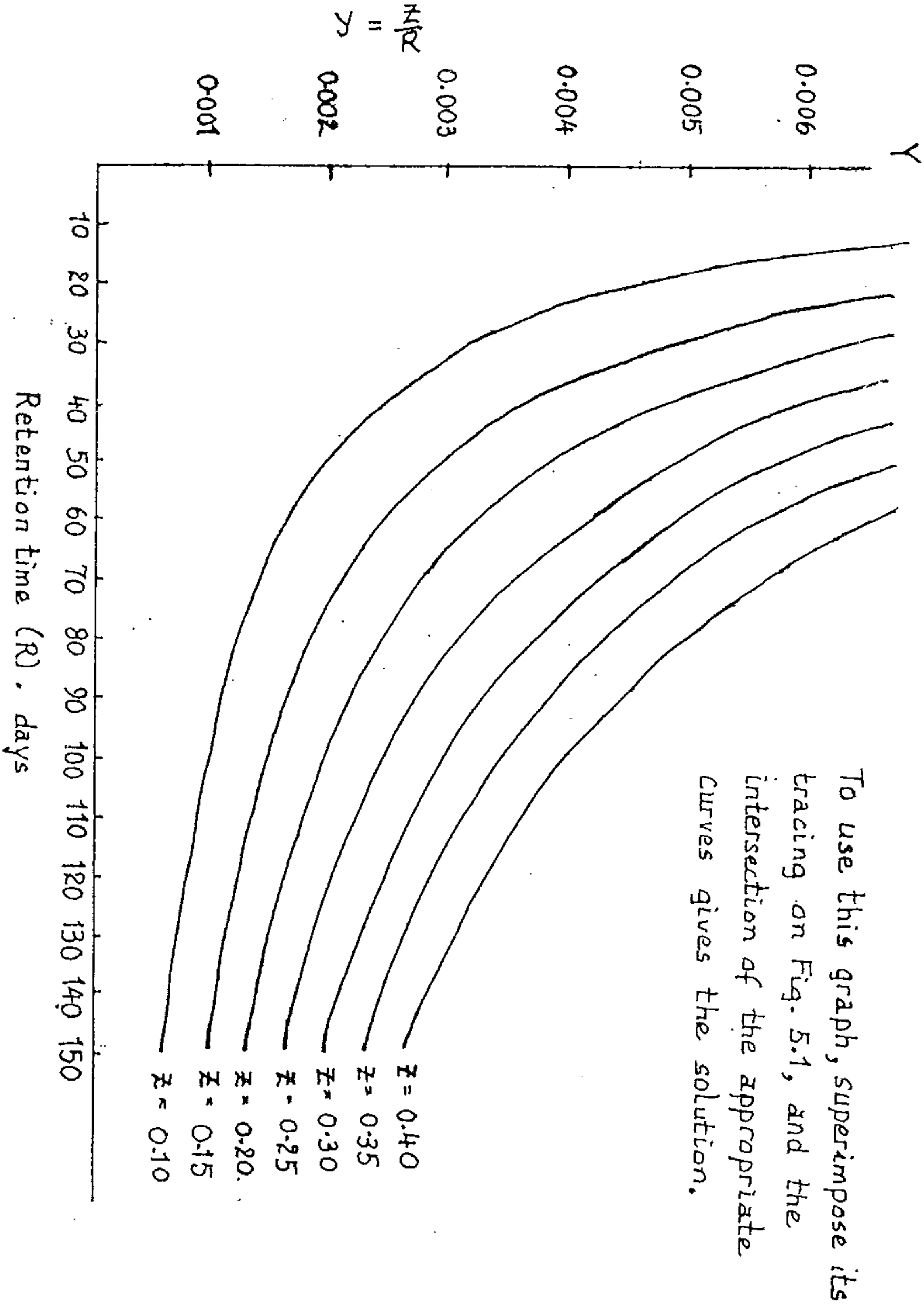


Fig. 5.2 <u>Graph of y = z/R</u> (M. Lau-Wong)

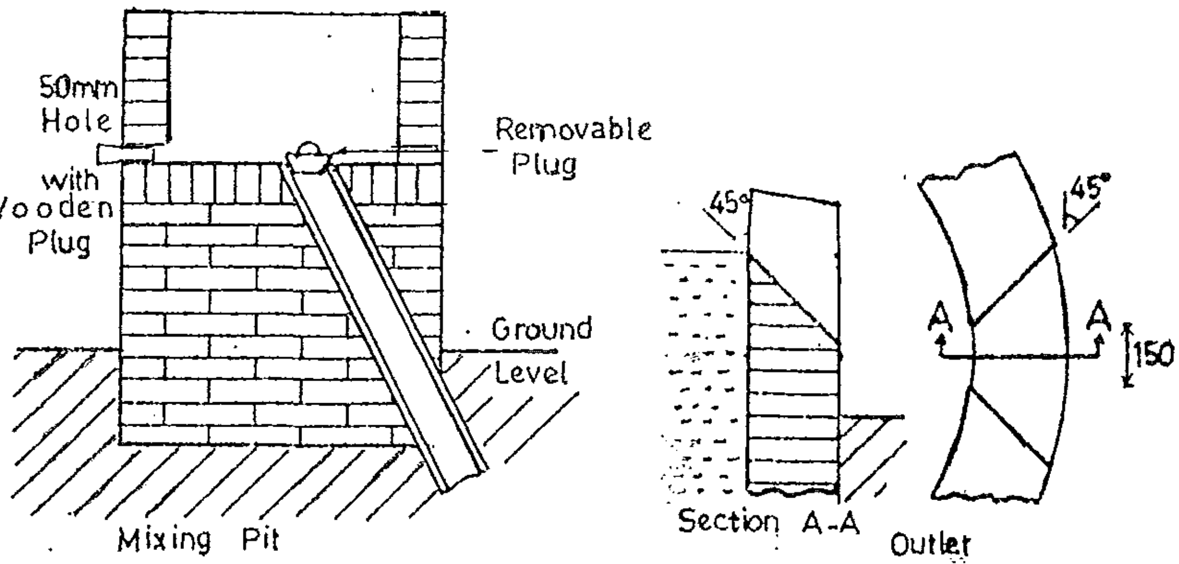


Fig. 5.3 Details of Inlet and Slurry Overflow

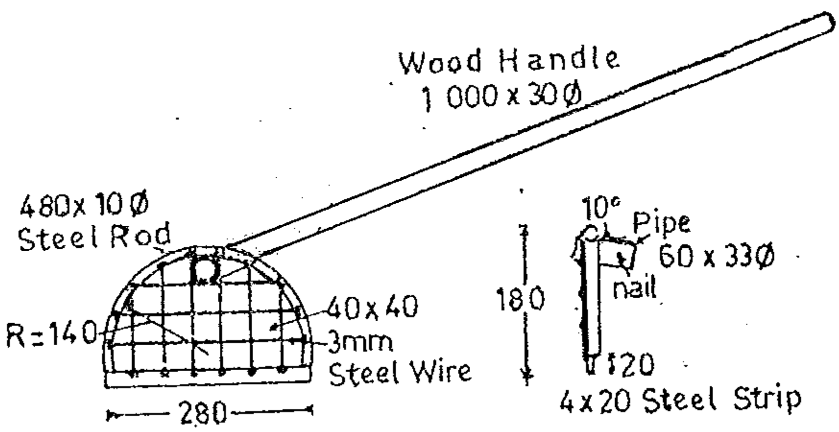


Fig. 5.4 Slurry Mixing Tool

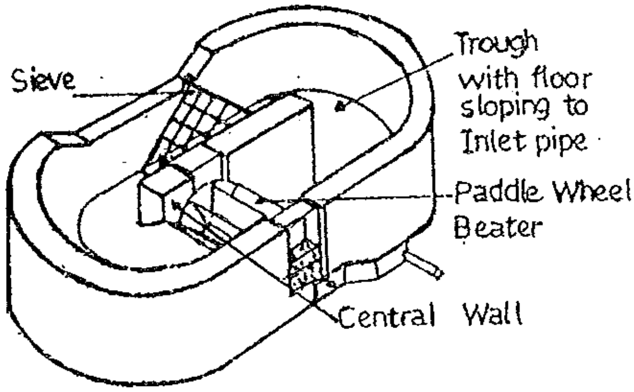


Fig. 5.5 Slurry Mixing Machine

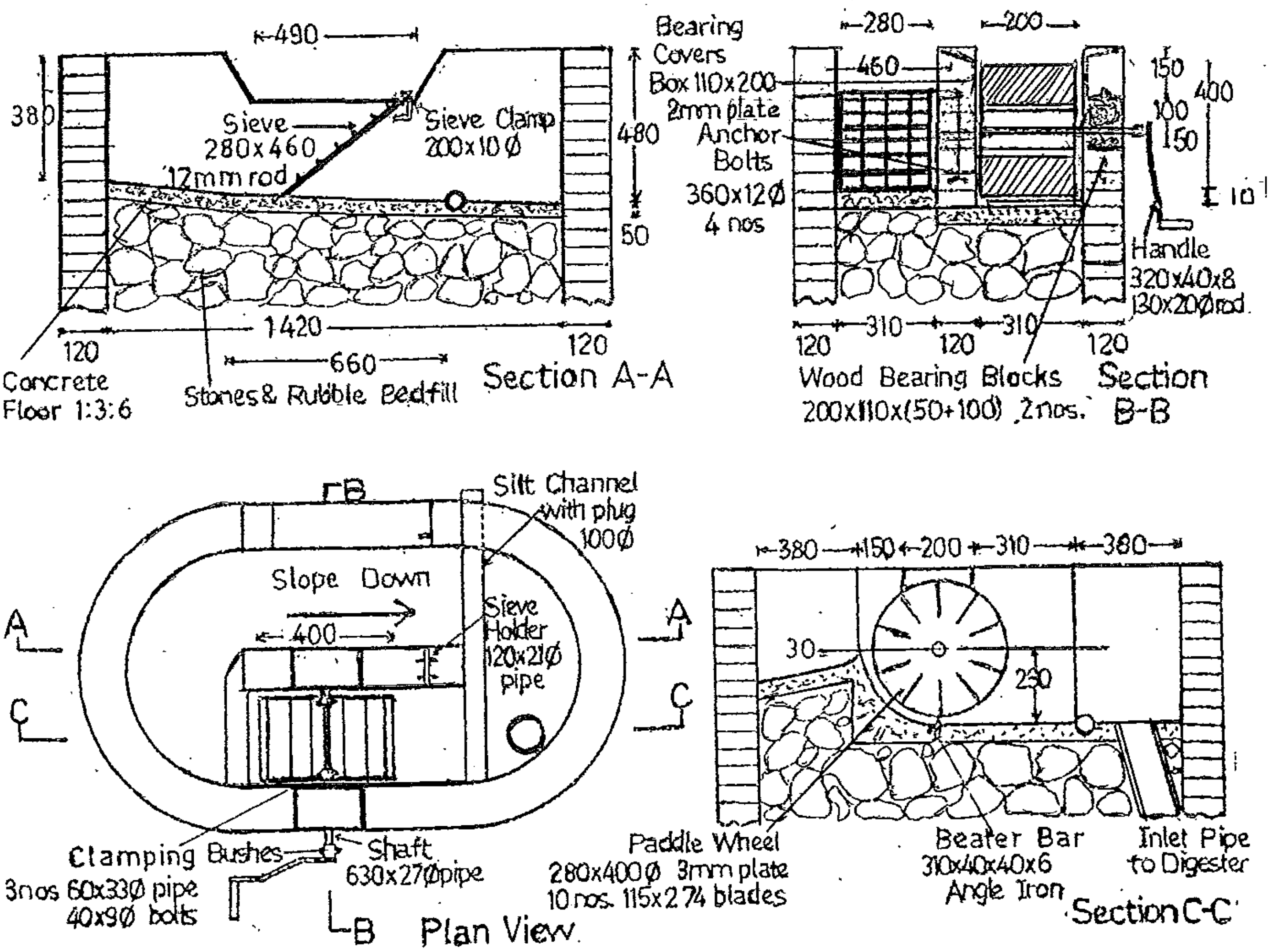


Fig. 5.6 Detailed Drawings of Slurry Mixing Machine

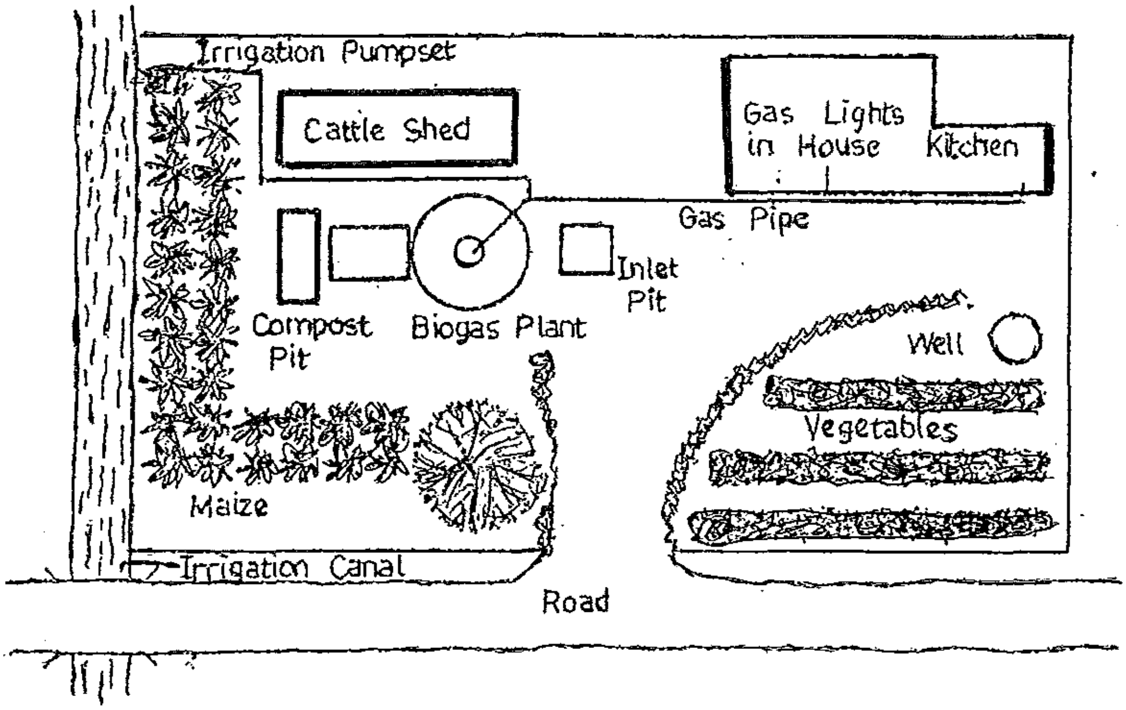


Fig. 5.7 An Example of Site Selection for a Biogas Plant

Chapter 6 GAS PIPING AND ACCESSORIES J. Finlay

6.1 Introduction

Biogas is taken from the gas plant to where it is to be used through gas pipes. Galvanized iron (GI) pipe is the most commonly used pipe in Nepal as it is readily available and cannot readily be cut by knives or rodents or damaged by sun light as is the case with plastic pipes. Pipework, especially joints, must be done well to avoid leaks. This is especially true with dome and tunnel plants when the gas pressure goes up to about 1200mm WG.

Biogas contains moisture, which condenses into water especially in underground pipes near the gas plant. This must be drained from the gas pipes otherwise it will collect and block the pipe. Therefore, all pipes must slope towards a trap and drain (Figure 6.1). The recommended slope is 1:100 but steeper slopes can be used. Failure to slope the pipes and provide drains are common faults. Most pipes are laid underground from the plant to the house. This is simple and is out of the way.

There is often confusion over pipe size because GI pipe sizes refer to the nominal bore size in inches whereas the plastic pipe sizes refer to the outside pipe diameter (Table 6.1). Gas piping is expensive and it is important to keep the length as short as possible.

Table 6.1 Common Pipe Sizes

Galvanized iron (GI) Pipes			Plastic Pipes	
Quoted size inch	ID mm	OD mm	Quoted size = OD mm	ID mm
1/2"	16	21	20	15
3/4"	21	27	25	19
1"	27	35	32	24
1 1/4"	35	42	40	30
1 1/2"	41	48	50	38

Note: The OD of GI pipes and the ID of plastic pipes vary depending on the pressure the pipe is designed to take.

6.2 Plastic Pipes

Originally may plants built by D.C.S. had plastic piping but because of various problems it is only used on very rare occasions now, such as, where a very long pipe run is required. In this case it is cheaper to buy, but careful supervision is needed to see it is installed correctly.

Only the best quality plastic pipes should be used. Recycled plastic pipe (recognisable by the rough surface on the inside of the pipe) should not be used as it will be hard to make good joints. Plastic pipes must be laid deeply and properly in sand, otherwise rodents (e.g. rats and porcupines) may eat it or it can be damaged by heavy vehicles passing over it or cut during agricultural operations such as ploughing. 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 and causes serious blockage problems. If the pipe is above ground then there is a danger, unless it is protected, of damage from the ultra violet rays of the sun, which causes it to crack and also mechanical damage, e.g. being hit. The pipe must be well supported to prevent it from sagging and collecting water. A difficulty with plastic pipes is making gas tight joints with steel pipe. It can be done with care. The plastic pipe is heated until soft. The mouth of the pipe is enlarged a little with a slightly tapered piece of wood. The pipe is then pressed on to the steel pipe and bound on with wire while still hot. In this way 25Φ plastic pipe could be fitted onto a 1/4" GI pipe.

Other parties in Nepal use plastic pipe extensively with tunnel plants. They have not experienced D.C.S.'s problems with rodents and mechnaical damage etc., and have found that the high pressure gas forces condensate along the pipe to a drain. The advantages claimed are minimum leaks because there are so few joints, the pipe is lower cost and it is quicker to install.

6.3 Galvanized Iron (GI) Pipes

These are commonly used as gas pipes and there is usually someone available who is familiar with laying these water pipes. The main difference is that the pipe must slope to a drain and the joints must be of a very high standard to prevent leaks. Joints are made using a jointing compound or stiff paint, and jute fibre wound round the threads. If some red lead powder is added to the jointing material it will turn black if there is a leak due to the traces of hydrogen sulphide in the gas. This is not essential but it is helpful when looking for a leak.

Various fittings are needed and a selection of the most common ones is given in Table 6.2.

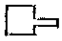
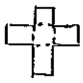
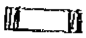
Often a gas plant is working well but the reason why the farmer does not have enough gas is due to leaks in the gas pipe. It cannot be stressed too much that all joints must be of a high standard especially for high pressure gas from dome and tunnel plants.

Being galvanized the pipes require no additional protection except where the soil is very acid. In that case the pipes should be well covered with paint or tar. In steel drum plants the gas pipe is attached to the support guide as shown in Figure 6.2. A socket is welded onto the support guide pipe. A nipple is not used as the external threads are likely to be damaged during handling.

By using this system a certain flexibility is given to the gas pipe which makes it much easier to lay it at a slope of 1:100.

With both dome and tunnel plants it is wise to have a union coupling near the gas outlet in case slurry enters the gas pipe and it has to be dismantled and cleaned out.

Table 6.2 <u>Commonly Used GI Pipe Fittings</u>

Fitting	Name		Use
	Socket Coupling		To join 2 lengths of pipe.
	Elbow	(L)	To join 2 pipes at 90°. Either same or different size of pipe (reducing elbow).
	Tee	(T)	To join 3 pipes, branch at 90°. Branch can be for same or smaller size of pipe.
	Reducing Socket		To join 2 different sized pipes.
	Cap		To close a pipe.
	Plug		To close a socket.
	Union Coupling		To join 2 pipes, without turning either pipe.
	Nipple		To join fittings.

6.4 <u>Gas Pipe Size Selection</u>

The size of gas pipe required depends on two factors: the length of the 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. Household gas appliances are designed to work most efficiently at about 65 to 100 mm WG gas pressure. Engines require about 75mm WG.

Most installations in Nepal including branch pipes to lights use about 40 to 50 metres of pipe. The main gas pipe to the house will be shorter by quite a bit as it excludes the branch pipes. The maximum amount of gas required per hour varies on what burners and lights are installed. Usually it will fall between 1.0 and 3.0 m^3/hr.

Dual fuel engines use between 1.5m^3/hr for 3.5 HP up to 3.4m^3/hr for 8 HP engine. Floating steel drum plants produce low pressure gas, usually about 80mm WG. Figure 6.3 gives the correct size of pipe for normal household installations. The following example shows how to use the diagram:-

A house has:

3 burners at 0.450m^3/hr.	=	1.35 m^3/hr (max.)
4 lamps at 0.160m^3/hr.	=	.64 m^3/hr (max.)
Maximum gas demand	=	1.99 m^3/hr

Length of pipe to burners, which are all located in one place = 25 metres.

Referring to figure 6.3, the point "a" corresponds to a rate of gas flow of 1.99m^3/hr and length of pipe of 25 metres. It will be seen that a 3/4" GI pipe is needed (Plastic pipe equivalent 25mm. Refer Table 6.1). This does not mean that all piping is 3/4" GI. It does mean it is required from the gas plant to where most gas is used, i.e. the burners. Branch pipes to individual fittings, i.e. lamps, can be 1/2" GI pipe. In view of the relatively high gas pressure in dome and tunnel plants it has been found that 1/2" GI pipe is adequate for all normal household applications.

6.5 Gas Taps and Valves

One main gas valve is usually placed beside the gas plant for shutting it off. Taps or valves are used for appliances and sometimes for the condensate drain. The type of valve used usually depends on what is available and suitable at reasonable cost.

Gate (Full way) valve (Figure 6.4) :

Gate valves are used in water systems and are usually readily available. D.C.S. has used many of them for all applications. Usually they are rather expensive. Farmers who have never used a valve before tend to overtighten them and break the spindle.

Ordinary water taps :

Water taps are not used because the gas pressure is not sufficient to open the washer used in these taps.

Quarter turn gas taps (Figure 6.5) :

These are commonly used for low pressure gas. D.C.S. had the taps held together with a spring and split pin instead of a nut so that the plug would always be held firmly in position even if wear took place. These taps show clearly whether they are on or off. If the handle is in line with the pipe the tap is on and if it is given a quarter turn so that the handle is across the pipe then the tap is off. The tap in Figure 6.5(1) can be put in a gas line or used for a condensate drain, whereas 6.5(2) is suitable for a rubber tube to be attached, for a burner.

This type of tap is currently used for all floating steel drum plants. The locally available quality are not satisfactory for the dome and tunnel plants as they leak due to the high gas pressure.

If tap becomes stiff it can be oiled by pulling the gas tap handle against the spring and pouring lubricating oil around the handle against the spring and pouring lubricating oil around the handle and into the hole.

Vegetable oils, e.g. linseed, sunflower, mustard seed oil, should not be used. These oils become sticky in time and make things worse rather than better.

D.C.S. taps for high pressure gas :

D.C.S. has designed its own taps using nitrite rubber 'C' rings to give the seal instead of brass against brass in the quarter turn taps. Quite a number of taps to the design in Figure 6.6 have been used and after strengthening the spindle and handle they have proved to be much better than the quarter turn taps. The bottom ring comes off on occasions and with so much turning there is a likelihood of the upper ring wearing. To overcome this problem a lever action piston valve and tap have been developed (Figures 6.7 and 6.8). Prototypes have ben made but the valves have not been field tested yet.

When making gas taps it is very important to use lead free brass. The traces of hydrogen sulphide in the biogas combines with moisture and attacks the lead causing leaks.

Ball valves :

Ball valves made for biogas are excellent if they are available (Figure 6.9). The problem for a local workshop is making the balls smooth, spherical and with a hole and slot. A quarter turn opens or closes the valve.

6.6 Condensate Drains (water traps)

Condensed moisture lies as water in gas pipes and must be removed regularly to prevent blockages. Drains must be placed at the lowest part(s) of pipework (Figure 6.1) for this purpose.

D.C.S. uses two designs of drains; draincock for shallow applications and dipper pipe for deep applications.

Drain cock (Figure 6.10):

Condensate collects in the 150 long branch pipe. A valve can be put on the end but this is expensive. The system illustrated is low cost and effective. To operate it the brass screw is released until the condensate passes through the small side hole. The screw is tightened up after all the condensate has come out.

Dipper pipe (Figure 6.11):

The dipper pipe device was designed for use with floating steel drum plants with gas outlet pipes that come under the side of the drum which are at least 1 metre underground. It eliminates the need for a deep hole in the ground for the condensate drain, which could easily fill up with rain water.

It is designed for gas pressures of 100mm WG and less. Two designs (Figure 6.11) have both been used in large numbers. The former design which requires more pipe and is more difficult to make is only used on rare occasions now.

Condensate collects in the "U" tube and is lifted out using the dipper bucket which is on the end of a long rod kept inside the dipper pipe. The process is repeated until the water container no longer fills. The design is such that it is impossible to take out too much water and let the gas escape provided the gas pressure is less than 100mm. The cover on the end of the dipper pipe is to prevent dirt getting inside and is not required as a gas seal. When starting a plant about 1/4 litre water needs to be poured into the dipper pipe to form the initial water seal. The 'U' pipe is made to the dimensions in Figure 6.11 and the upper pipe and rod lengths are made to suit the plant being installed.

6.7 Measurement of Pressure

With floating steel drum plants the gas pressure is constant and there is no need to constantly measure the pressure. It can be measured using a manometer (Figure 6.12). Alternatively the pressure can be measured by connecting a length of rubber pipe to a gas tap and inserting the end into a container of water. The minimum depth (MM) to which the pipe must be inserted to stop bubbles of gas coming out, when the gas tap is open, is the measure of gas pressure in mm water gauge.

With cement dome and tunnel plants a manometer can be used to show the pressure and therefore the amount of gas available. The length of piping must be longer than the maximum gas pressure, which, with these plants, could go up to 1400mm WG.

As an alternative to such a large manometer D.C.S. has made a pressure indicator (Figure 6.13), in which the gas pressure is balanced by air pressure in a reservoir. While not being as accurate as a manometer it gives a useful indication of how much gas is left in a dome or tunnel plant and is much smaller.

6.8 Safety Valves

All D.C.S. plant designs allow gas to escape from the gas drum or digester after the gas storage space is filled. With drum plants the gas escapes from under the edge of the drum. In the dome and tunnel plants gas escapes from under the gas storage dome and out through the slurry reservoir. Because of this, no safety valves are required.

6.9 Flame Arrester

The gas pressure in all D.C.S. plant designs is always positive. The means that air cannot get into the plant or pipework and make a potentially explosive mixture. For these get into the plant or pipework and make a potentially explosive mixture. For these two reasons no flame arresters are used or considered necessary. Care must be taken when starting up a plant, or after repairs, to remove all the air from the system. This is dealt with in Ch.9.

6.10 Testing and Repairing Leaks

Leaks in gas piping is an all to common occurance. The most likely places to find leaks are at taps which, if they are made of brass, usually will turn black if they are leaking, or at joints. At a bad leak there will be an odour from the biogas. Soapy water should be put on all taps and joints and fittings etc. and bubbles will form if there is a leak. Defective joints or parts must be repaired or replaced as necessary.

A pipework system can be tested for leaks by measuring the rate of pressure loss on a manometer (or a length or transparent plastic pipe made into a 'U' and filled with water like a manometer) which is attached to one of the gas taps. Pressure is applied to the pipe line, either by opening the main gas valve or by blowing through a rubber pipe attached to a second gas tap. The pressure source is closed (i.e. by closing the main gas valve). If the levels in the manometer do not alter then there is no leak. If they do alter there is a leak and the faster they level out the larger the leak.

The amount of leakage per day can be worked out as follows :-

where

$$V_1 = \frac{p\ V}{P\ t} \times 1440$$

Leakage per day : V_1 (m^3)
Pressure drop during test : p (mm WG)
Final absolute pressure at end of test : P (mm WG)
(Absolute pressure = manometer reading + 10330)
Time of test : t (mins)
Internal volume all gas pipes under test : V (m^3)

<u>Example</u>

A pipework system uses 40 metres of 1/2" GI pipe (16mm bore). At the start of the test the manometer read 1150mm WG and at the end of the test it reads 1095mm. The test was over 3 minutes. What gas leakage would there be in one day?

Volume of pipework = $\frac{\pi}{4} d^2 l$ m^3

where d = diameter of pipe in m
l = length of pipe in m

$$V = \frac{\pi}{4} d^2 l = \frac{\pi\ 0.016^2}{4} \times 40 = 0.00804 \ m^3$$

$p = 1150 - 1095 = 55$ mm WG
$P = 10330 + 1095 = 10425$ mm WG
$t = 3$ minutes

$$V_1 = \frac{p\ V}{P\ t} \times 1440\ m^3$$

$$= \frac{55 \times .00804}{10425 \times 3} \times 1440 = 0.020 m^3/day$$

Such a small leak is hard to locate. If it is remembered that the main gas valve is usually opened for an average of about 7 hours per day it will be seen that the daily loss is very small, $0.006m^3$ = 6 litres. All leaks should be found and repaired.

It is a big job to dismantle pipes if one joint is leaking. Sections of the pipeline can be tested during installation by fitting a rubber bung with two pipes through it into the open end of the pipeline (Figure 6.14). One pipe is connected to a manometer and the other to a length of rubber pipe. Air is blown into the pipework until there is a reasonable pressure shown on the manometer. The rubber pipe is then folded over to close any pressure drop in the manometer noted as above.

Care must be taken that there are no leaks between the steel pipe and rubber bung.

Small leaks at joints can sometimes be repaired by putting on jointing compound or thick semi-dry paint and binding it on with cloth. Allow this to harden before amplying pressure, especially high pressure. If neither compound or paint is available then a temporary repair can be made in a similar way but using soap instea.

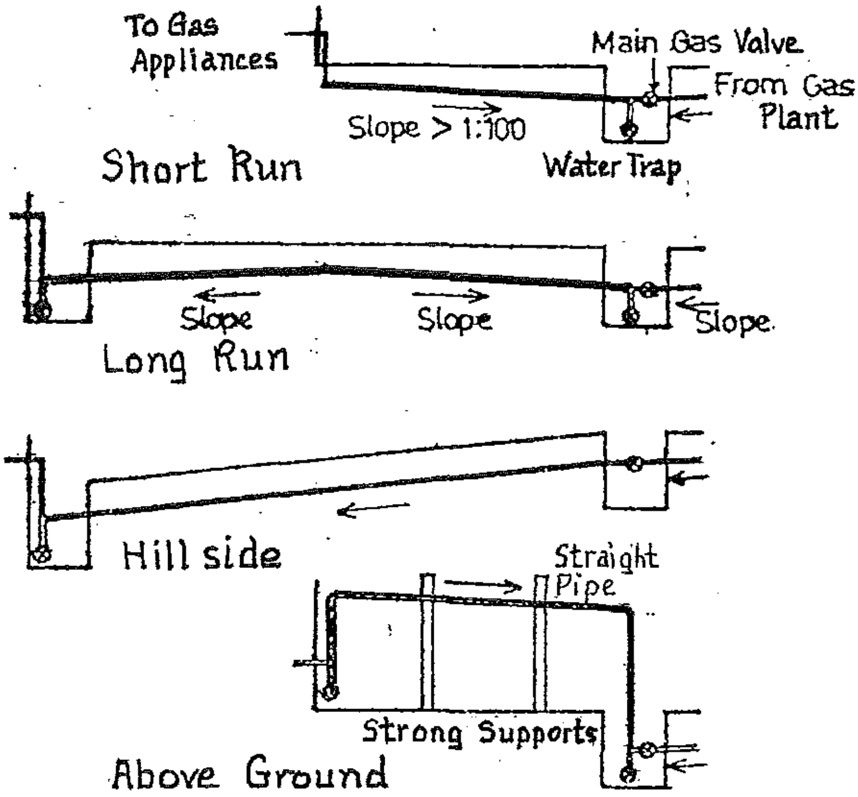


Fig. 6.1 Different Pipe Installations Showing Water Traps
(Nepal Biogas Newsletter)

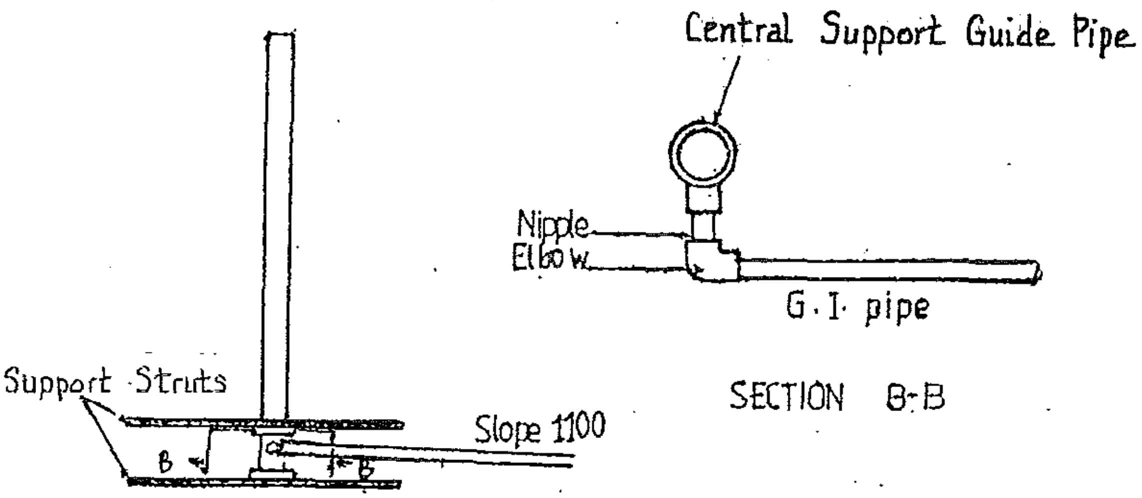


Fig. 6.2 Method of Attaching Gas Pipe to Central Support
(ESCAP, United Nations)

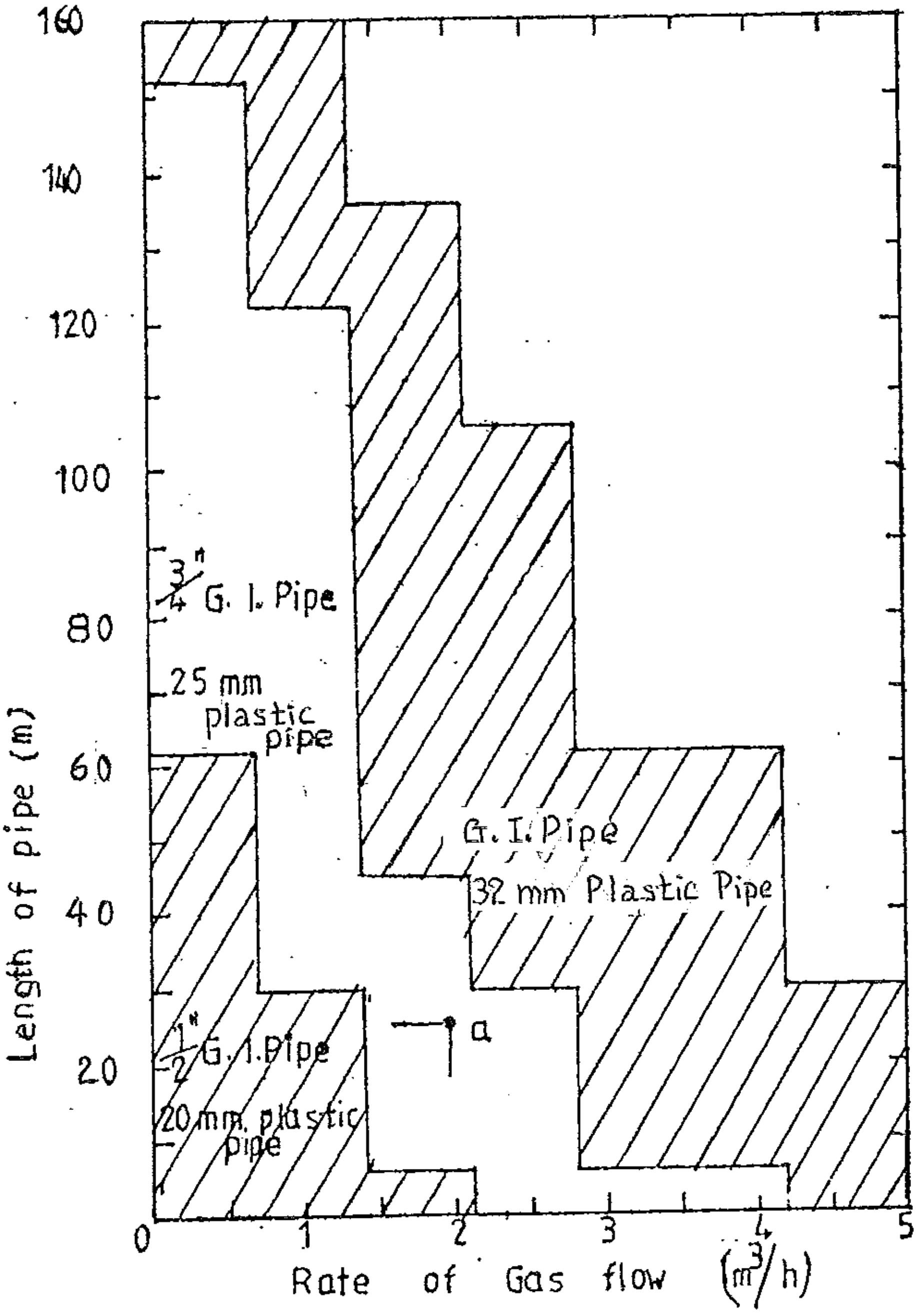


Fig. 6.3 Diagram for Quick Determination of Adequate Gas Pipe Diameters for Ordinary Small Installations at Low Gas Pressures (70-100mm WG)

Note: Diagram based on a 5mm permissible gas pressure fall in the installation

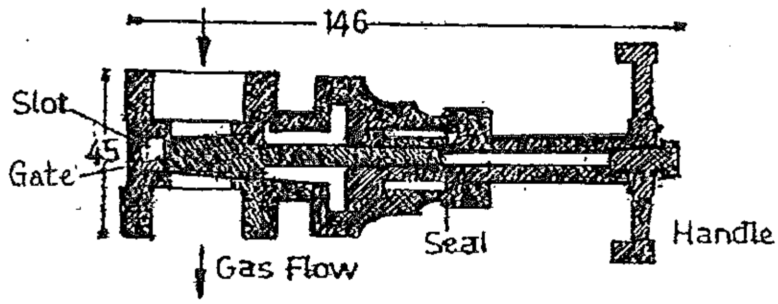


Fig. 6.4 A Typical Design of Gate (Full Way Valve)

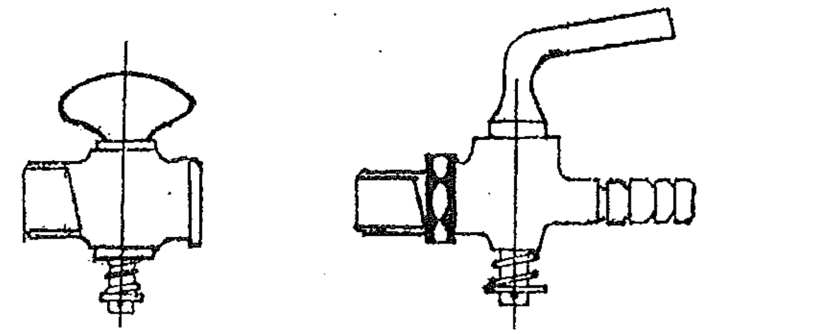


Fig. 6.5 Quarter Turn Gas Valve (ESCAP, United Nations)

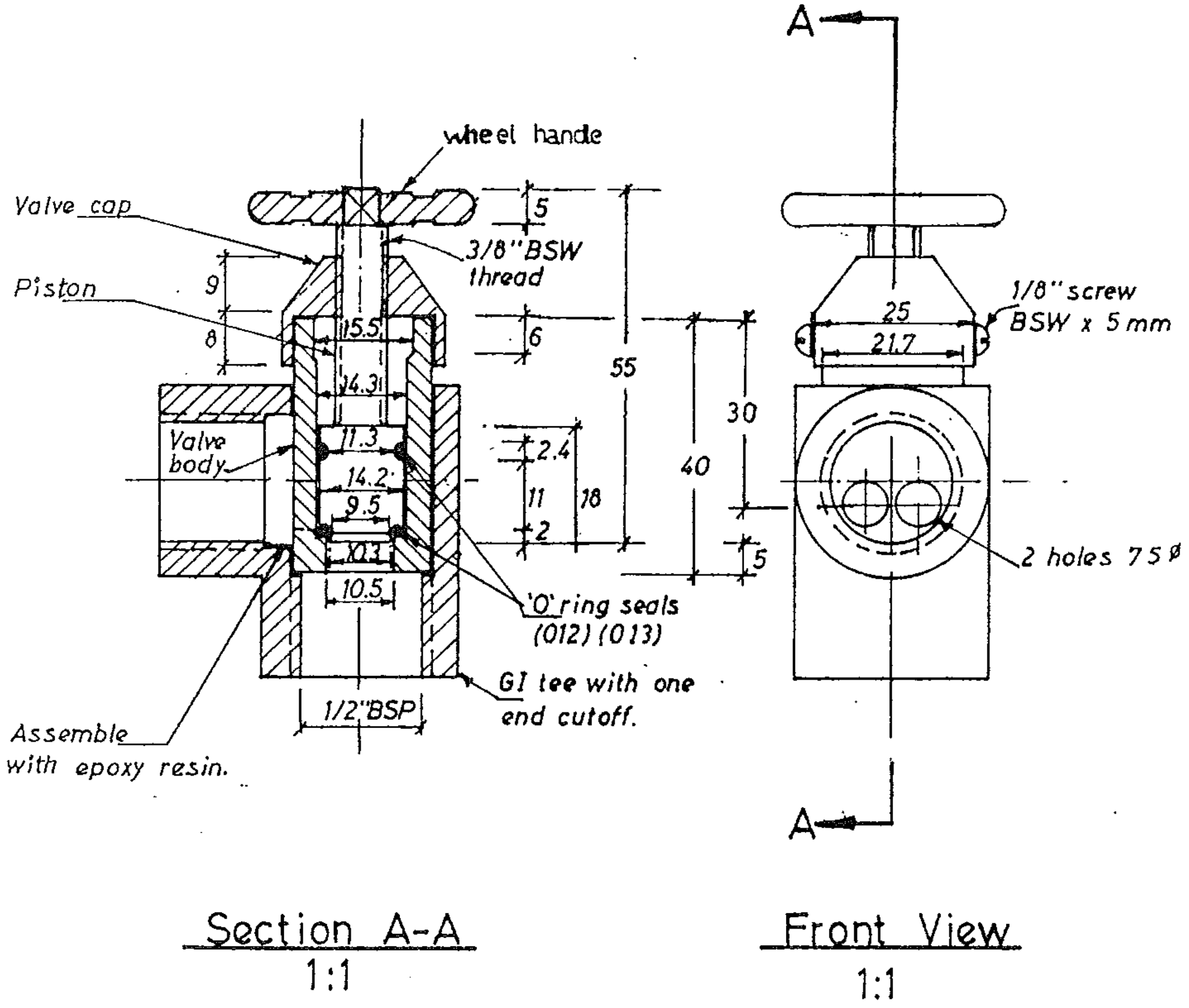


Fig. 6.6 <u>½ Inch Main Gas Valve (Screw Action)</u>

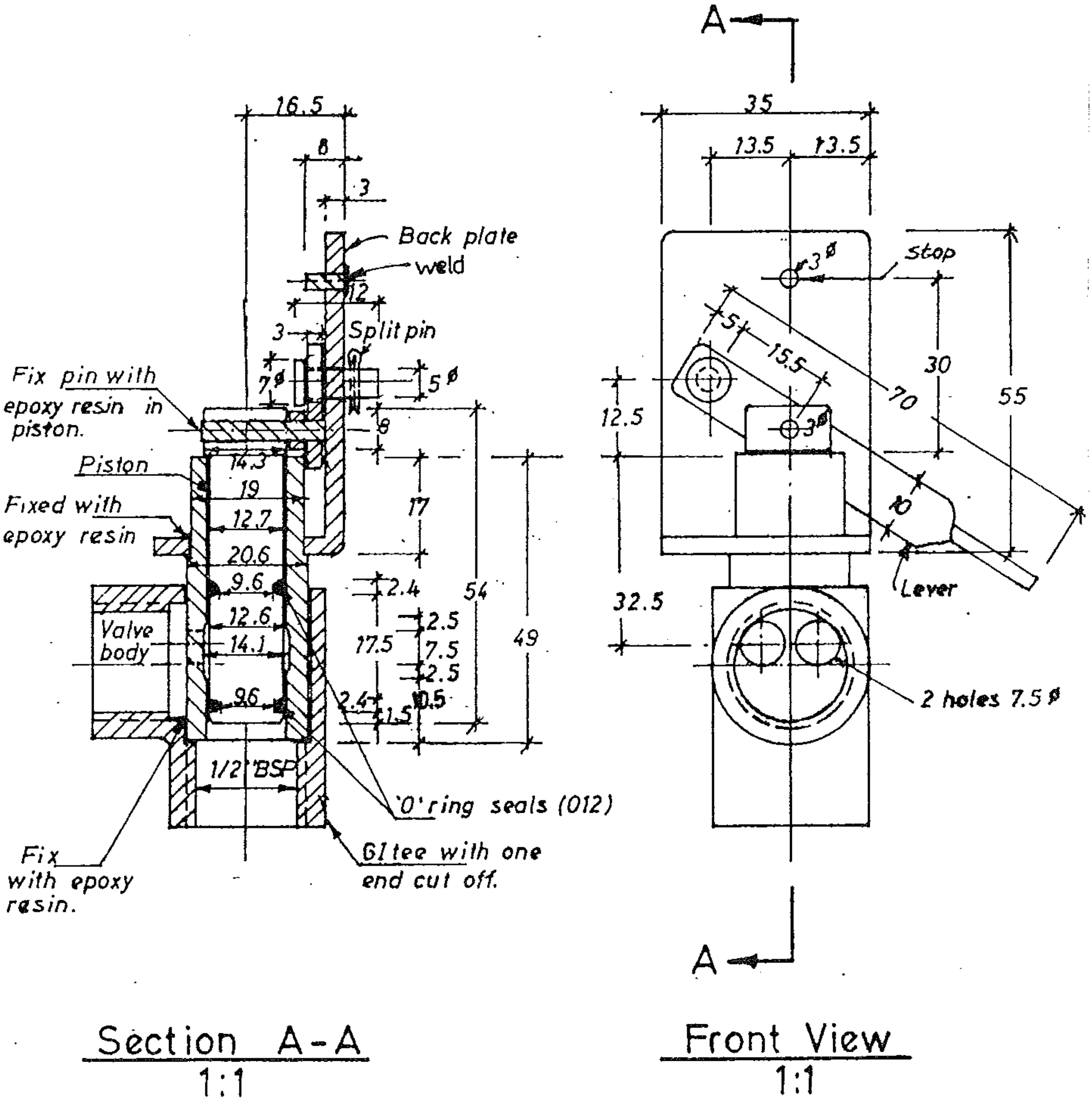


Fig. 6.7 <u>½ Inch Main Gas Valve (Lever Action)</u>

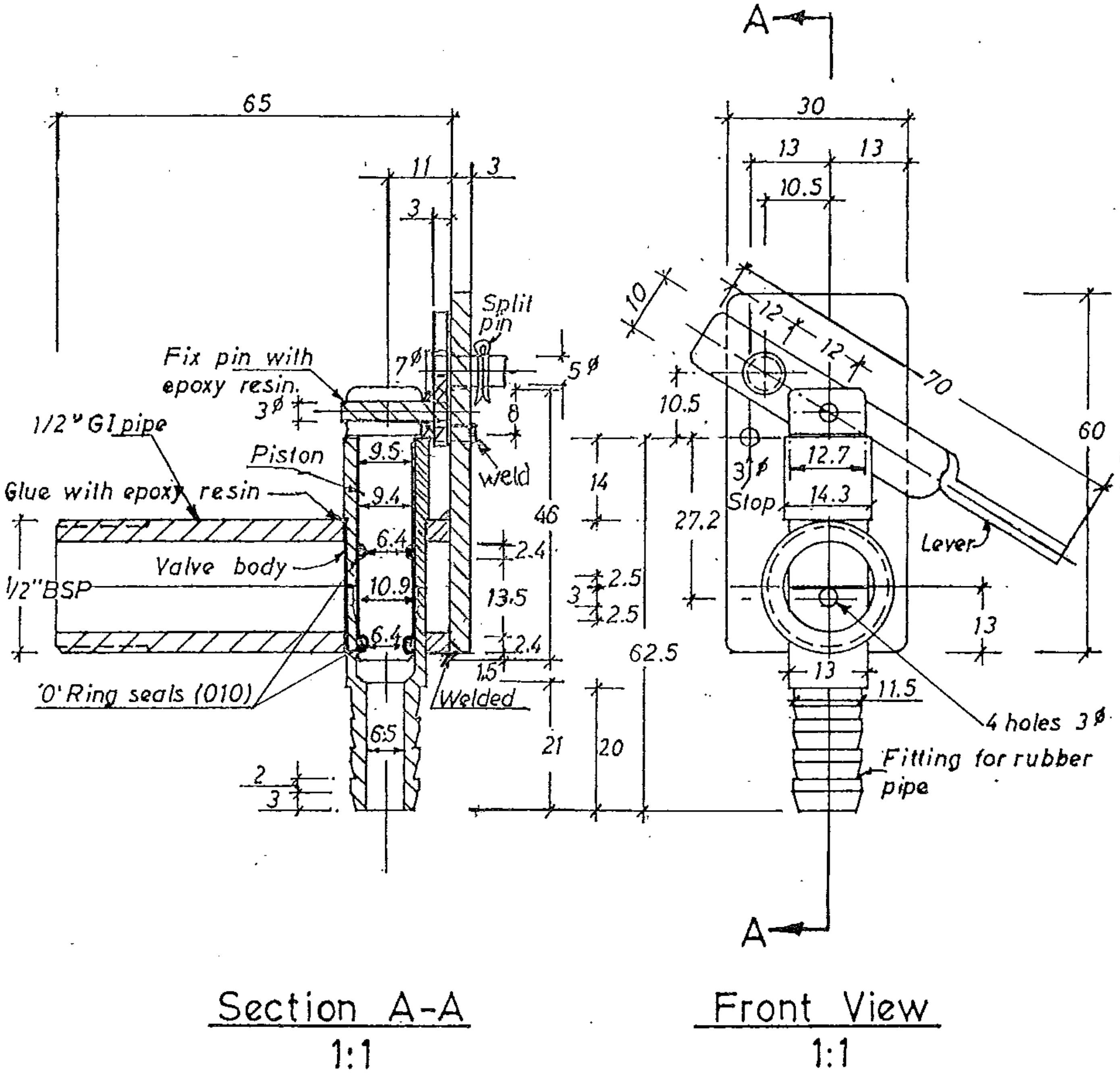


Fig. 6.8 ½ Inch Gas Tap to Suit Rubber Pipe for Stove (Lever Action)

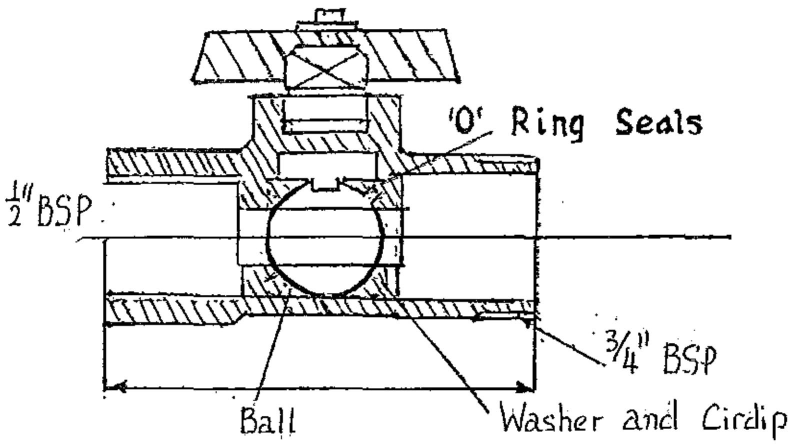


Fig. 6.9 Ball Valve

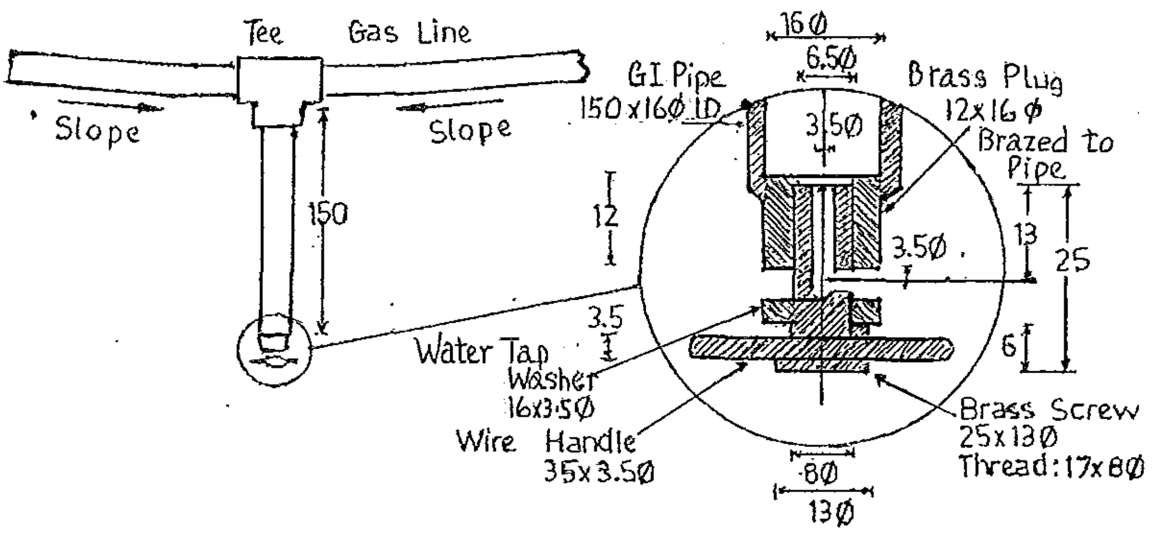


Fig. 6.10 Drain Cock for Removing Water in a Gas Pipeline

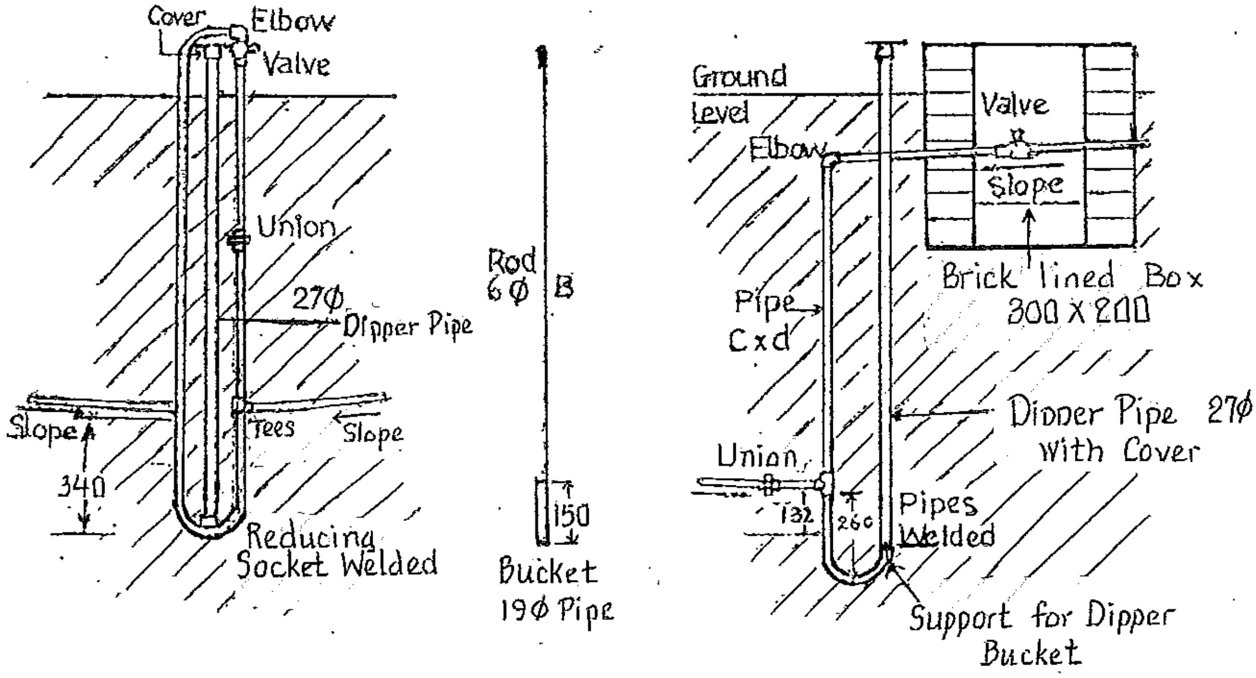


Fig. 6.11 Dipper Pipe for Removing Water in a Gas Pipeline

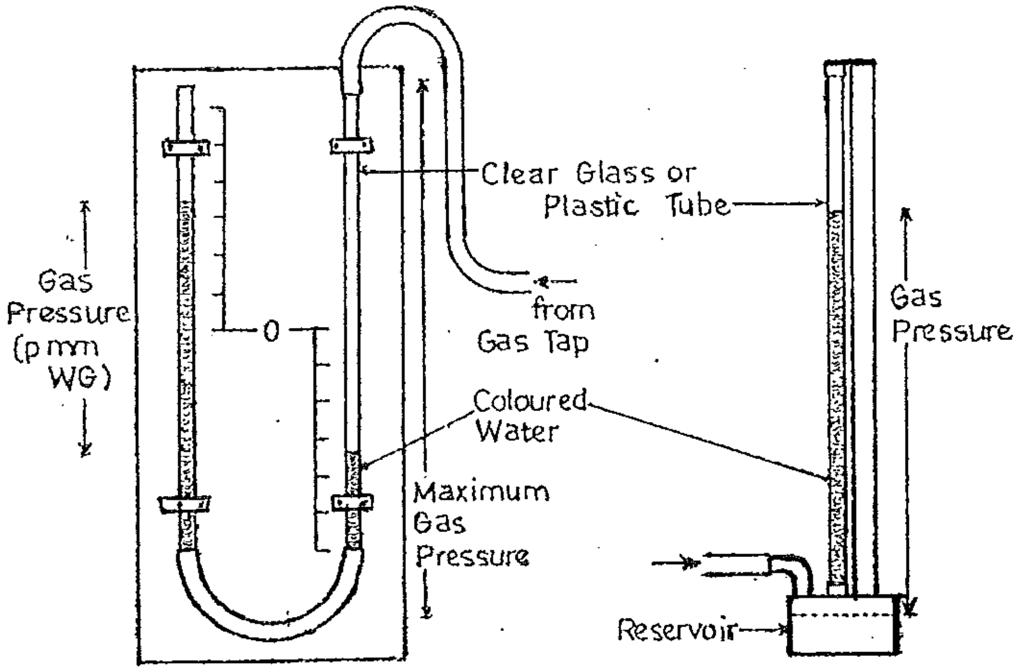


Fig. 6.12 Two Designs of Water Manometer to Measure Gas Pressure

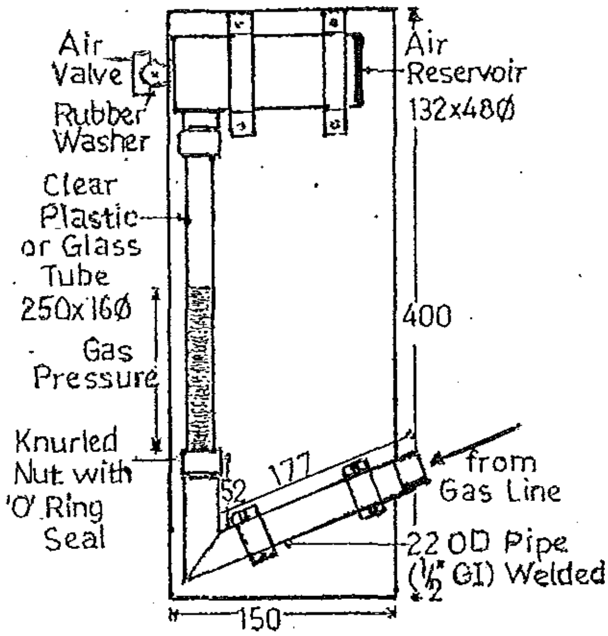


Fig. 6.13 Gas Pressure Indicator Design Made in DCS

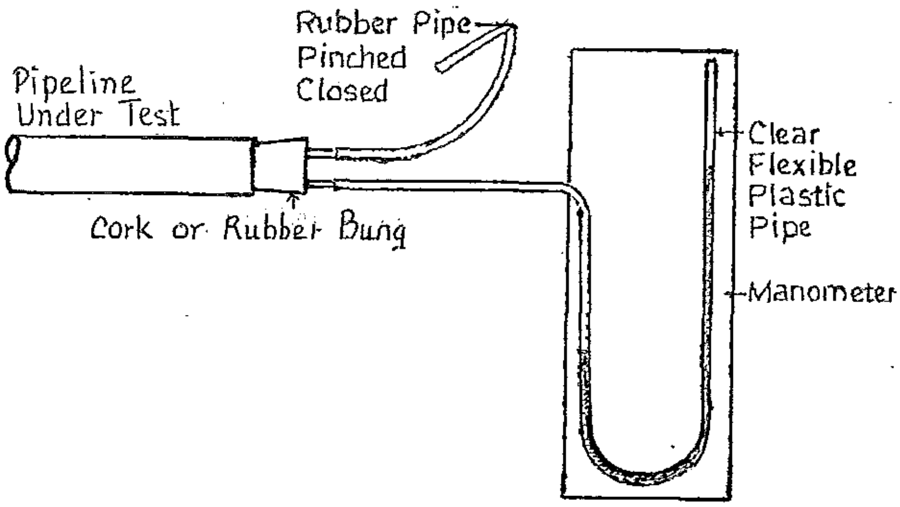


Fig. 6.14 Measuring Gas Leaks During Pipeline Installation

Chapter 7 HOUSEHOLD GAS APPLIANCES

J. Finlay

In Nepal the main use of biogas from family sized digesters is for cooking and lighting. Biogas has been used to run an absorbtion-type refrigerator and a clothes pressing iron. Originally, all appliances for cooking and lighting were purchased from Indial manufactures. D.C.S. has worked on import substitution, design improvements and cost reduction.

7.1 Cooking

Traditionally Nepali people cook over wood or dried cattle dung cake fires. Most food is boiled but some is fried. Biogas is an excellent fuel for cooking. It is:-

Efficient : if properly designed stoves are used. It is worth noting that 1 kg. of wet cow dung will give about 46 kCals of heat if dried and burnt in a fire, but above 80 kCals if turned into biogas and used in a well designed stove. (Pang.)

Fast : it produces immediate heat and does not need frequent attention.

Clean : it does not form soot on cooking vessels, clothes or kitchen.

Healthy : it does not produce smoke to irritate eyes or lungs.

The amount of gas needed to cook the daily food for a person depends on a number of factors. These include : type of food cooking method, number of meals and snacks per day, number of people being cooked for at a time. Another factor which is very important is the care of the cook, e.g. turning the gas down once the pot boils so that there is only a small flame to keep the pot boiling. Under Nepali culture traditions in which there are two main meals a day and snacks, the amount of gas required varies form 0.2 to 0.4 m^3 per person per day.

7.2 Burners

The size of burner is usually defined as the amount of gas consumed per hour when the gas tap is fully open and the gas pressure is about 75-80 mm water gauge. The most popular size is one burning approzimately 450 litres per hour. When high pressure gas is used (i.e. from Displacement or Tunnel plants) it is necessary to either reduce the flow by adjusting the tap or fitting a smaller gas jet to the burner.

Biogas burner flames have a characteristic called "lift-off". If a burner is adjusted for maximum efficiency when the cooking pot is in position, then when the pot is removed the flame is liable to go out. Actually a gap of unburnt gas appears between the flame port and the flame. This gets higher until the flame goes out. To prevent this the air control can be closed and reopened when the cooking pot is replaced. If the air control is not reopened after replacing the cooking pot the gas will burn at low efficiency.

Two burners, both of which consume 450 litres per hour, are shown in Figure 7.1 and 7.2. The former is imported and the latter designed by D.C.S. As regards efficiency they are both almost identical but as regards other design features there are significant changes as the comparison below will illustrate:

Ring burner (Figure 7.1)	DCS burner (Figure 7.2)
Robust	Robust
Efficient	Efficient
Screwed air control ring, which is slow to adjust and gets stuck in time with spilt food	Easy quarter turn air adjuster
(Designed to have cooking pot on burner and then gas lit. A practice culturally and religiously not acceptable in Nepal)	(Designed that gas is lit then cooking pot is put on it. This is culturally and religiously acceptable in Nepal)
Dirt in flame ports falls inside is troublesome to remove	Removable burner cap for easy cleaning
Correct height flame ports to base of <u>flat</u> bottomed cooking pots.	Ditto, with grate in position as shown in Figure 7.3
Not so stable for locally used round based cooking pots. Also height from flame ports is too low for maximum efficiency	With grate in position shown in Figure 7.2, round based cooking are stable and the height from flame ports is correct.
	Legs spared further apart for greater stability
	Burner cap replaceable 30% lower cost.

Burners can be supplied with a tap attached (Figure 7.1) or without one but with a tap on the main gas pipe. The latter system is recommended because it allows the gas to be immediately turned off should the rubber pipe be pulled off, i.e. by moving the burner on by a child playing. Details of the DCS burner are given in Figure 7.3.

7.3 Double Ring Burner

There is a demand for large burners both for cooking for large numbers of people and cooking animal food. Large imported burners of the type show in Figure 7.1 and burning 1,100 litre per hour have been used.

D.C.S. has made a double ring burner (Fig. 7.4). The inner burner is identical to the 450 l/h burner described above. The outer ring uses 900 l/h. The two bruners have separate jets and gas pipes so they can be controlled independently. This stove is intended to give quick heating (900 + 450 l/h), efficient simmering (450 l/h or adjusted lower) and good frying (900 l/h). This is a new item which has proved to be efficient. The outer ring burner has been made of welded mild steel but in future it is probable that it will be made of two separate castings. The top one, including pot rests and flame ports, would be removeable for cleaning. Under local conditions a casting should be a lower cost.

D.C.S. burners were mainly arrived at by experiment and testing. Experience showed that to prevent flames being blown out relighting that the distance between flame ports should not be more than 10 mm and that groups need to consist of not less than 5 flame ports. Further, if the flame ports come out of a flat surface then they need to be raised up by about 6 mm from the flat surface in order to get good combustion.

7.4 Adjustment and Care of Burners

Biogas flames tend to "lift off" from flame ports when the burner is adjusted for efficient burning but the cooking pot is not in place. By closing the air adjuster the efficiency goes down but the flame will not "lift off" easily.

Normally the air adjuster is closed, the gas is turned on and lit, then the cooking pot is put into position. It will been that the flames are weak and long and lazily come up the sides of the cooking pot. There will be a slight smell from the burning gas. This indicates that the gas is burning inefficiently and more air (called "primary air") needs to be mixed with the gas. This air is provided by opening the air adjuster beside the gas jet until the flame burns with a slight roaring noise. If the gas pressure is low (steel drum type plants) then for maximum heating the gas tap is fully opened. If the gas pressure is high (dome or tunnel plant) the tap needs to be partly closed otherwise the flame will lift off or burn eficiently. The flame should not be too noisy.

Flame ports and air holes can, in time, become partly or completely blocked with spilt food. They should be cleaned out as necessary. The gas jet seldom needs cleaning but should it be necessary it must be done carefully using something like a match stick. This is to prevent to jet being damaged or enlarged. The rubber pipe that connects the gas tap to the burner can perish and crack at the ends. If this happens the ends can be cut off and a shorter pipe used.

7.5 Lighting

In Nepal there is a large demand for biogas lamps in unelectrified rural areas. Biogas lamps tend to be expensive (especially good quality ones), use biogas inefficiently, require regular servicing and need a good supply of mantles. Electric lighting, when available, is much better in every way.

Lamps working at 50 to 100 mm WG gas pressure use about 130 to 175 gas per hour and give about the same illumination as a 40 to 60 W electric bulb, depending on how well it is running. At higher gas pressure the mantles break more frequently.

The biogas lamps installed in Nepal have come from Indian manufacturers. The quality and price vary by a factor of 4 although of the same basic design as given in Figure 7.5. The low cost ones can start giving trouble within 4 months and there are two main problems. The gas tap and gas jet adjuster are made out of brass which contains lead. The trace of hydrogen sulphide in biogas attacks the lead and soon these fittings leak. A glass globe is fitted around the light to protect it from drafts and insects flying to the light and breaking the mantle. A globe made of heat resistant glass works well but low cost globes made of strips of plain glass held in metal frame with light wire quickly fail.

D.C.S. has designed and made a new lamp (Fig. 7.6). It is low cost using where posible, steel and ceramics instead of brass. The gas tap (for principle refer Fig. 6.8), and needle adjuster are both controlled by the same lever. The former by the first movement and the latter by the continued movement of the same lever. A deflector plate is used to prevent the rubber '0' rings getting hot and has proved to be effective. The lamp works well and gives a similar light to imported lamps although it uses a little more biogas especially at higher pressures. This may be improved by adjusting the jet size.

D.C.S. has helped test a locally made lamp based on Chinese technology (Fig. 7.7). This uses a fixed size glass jet in a ceramic mixing tube. The reflector is also made of ceramic. A diaphram type of valve is used to control the flow of biogas: a device made to control drip intravenious feeds in hospitals. It is a nylon wheel held in an inclined groove so that it presses on arubber pipe and partly closes it. The air supply is varied by moving the glass jet in and out of the end of the mixin tube. This type of lamp seemed to work well in the laboratory tests with the higher biogas pressures from a dome plant (above 200 mm WG). It does not work at lower biogas pressures and may not be robust enough to offer commercially to customers. It is very cheap, especially if used valves can be obtained from hospitals after they have been discarded.

7.6 Adjustment and Care of Biogas Lamps

The glass globe is hinged to one side and a mantle is tied on to the clay nozzle which usually has one large hole in the centre and a series of small holes around the side. The mantle is opened to a ball shape. Having turned the gas tap on and opened the jet adjuster to maximum, the gas is lit and mantle burned. Now the globe is closed and the lamp allowed to heat up until the burning gas makes a soft roaring noise. At this point the lamp will burn brightly and ths can be optimised by adjusting the adjuster. It is usually unnecessary to operate the adjuster again until the mantle is changed. If the lamp is hot but the flame tends to burn outside the mantle and there is no soft roaring noise it can usually be overcome by blowing gently on the mantle.

To turn off the lamp, only the gas tap should be closed. However, in the D.C.S. lamp the same lever is used to operate both the gas tap and jet needle adjustment so it needs adjusting each time the lamp is used. 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 globe. Then the gas 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 ventury tube should be throughly cleaned out of any insects, cobwebs, carbon or dirt. A piece of cloth wrapped aroung a pencil or small stick can be used. The globe and reflector should be washed with soap (or ash) and water, whenever necessary, and left to dry before the lamp is lit.

The most common reason for properly adjusted lamps not working well is cobwebs and insects' nests inside the venturi tube. A second problem, especially in lamps using low gas pressure, is a defective needle in the gas adjuster. The point should be long, thin and have a fine point. It must come down low enough to protrude through the jet and close it off. The point can be filed to shape and the hole filed to make a slot into which the pin of the regulator control fits, so that the needle can again enter the jet (Figure 7.8). The D.C.S. lamp uses a different type of regulator control, but if the needle is filed correctly, it should fit into the jet orifice without any other alterations.

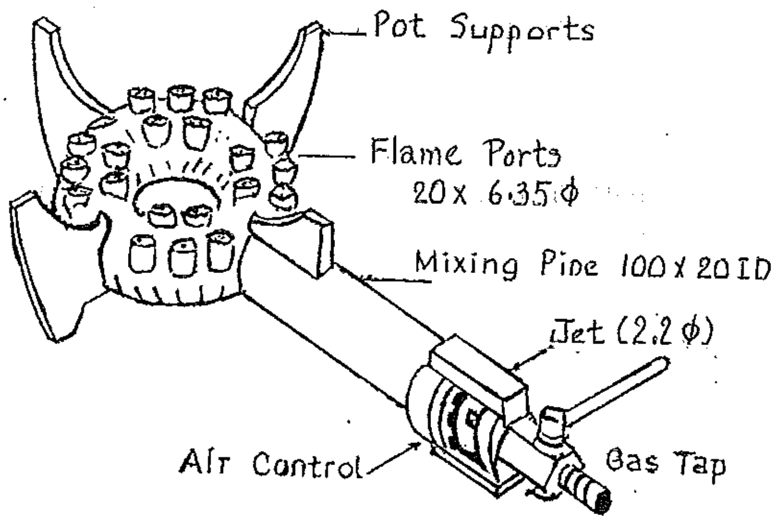


Fig. 7.1 Sketch of a Typical Biogas Ring Burner (ESCAP, United Nations)

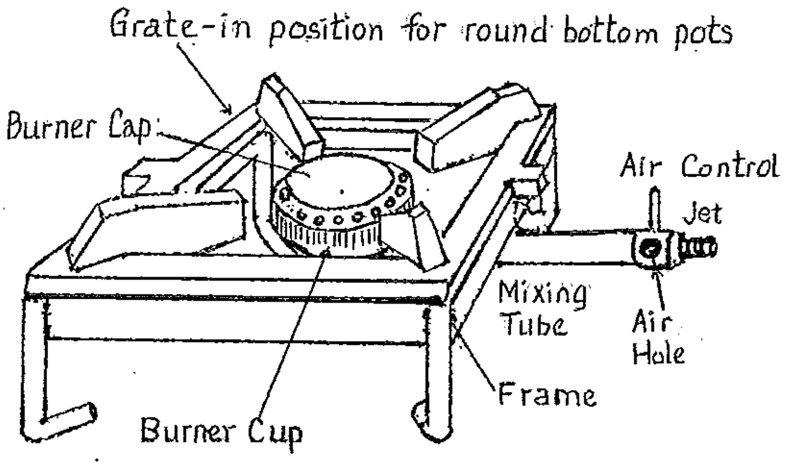
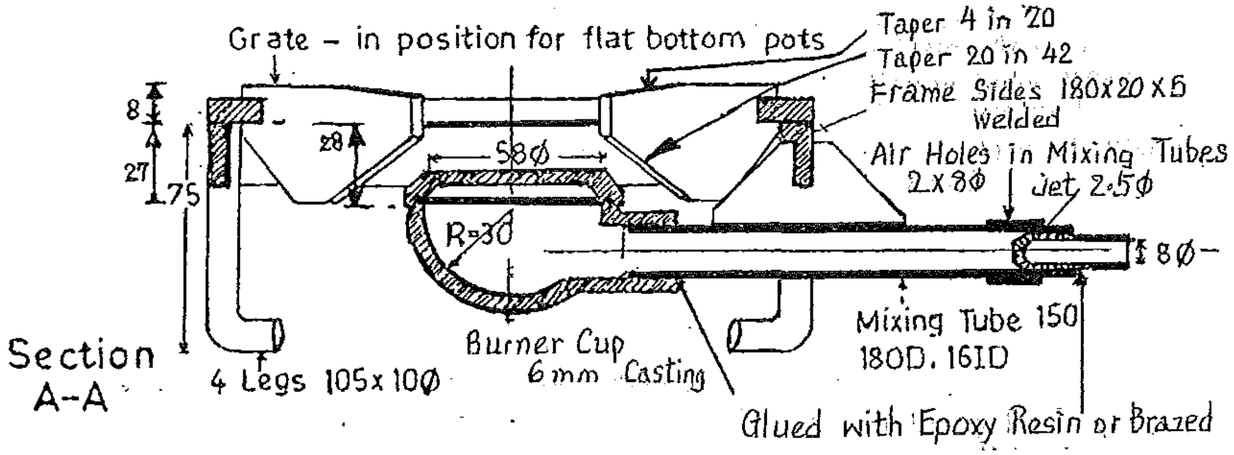


Fig. 7.2 Sketch of the DCS Biogas Burner



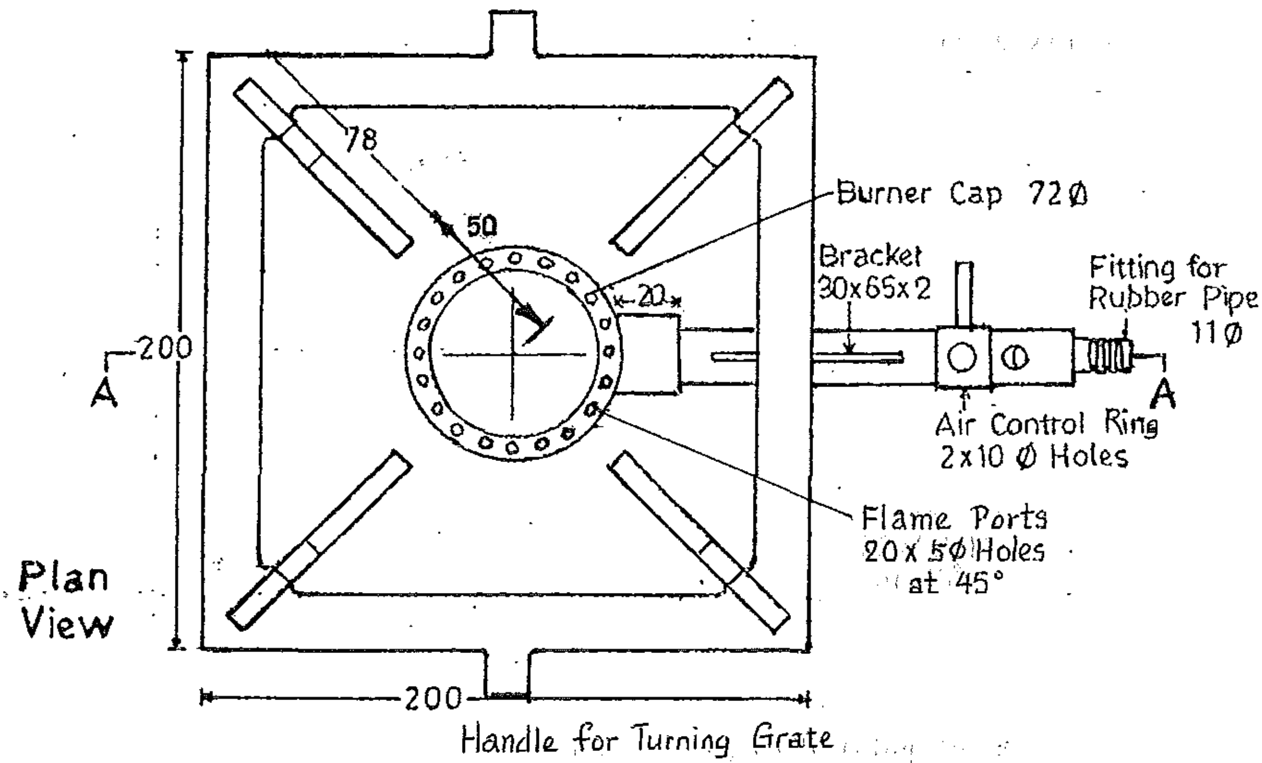


Fig. 7.3 <u>Detailed Drawings of DCS Biogas Burners</u>

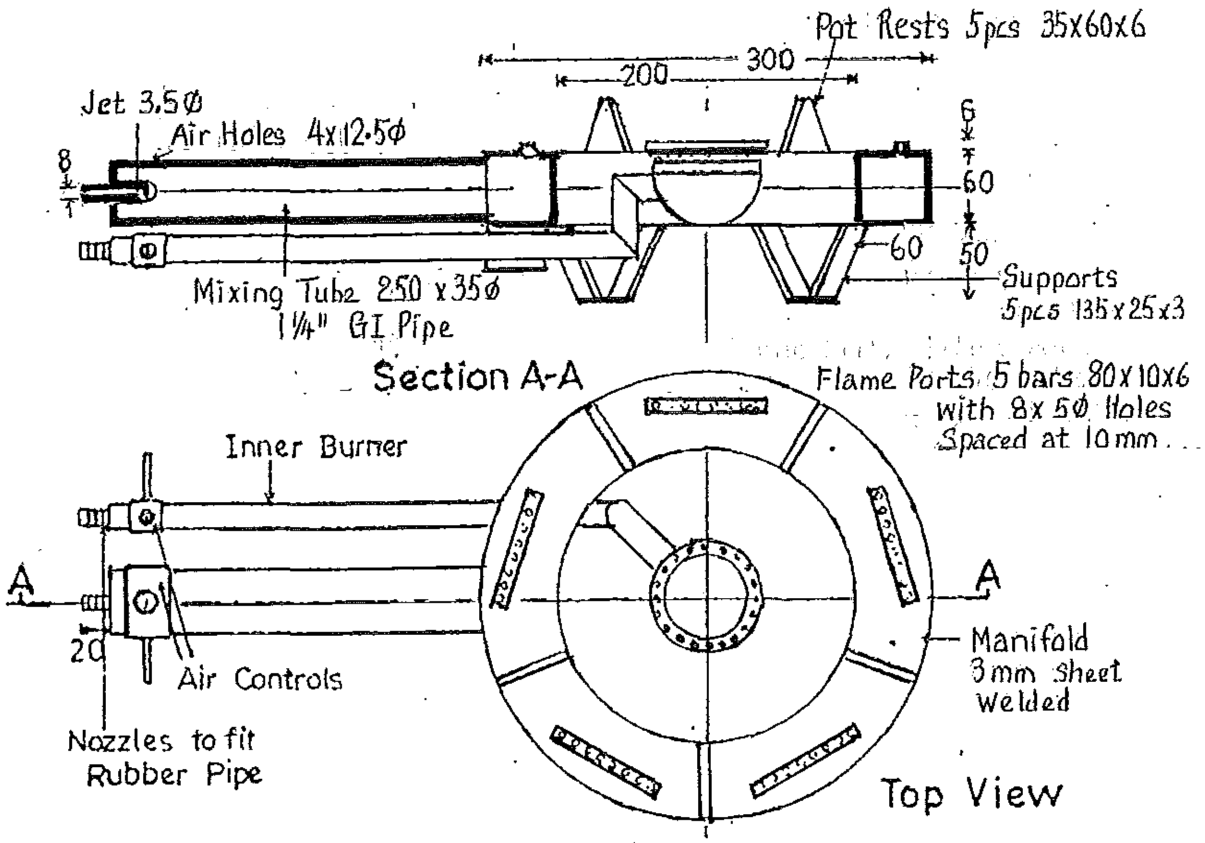


Fig. 7.4 DCS Double Biogas Ring Burner

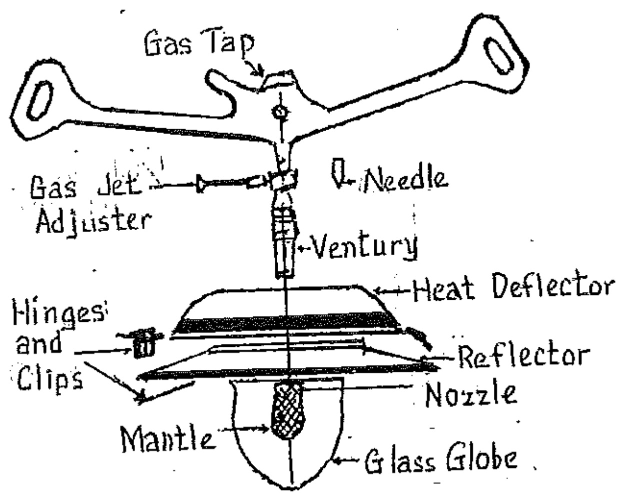


Fig. 7.5 Typical Indian Biogas Lamp

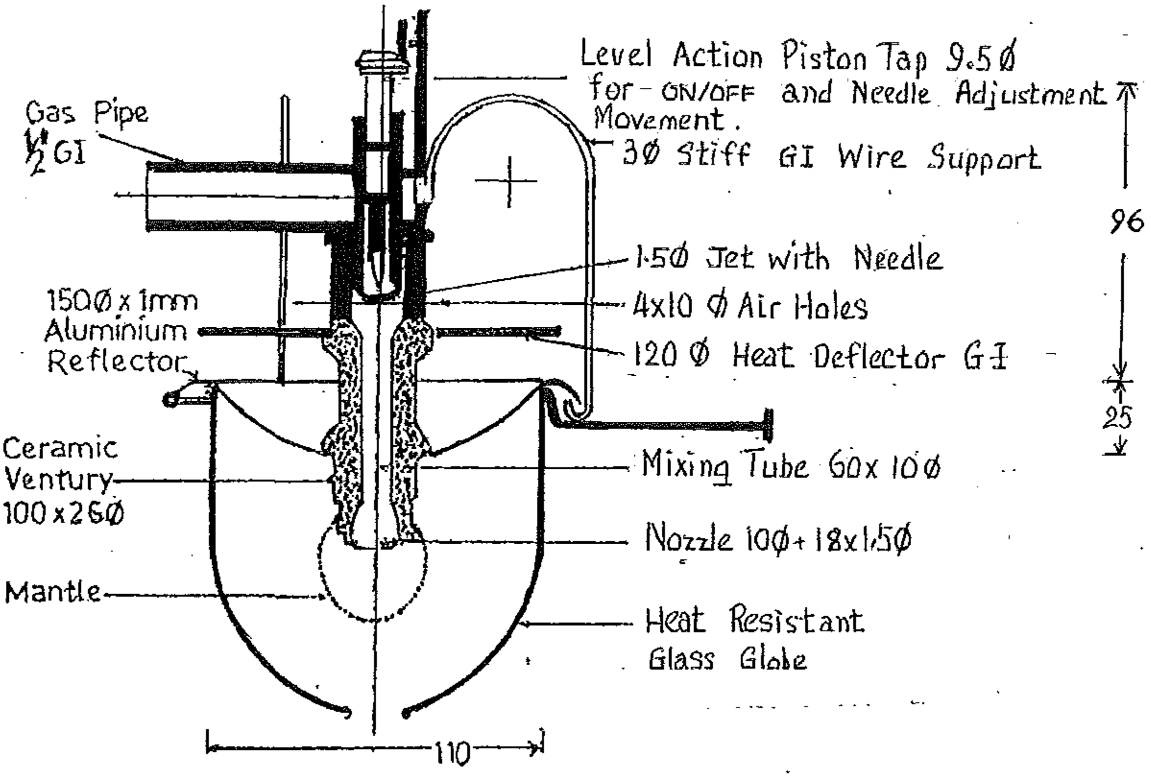


Fig. 7.6 DCS Design of Biogas Lamp

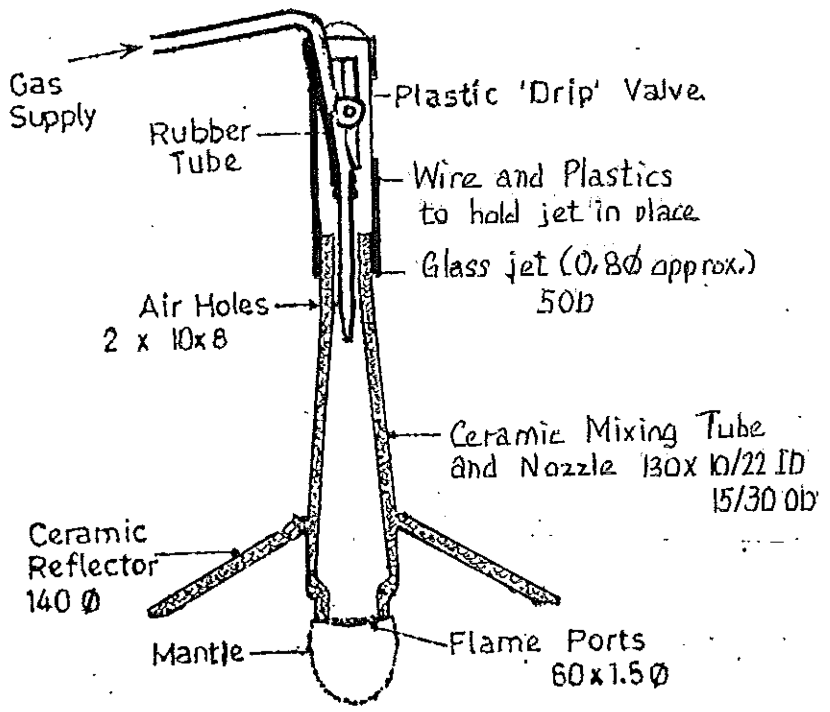


Fig. 7.7 Biogas Lamp Based on Chinese Technology

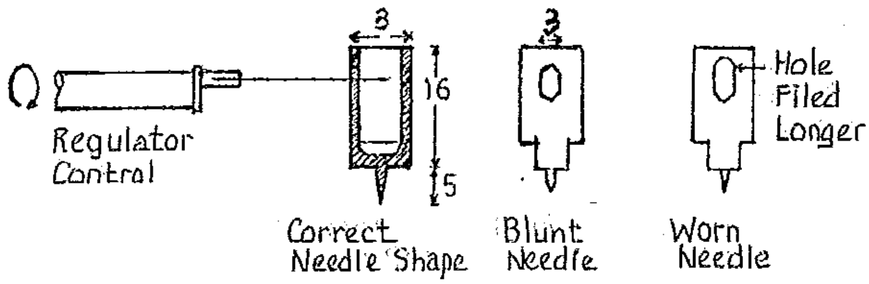


Fig. 7.8 <u>Shapes of Lamp Regulator Needles</u>

Chapter 8 COMMERCIAL USES OF BIOGAS D. Fulford

Biogas is a 'high grade' fuel because it burns at a fairly high temperature (about 1,900°C in air). Biogas can therefore be used for many purposes other than cooking and lighting, such as fuel for internal combustion engines and to run small-scale cottege industries.

The use of biogas for commercial activities introduces a new dimension to the economics of biogas. A biogas plant is a relatively large investment for a subsistence farmer (or group of farmers) and the cash saving on cooking and lighting fuel is low (see Ch. 11). Therefore a biogas plant owner must find the money to repay any loan taken to purchase the plant, from another source. If biogas can be used to fuel an income-earning activity, the cash accumulated can help to pay off the loan for the plant and biogas technology becomes economically viable for a far greater number of poorer people.

Development depends partly on energy; people who want a more advanced life-style than can be obtained from subsistence farming, must move to a place where energy is available, which is usually the larger towns and cities. Centralized power production, such as electricity from power stations or a gas supply from natural gas wells or the gasification of coal, means centralised usage of power. It is easy and relatively cheap to run electric lines and gas pipes to houses and factories that are close together, but it is very expensive to supply the same sort of energy to villages that are scattered and distant from population centres.

Biogas offers a decentralised power supply. The energy is created in the villages, where the animals are kept and the crops grown. It cannot be used in the city, where there are few cattle and little crop residues. Biogas can be used to supply energy for cottage industries in the villages themselves and to catalyse development away from the towns and cities. Village people can begin to consider a more advanced life-style and the earning of extra cash incomes in the place where they are already living. Biogas offers the rural areas increased self-sufficiency and reduced dependence upon energy supplies from the towns.

In Nepal, the main semi-commercial uses for biogas have involved the running of dual-fuel engines to drive grain mills and irrigation pumps. There is a growing interest in this approach, even though a dual-fuel engine still requires some diesel and engine oil. The running costs for the engine are reduced and fuel does not need to be transported out to the village as often as when the engine is run on diesel alone.

8.1 Running Engines on Biogas

There are basically two types of internal combustion engine : the 'Otto' engine and the 'Diesel' engine. The Otto cycle uses a spark to ignite the fuel, and the Diesel cycle uses spontaneous ignition of the fuel, at the high temperature and pressure produced by the compression of air (Picken). Biogas can only be used in a 4-stroke engine, as 2-stroke engines rely on oil mixed with liquid fuel for lubrication. The 4

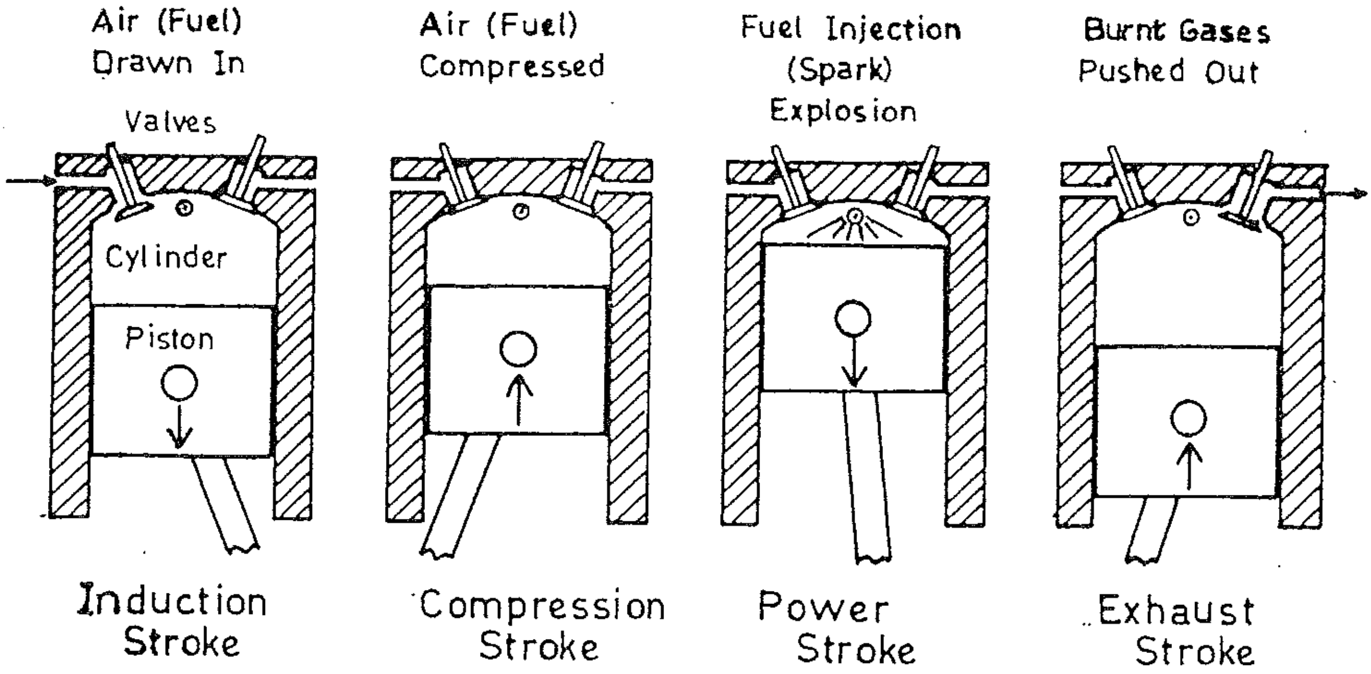


Fig. 8.1 <u>Four Stroke Cycle of a Diesel Engine</u>

movements of the piston in the 4-stroke cycle are shown in Fig. 8.1).

The Otto engine is normally designed to run on petrol (gasoline), although some are designed to use kerosene (paraffin), natural gas or alcohol. The fuel is mixed with air and drawn into the cylinder in the induction stroke. The compression ratio is usually betwen 7:1 and 9:1 (giving an air temperature of 400°C), so that the fuel/air mixture does not spontaneously ignite (causing knocking). Ignition is by an electric spark that fires the mixture at an appropriate point near the end of the compression stroke. Biogas can be used directly in an Otto engine, as it does not knock (Octane Number: 128 - Maramba 1978), but is easily ignited by a spark. Biogas is used fairly inefficiently in such an engine (20 to 25% at a compression ratio of 8:1 - Mosey 1979) and the power output is only 60% of that when the engine is run on petrol (Maramba 1978). Hydrogen sulphide is burnt to sulphur dioxide in the engine and it tends to corrode the exhaust valves and pipes.

In the Diesel engine, only air is compressed and the diesel is injected at high pressure into the cylinder near the end of the compression storke, when it spontaneously ignites. To reach the high temperatures required (500°C), high compression ratios are used (14:1 to 22:1). As biogas has a high spontaneous ignition temperature (700°C - Mosey 1979), it can be mixed with the air and compressed in the cylinder with little risk of pre-ignition. If a diesel engine is used in this way, when it is called a dual-fuel engine, the efficiency is about 30 to 35% and the power rating about 80% of diesel-only operation. There seems to be a lower risk of corrosion in the exhaust system when biogas is used in a diesel engine. For these reasons, the use of biogas in dual-fuel engines is most common.

The speed of a diesel engine is altered by varying the amount of fuel injected into the cylinder. On stationary engines, the speed is usually kept constant by a governor, which uses centrifugal fly-weights to control the fuel injector valve. When biogas is introduced into the air supply, the engine speeds up, so the governor automatically reduces the diesel supply until the engine again runs at the designed speed. In this way, the biogas to diesel ratio is kept at about 5:1.

A third approach is to adapt a diesel engine to biogas operation with spark ignition (Fry, 1974). With the high compression ratio, this type of engine is more efficient than an Otto engine. Such an approach required good engineering knowledge and experience and access to tools and part such as suitable generators, distributors and spark plugs (usually second-hand), so it is really not suitable for an extension programme for biogas in a developing country, such as Nepal.

8.2 Use of Biogas in Dual-Fuel Engines

Several dual-fuel engines are working in Nepal on biogas and they were mainly purchased in India, where they are available commercially. They use a very simple gas carburettor and seem to be fairly robust and reliable. A 5 Horse Power (HP) engine (3 kW) uses about 2.1 m^3 (75 cu.ft) of biogas and 0.2 litres of diesel in an hour, as opposed to 1.2 litres of fuel, when on diesel alone (Kirloskar).

The biogas pressure should be above 75 mm WG and the biogas supply is controlled by a valve in the line (usually a ball valve). This type of engine is usually used as a static engine to drive machines such as grain mills and water pumps. The engine should be started on diesel alone and the biogas valve opened slowly until the engine starts to run unevenly. The valve can be closed slightly until the engines runs smoothly again, and this is the correct position.

A dual-fuel engine runs at a higher temperature when used with biogas, so the cooling system must be effective. The "hopper" type of cooling system, in which water is added to an open hopper in the top of the engine, is not adequate. Even with a thermosyphon system, in which water circulates by convective flow into a water tank placed above and to the side of the engine, a dual-fuel engine can overheat, if the air temperature is already high. If the engine is being used with an irrigation pump, cooling water can be bled from the outlet of the pump and circulated through the engine. This system works well, as long as the water is fairly clean and dirt does not block the water passages. The outcoming water should be just too hot to touch. If the engine is being used to drive other machinery, a small water pump, driven by a pulley and belt on the fly-wheel, should be used to circulate water. The hot water can be cooled in a radiator, or by running it down a length of corrugated steel sheet into a water tank (Fig. 8.2).

The cooling water from the engine can also be pumped around a heat exchanger in the slurry in the digester pit (see Ch. 10). A bypass valve should be included, and a water cooler, so that both the engine and the digester can be set at the correct temperatures.

Full details for running and maintaining a diesel engine are given in the manufacturer's manual, which should be carefully sutdied and followed. Great care should be taken that the engine oil is kept topped up and replaced at the correct intervals. Inadequate or dirty engine oil can cause an engine to overheat or even fail. Another common cause of failure

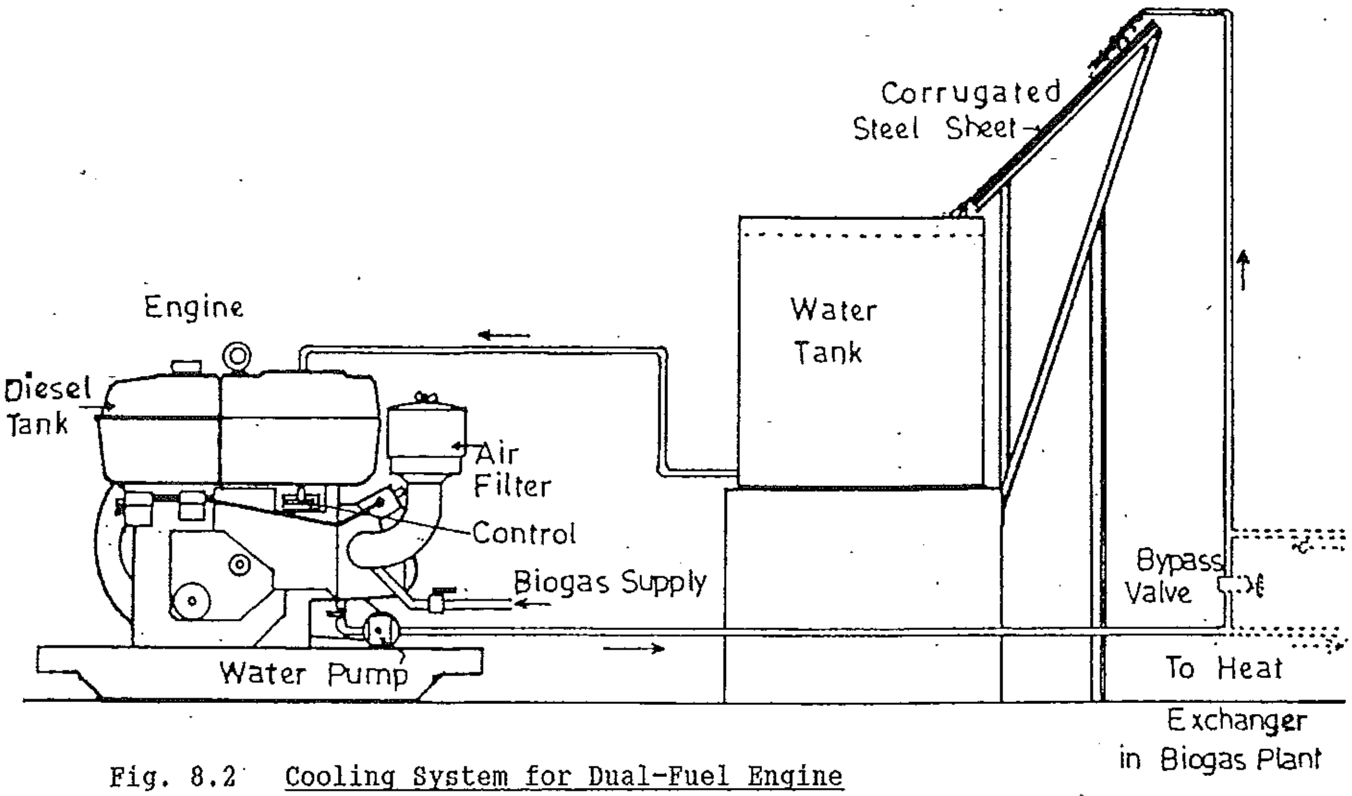


Fig. 8.2 <u>Cooling System for Dual-Fuel Engine</u>

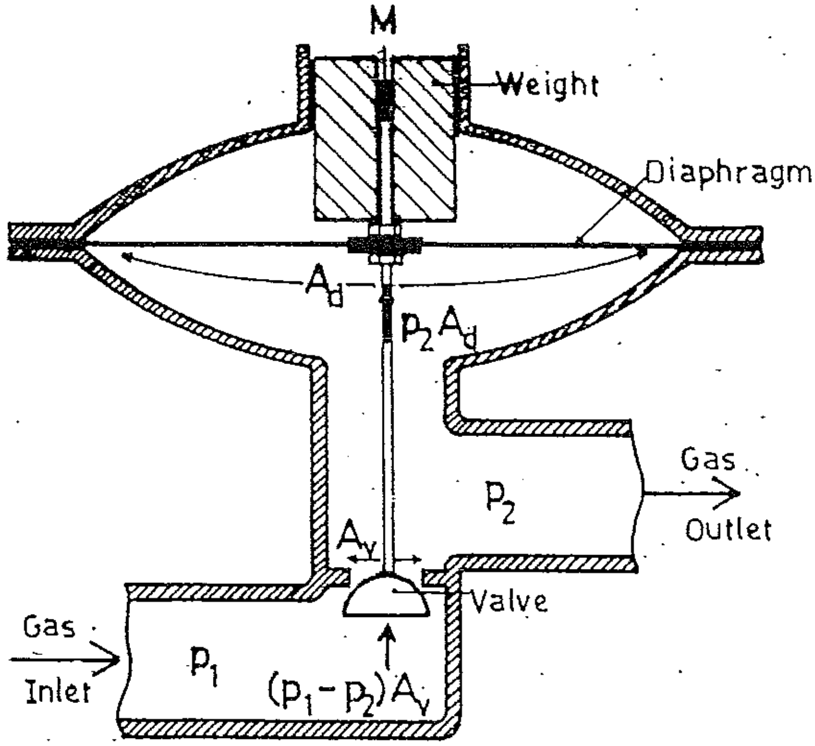


Fig. 8.3 <u>Principle of Operation of a Pressure Regulator</u>

in engines used in rural areas is bolts shaking loose. Regular checks should be made that all bolts are tight.

If the use of biogas in engines is part of a biogas extension programme then the training of villagers to operate engines and to do simple maintenance must be part of the programme.

8.3 Use of High Pressure Biogas in Dual-Fuel Engines

The optimum pressure for biogas to be used in a dual-fuel engine is 75mm WG. The biogas pressure from a dome or a tunnel plant is between 200mm and 1,400mm WG. Attempts have been made in DCS to design a pressure regulator, so that the pressure can be automatically controlled at around 75mm WG, but they do not work effectively. The operation of such a regulator is given in Fig. 8.3. The pressure of the outlet gas (p_2) is balanced by a weight (or spring) (M), acting over the area of the rubber diaphragm (A_d). When the pressure is too high ($p_2 > M/A_d$), the valve is closed. As gas is used, the valve opens ($p_2 < M/A_d$). In more accurate pressure regulators, the effect of the inlet pressure (p_1) acting over the valve area (A_v) is cancelled out with a second diaphragm (area A_v), placed so that the inlet pressure (p1) acts in the opposite direction.

Commercial regulators are available and can be purchased in India and elsewhere. Even they do not always work reliably on the relatively low flows and pressure differentials used in biogas technology. Problems also exist with corrosiion of the regulator parts with biogas.

Engines are being run using biogas from dome plants without the use of such complex equipment. The excess pressure can be dropped across a suitably sized orifice, which can be a parially closed valve. the pressure drop (Δp) is of the order of :

$$\Delta p \simeq \rho u_o^2/2g \quad \text{or}$$

$$\Delta p \simeq 15.57\ Q'^2 / A_o^2 \quad \text{mm WG}$$

ρ is the density of biogas, g is the acceleration due to gravity.
Q' is the instantaneous biogas flow rate (litres/min).
Q' = 4 x Q, the average flow rate, as the biogas is drawn into the cylinder for only 1/4 of the 4-stroke cycle.
A_o is the orifice area (mm^2).

If the gas valve is adjusted as suggested above, ie. until the engine just runs smoothly, then the pressure drop across it should be correct. The valve will need to be adjusted every 15 minutes or so, as the pressure from the dome or tunnel plant will drop as the biogas is used. A graph of the pressure drop across the ball valve shown in Fig. 6.11 against the angle of closing (O) is shown in Fig. 8.4 for different gas flows.

The above expression gives a value for the pressure drop in any pipe fitting, when multipled by a suitable factor: K, i.e.:

$$\Delta p = K.\ 15.57\ Q^2 / A_p^2 \quad \text{mm WG}$$

where A_p is the internal area of the fitting (mm^2)= $d_p^2/4$

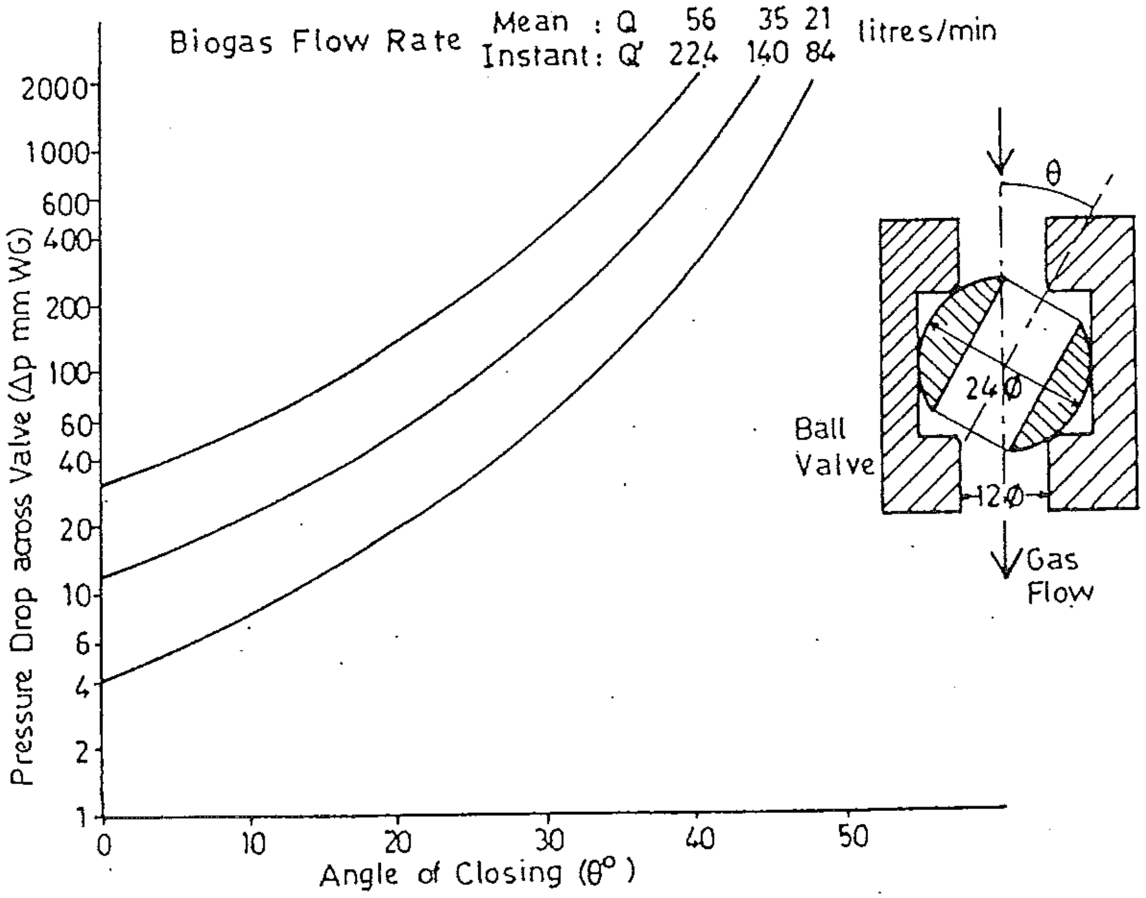


Fig. 8.4 Pressure Drop Across a Ball Valve, Partly Closed

Table 8.1 Values for Pressure Loss Coefficient (K) for Fittings (Pritchard, 1977, Perry, 1973).

Fitting	Pressure Loss Coefficient	
	Re > 2,000	Re < 2,000
Elbow (90°)	0.75	0.9
Tee (Branch Line)	1.0	1.5
Tee (Straight Line)	0.4	0.5
Socket	0.04	0.05
Reducing Socket	0.5	-
Sudden Expansion	$(1 - d_1/d_2)^2$	-
Meter		-

Values for K for different fittings are given in Table 8.1. They depend on the Reynold's Number Re (see Chapter 6). The values of K for differenct fittings should be added together to give a value of K for the whole pipeline. The values of pressure loss for the ball valve (Fig. 8.4, above) were calculated assuming the valve is a sudden reduction in diameter (K = 0.5) followed by an expansion (K = $(1 - A_o/A_p)^2$ - Borda-Carnot formulat - Perry, 1973).

8.4 Carburettors for Mixing Biogas and Air

If a diesel engine is to be adapted to a dual-fuel engine, the main alteration is the addition of a carburettor to mix the biogas and air in the correct proportions. For a static engine that runs at a fixed speed, the gas/air mixture is roughly constant (1:5 approx.), so a simple design of carburettor can be used. For mobile engines, or static ones that must be run at varying speeds, the gas/air mixture must be adjusted to suit the engine speed, so the carburettor must be more complicated (Hollingdale, 1979).

Two types of carburettor have been used in Nepal: one is a simple mixing chamber device, the other uses a ventury. The mixing chamber design (Fig. 8.5) uses the pressure drop across a paper air filter to create enough suction to draw biogas through the gas valve druing the intake stroke of the engine. The areas of the gas inlet pipe (16 Φ), the air inlet orifice (36 Φ) and the mixture pipe (39 Φ) help to control the gas/air mixture. The gas supply is regulated by the gas valve.

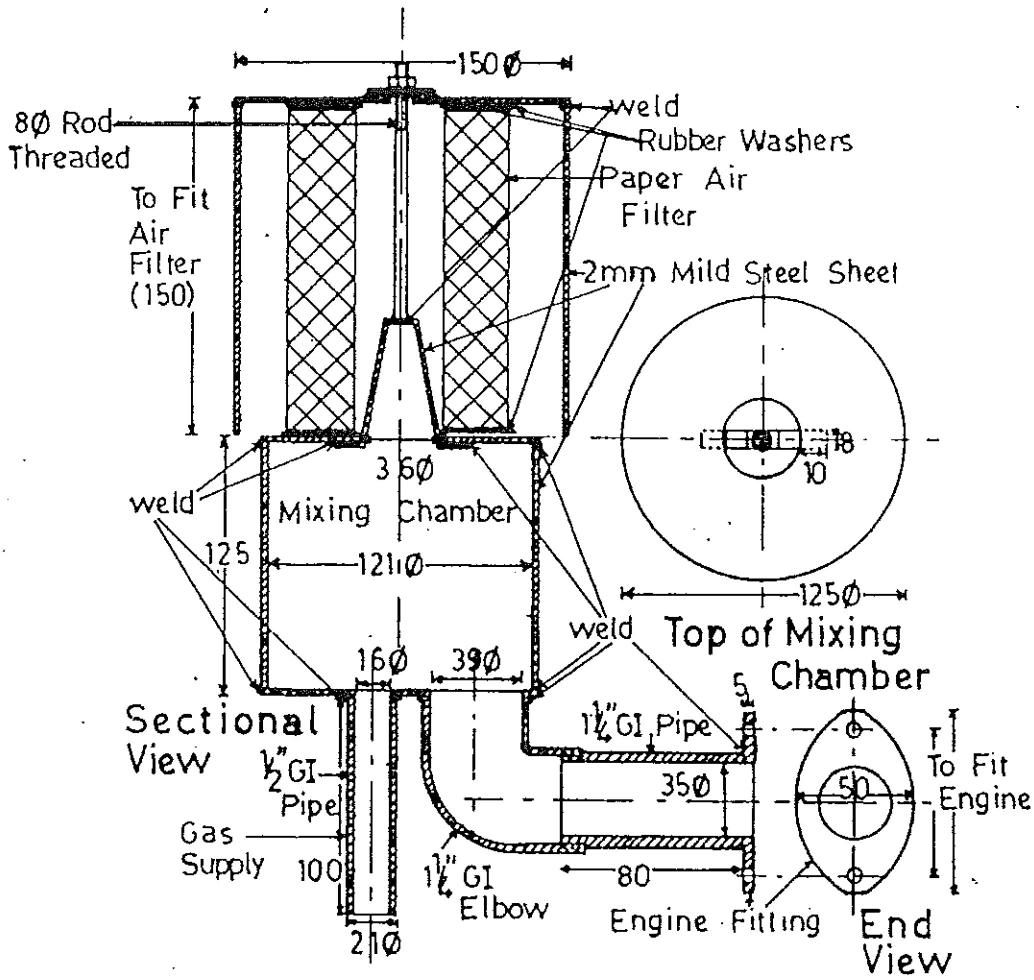


Fig. 8.5 Mixing Chamber Type of Carburettor

The mixing chamber has been used with several types of Indian made diesel engines (3 to 7 HP; 2.2 to 5.2 kW) and it seems to work well. Further improvements may be made : for example, the engine performance could be improved by making the air orifice adjustable (Lichtmann, 1983). This type of carburettor did not work with a Japanese made engine that has a higher compression ratio (23:1 instead of 17:1) and ran at slightly higher revolutions (2,000 rpm instead of 1,500 rpm at 5 HP, 3.7 kW) than the Indian models. This engine could not be used with a paper air filter, and the pressure drop across the oil-soaked wire mesh filter was too low.

A ventury type of carburettor was designed for use with this engine (Fig. 8.6). It fits between the air intake pipe and the air manifold in the cylinder head. As the incoming air is drawn through the ventury, the change in pipe cross-section causes a reduction in pressure, which draws in biogas through the holes. The uses of several holes in the ventury should allow for good mixing. Tests with the 5 HP Japanese engine give biogas to diesel ratios of 4:1 (ie. a 75% saving on diesel). Further tests and adjustments may improve these figures.

There are many other designs of carburettor used by different groups involved in biogas technology (ESCAP 1980, Picken) and further research may offer better designs.

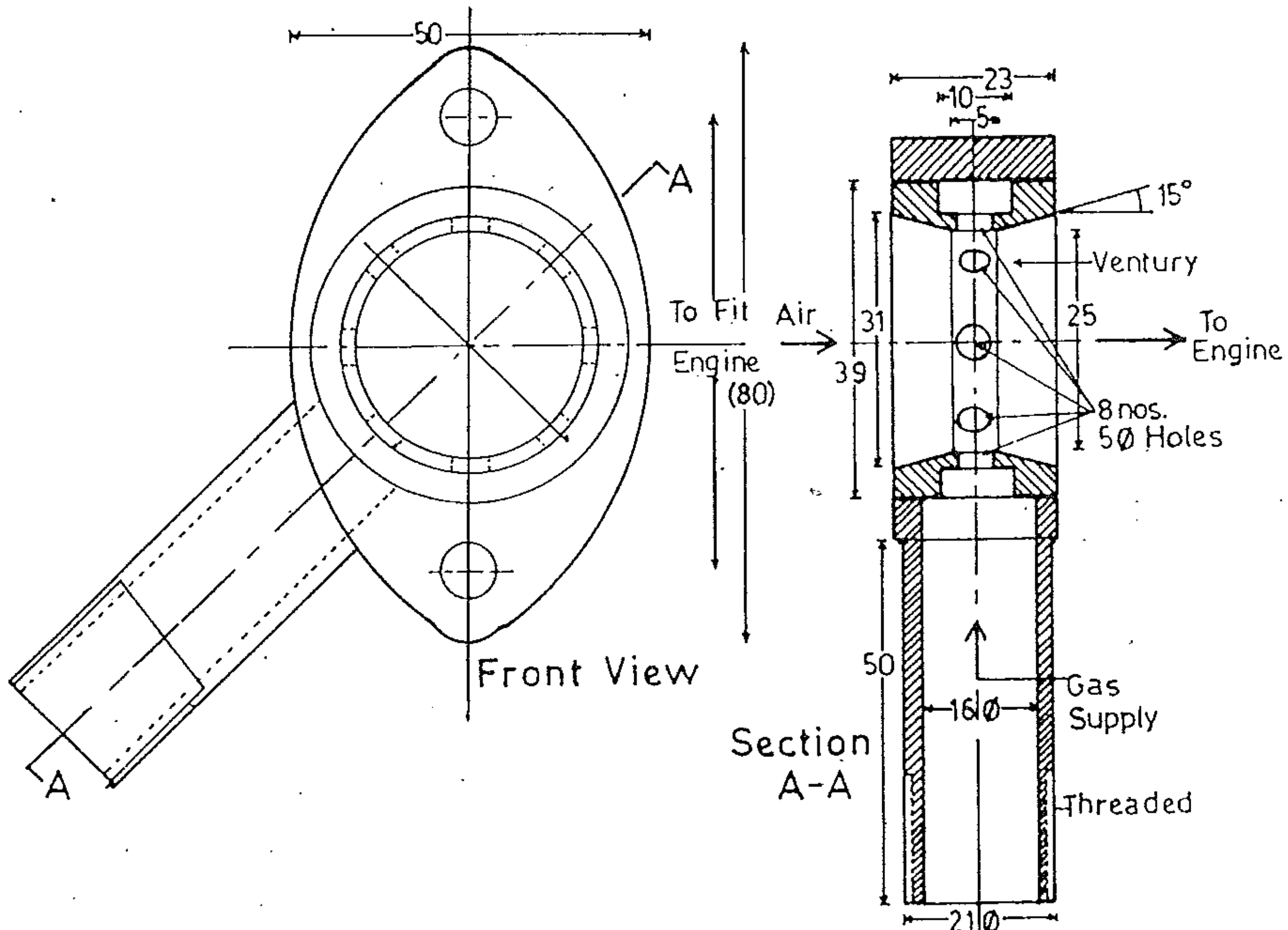


Fig. 8.6 <u>Ventury Type of Carburettor</u>

8.5 Use of Biogas for Milling

Most mill engines in Nepal are slow running diesel or kerosene engines, although electric motors are taking over, where electricity is available. Biogas dual-fuel engines tend to be faster running and smaller and are used with smaller sizes of milling equipment.

The two machines used mainly in a mill in Nepal are a rice huller, that removes the hard hulls from the grains of rice, and a flour mill that grinds grains of wheat, maize and millet to flour. An oil expelling machine, that presses cooking oil from mustard, sesame and other oil seeds, is also often used. Each of these machines are available in different sizes from commercial sources in India. A typical small machine uses 7 or 8 HP dual-fuel engine.

Such an engine could be used for 3 to 4 hours a day with an SD500 biogas plant (depending on ambient temperature and whether slurry heating is employed). It could be run with diesel alone, but the running costs would be higher. The dung from 30 cattle would be required to feed such a plant. A larger biogas plant could also be used (an EP80 would run the system for 6 hours a day, an EP95, for 8 hours), but the capital cost and number of cattle required would be proportionally greater (45 and 60 cattle respectively).

The outputs from the 7 HP machines are : 150 kg of paddy per hour for the rice huller; 90kg of flour per hour from the flour mill; and 30kg of oil seed from the oil expellor. One such system has been installed near Butwal and has been running for over 2 ½ years. It uses a 7 HP dual-fuel engine, a rice huller, a flour mill and an SD500 biogas plant, without digester heating. Running water from an artesian well is used to cool the engine. The 4 joint owners are very happy with the system and are making enough profit to pay back the loans taken to pay for all the equipment (less a 50% subsidy for the biogas plant). Five or six similar systems have also been installed in Nepal and more are being ordered. Most are working well, although a few have some problems with cooling the engine.

When such a system is installed, the engine and milling equipment must be properly installed. They must be bolted to strong foundations that will not be damaged by the vibration of the machinery. Plants of wood between the engine and a concrete base help to absorb vibrations. A diesel engine should be started with no load on it, so the machines must be linked to the engine while it is running. Traditional mills use a flat-belt drive, with a split drive pulley. The belt can free-wheel on one half of the pulley, and is pushed onto the driven half to start the machine. Flat belts are inefficient and can be dangerous if they jump off a fast spinning pulley.

DCS uses 'V' belt drives, which are more efficient at transmitting power and do not jump off the pulleys. The engine and the machines are mounted so that the belt is loose and the belt can be tightened with a third pulley on a weighted lever (Fig. 8.7). An alternative approach is to mount the machines on a metal frame hinged to the floor. The whole machine can be lifted by a lever to loosen the belt, while the whole weight of the machine is used to keep the belt tight (Fig. 8.7).

The details of the operation and maintenance of milling equipment is given in the manufacturer's manuals and these should be carefully read before any machine is installed. Training courses must be given to all villagers who are to operate these machines.

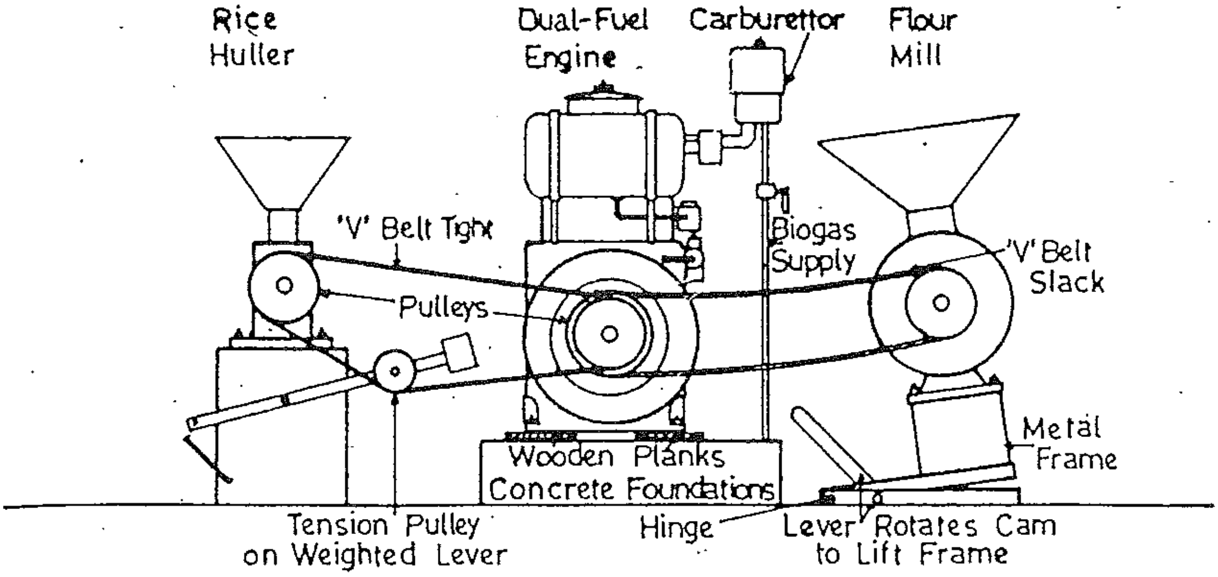


Fig. 8.7 Two Methods of Tensioning 'V' Belts

8.6 Use of Biogas for Water Pumping

If water is to be lifted from one level to another, higher one, a pump can be used. Mechanical pumps can be driven by a dual-fuel engine, using biogas as a fuel, but the pump and the engine must be matched together and to the situation in which they are used. Usually a matched "pump-set", including both the engine and the pump, is supplied.

A supply of water is required that will meet the demand, whether it be for irrigation or drinking water. In a monsoon climate, as in Nepal, many water source dry up in the dry season, so would not be useful to irrigate a crop, for example, in this season. The water source may be a river or irrigation canal, a shallow dug well or a deeper tube well. The water must also be taken to where it is required, by an irrigation canal to the fields, an artificial canal (flume), by a pipe to a storage tank or to overhead or underground sprinker systems.

If water is taken from a river or canal, a suitable site must be made for the pump. The bank may need to be reinforced with concrete or by gabions (wire cages filled with rocks), to prevent erosion. If no river or canal is available, a well may need to be dug. Advice should be sought from local people and water supply experts as to where under-ground water is likely to be, and to how deep the local water table is. Other nearby wells can be studied. Local well diggers can be approached to dig the well. If local expertise is not available, then a suitable book must be consulted (Minto 1975, Stern 1979). If the water table is more than 10 to 20 metres deep, a tube well can be drilled. This requires special expertise and machinery, but there are many water drilling projects in Nepal and other developing countries, that can be approached for help.

Once a suitable source of water is found, the "pumping head" can be measured, which is the difference in height between the surface of the source water and the point to which the water is pumped. If water is pumped from dug wells or tube wells, there may be "draw-down", ie. if the water is pumped out of the well faster than it enters, the water level will drop until the two are equal. The pumping head is in two parts : the "suction head", between the supply water level and the pump, and the "delivery head", betwen the pump and the outlet. The total head is the sum of the two. The suction head may be negative, ie. the pump may be below the surface of the supply water, so the height difference must be subtracted from the delivery head. The suction head cannot be more than about 7 metres as "suction" relies on atmospheric pressure (10.33 metres of water) to drive the water up the pipe.

The relationship between pumping head (H, metres), water flow rate (Q, litres/sec) and power requirement (P, kW or HP) is given by :

$$P = \frac{H\,Q\,\rho\,g}{\eta\;1{,}000}\ \text{kW} \quad \text{or} \quad P = \frac{H\,Q\,\rho\,g}{\eta\;746}\ \text{HP}$$ (Morris).

ρ is the density of water (1,000 kg/lit),
g is the acceleration due to gravity (= 9.81 m/sec^2),
η is the efficiency of the pump.

There are several types of pump that can be driven by a dual-fuel engine. The most common is a centrifugal pump, which has a vaned impeller that rotates rapidly. The water enters the centre of the impeller and is thrown outwards by centrifugal force, which gives it pressure and drives it through the outlet. Centrifugal pumps are usually driven directly by the engine flywheel, through a flexible coupling. They are designed for a particular head and flow rate, and if used close to the design point, can be up to 90% efficient. If a centrifugal pump is used in a situation for which it is not designed, the efficiency can be as low as 30% or less. The manufacturer's catalogues must be consulted for these details. A typical set of design curves for a particular centrifugal pump (Kirloskar) are given in Fig. 8.8).

Tube well pumps are either axial flow impellers (like a propeller in a pipe) or positive displacement pumps (a piston in a cylinder). The drive from the engine has to be transmitted to the pump, which is down the pipe immersed in the water, so the overall efficiency of the system is reduced. An average efficiency can be taken as 60% (Stern, 1979), but the actual value for any pump in a given situation must be obtained from the manufacturer's literature.

Other types of water pump, that can be run on biogas but do not use a separate internal combustion engine, are being developed. They include the Humphrey pump (Dunn 1978), which is an internal combustion gas engine that uses a water column as a piston, steam pumps (Pickett) and also steam engines driving conventional pumps.

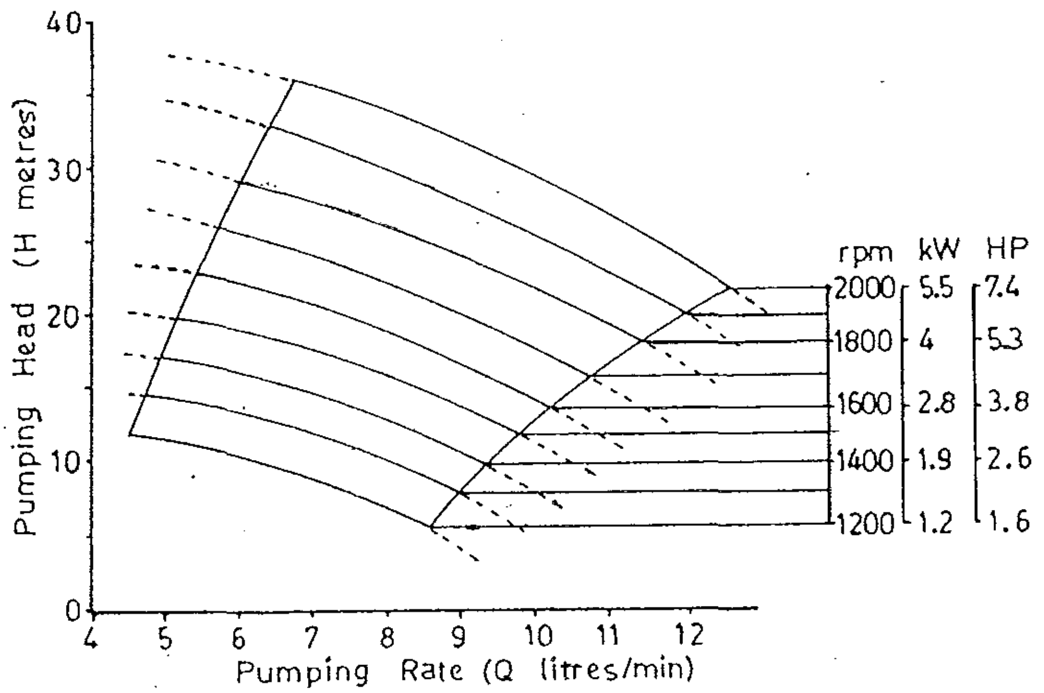


Fig. 8.8 A Set of Design Curves for a Typical Centrifugal Pump (Kirloskar)

The size of a dual-fuel engine and its daily use is usually limited by the amount of biogas available. A 5 HP engine can be used with an SD500 biogas plant for about 6 hours a day, if the ambient temperature is high (giving a total of 23 kW.hrs a day). Given the pumping head and an estimate of the pump efficiency, the above formula will give the amount of water available each day (W m^3/day):

$W = Q \times 3.6 \times n$, where n is the number of hours/day that the pump is used.

The availability of water determines the area of land that can be irrigated (I, hectares). The amount of water required by a hectare (10,000 sq.m) of land (w, mm depth per month) is affected by the porosity of the soil (how fast the water drains away), the humidity (how fast the water evaporates), the crop (rice demands more water than maize), the farming techniques (a mulch can reduce evaporation) and many other factors (Israelson 1962). If a value for water requirement (w) can be found, then the irrigated area of land (I) can be calculated:

$$I = \frac{W \times 30}{w \times 10} = \frac{3W}{w} \text{ ha, assuming 30 days in a month.}$$

For the Terai of Nepal, an average value for w is 160 mm/mth, but local agricultural experts should be consulted to obtain the relevant figure for a particular location and crop.

One biogas irrigation system has been operating in Nepal, in Parwanipur near Birgunj, for over 5 years and has proved very successful. It pumps water from a small all-year canal to an irrigation flume that takes it to the fields; up a head of 3.3m (Fig. 8.9). The biogas plant is an SD500 and is supplied with dung from a herd of 30 buffalo. The effluent from the plant is mixed with the irrigation water in the flume. The pump should supply about 700 cu.m. of water per day, to a land area of 34 ha. This is insufficient (34 ha needs at least 1,500 cu.m a day), so the biogas system is supplemented by an electric pump. The owner prefers to use the biogas system as far as possible, as it is much cheaper to run and the supply of biogas is much more reliable than the local supply of electricity.

In this case, the cattle sheds, biogas plant, pump, canal and irrigation flume have been arranged to be close together. In other places one or more components of the system may be some distance from the rest. Cattle dung may need to be carried some distance; gas may need to be piped along a long pipe (see Ch. 6); a canal may need to be made to carry the water. The layout and siting of each component of the system must be carefully planned before it is built.

8.7 Use of Biogas for Electricity Generation

Biogas engines can be used to drive generators for electricity, and several systems have been set up in Nepal. If a dual-fuel engine is being used for another purpose, a small (0.5 to 1 kW) generator can be run at the same time, to provide lighting. Electric light is far more efficient than gas light: 700 litres of biogas could generate 1 kW.hr of electricity to run sixteen 60 W light bulbs; the same gas could only run 5 biogas lights for an hour.

Apart from lighting, it is usually more efficient to use energy directly, rather than generating electricity and using that. Biogas can be burnt to give heat, or used in a dual-fuel engine to give mechanical power.

8.8 Biogas Used in Cottage Industries

As biogas gives good heat with suitable stoves, it can be used in cottage industries that require heat. Several such industries have been considered for Nepal: making cheese from milk, making soap from vegetable oils and caustic soda, extracting medicinal oils (eg menthol), by boiling, making jam and other preserves for bottling and roasting coffee beans are a few. Only one such system has been built: a cheese plant in Pauwa (Meier 1978) by the Swiss Association for Technical Assistance to Nepal (SATA 1977).

The amount of heat required for a process must be calculated, when deciding whether it can be run on biogas. Taking the cheese plant as an example: each 100 litres of milk requires 5,500 kCal to sterilise it (heating from 20°C to 75°C) and a further 2,200 kCal to warm the culture of milk and rennet (at 42°C). Boiling water is also required to clean the equipment (say 50 litres, needing 4,000 kCal). Taking an overall efficiency of 50%, about 25,000 kCal are required each day, or about 5 m^3 of biogas. It works out that the amount of dung produced by a herd of cattle is enough to process the amount of milk produced by the same cattle to cheese using biogas as a fuel.

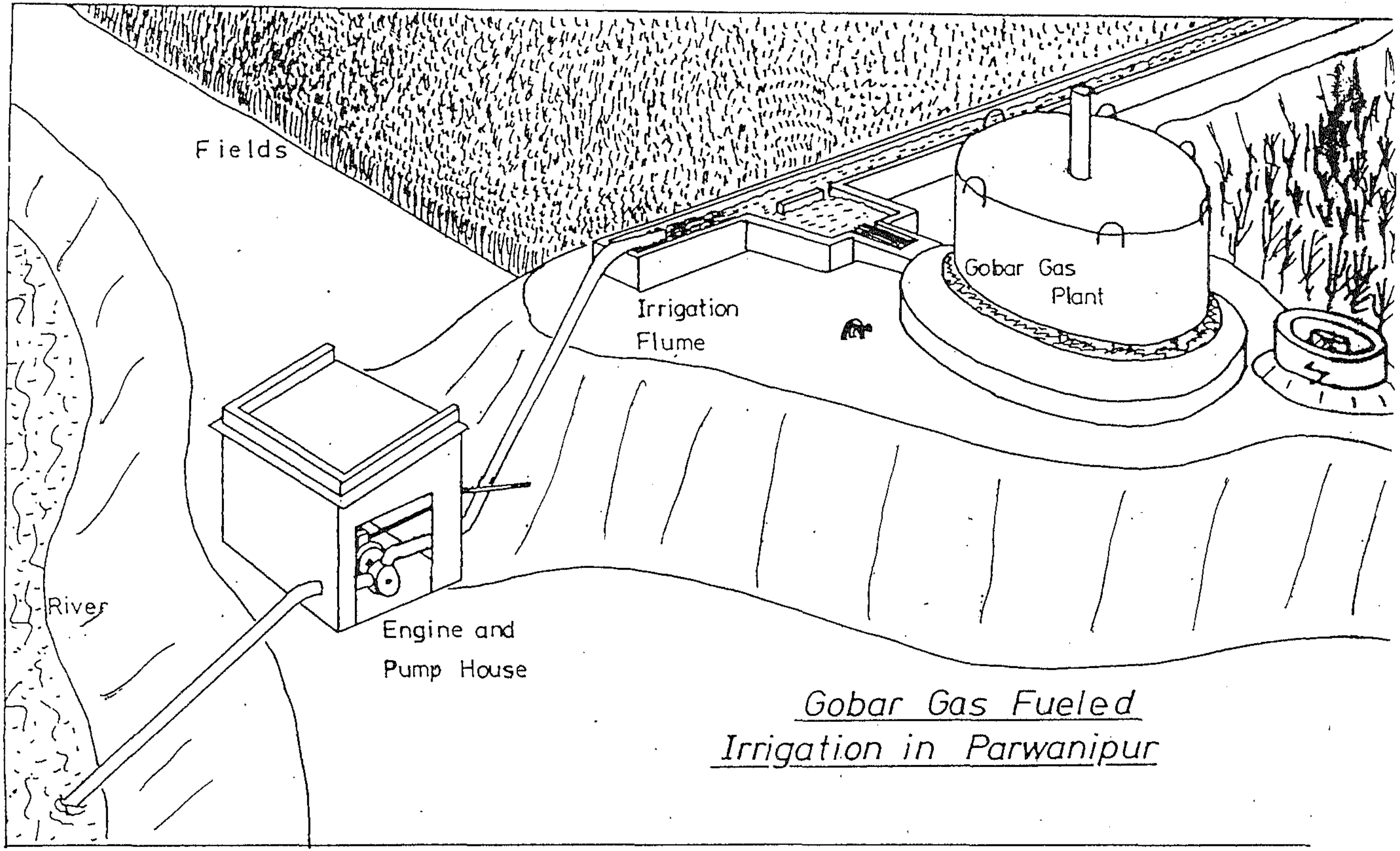


Figure 8.9 Biogas Irrigation Scheme

Unfortunately, the Pauwa cheese plant has not been very successful, so the technology has not been adopted elsewhere. In Nepal, the Dairy Development Corporation builds cheese plants of a size to process 1,000 litres of milk a day. If such a plant were run on biogas, the dung of 150 cattle would be required. While farmers are prepared to carry a few litres of milk to a central plant each day (often half-an-hours' walk each way), they will not carry dung. The Pauwa plant was designed to run on dung from a central piggery, from animals fed on the whey from the cheese plant. Ill-health among the pigs has been a recurring problem, resulting in poor biogas production. Pauwa is sited at 1,800 metres above sea-level, so solar heaters were used to keep the biogas plants at a suitable temperature and to preheat water before it was heated in a boiler by biogas. This approach proved very expensive.

If biogas is to be used in this type of cottage industry, the scale of the process must be reduced, to suit the supply of biogas. Several small-scale units (e.g. cheese plants processing 100 or 200 litres of milk a day), each sited near the cattle sheds of one village, are to be preferred to one central unit, as dung is difficult to transport. A central office can offer quality control, marketing and maintenance facilities. This approach, of using a Service Centre to help village-based industries or workshops, has been successful in other contexts (Garg).

If biogas production is likely to be inadequate for an industrial process, consideration should be given to the use of higher efficiency heating systems. An open gas burner loses much of its heat (40 tof 50%) to the open air. This heat could be trapped and used, if the whole unit (burner and vessel being heated) was placed in an insulated enclosure (Fulford 1978). Suitable vents (of at least 150 sq.mm area per litre/min of biogas used) should be provided for the burnt gases, but they should be arranged so that the gases give up most of their heat before they escape (Fig. 8.10).

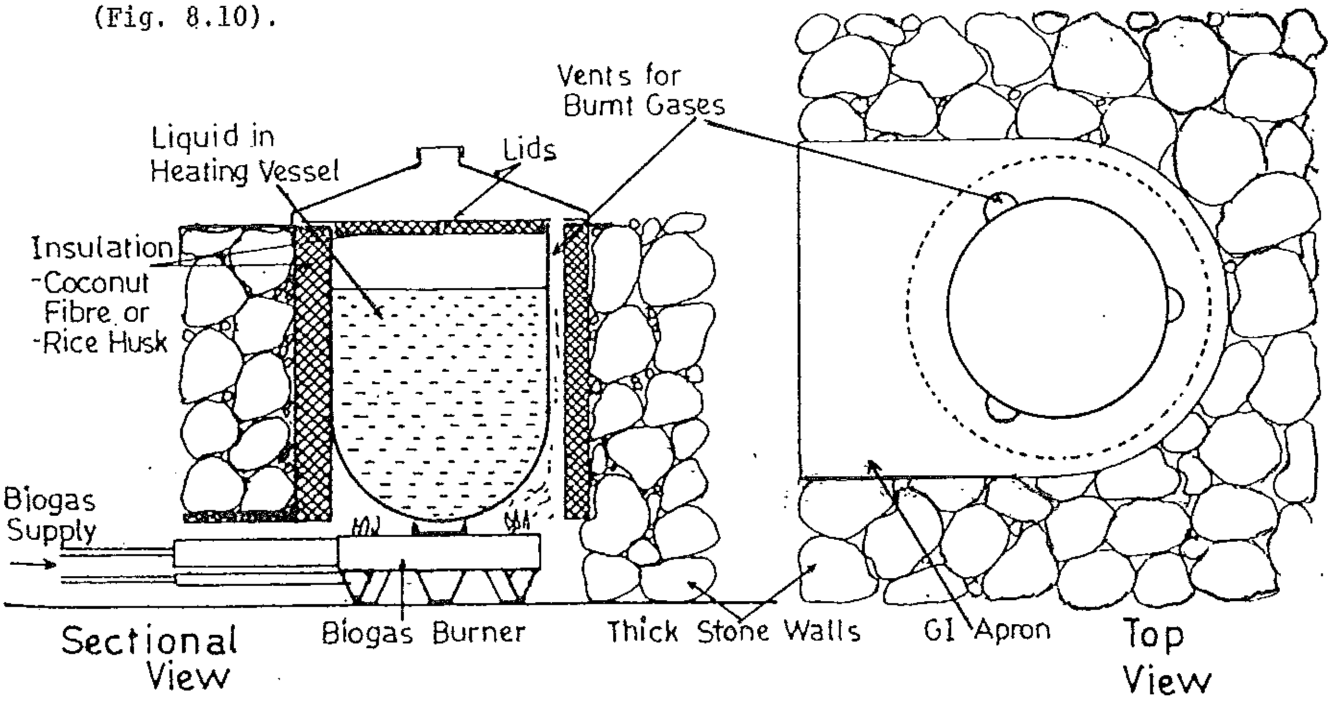


Fig. 8.10 Suggested Design for a Heat Saving Boiler

Chapter 9 STARTING, OPERATING, SERVICING AND SAFETY J. Finlay

This chapter starts from the point where the gas plant has been built, all pipe work completed and the appliances fitted. First the digester needs to be filled with feedstock mixed with water to make a slurry.

In Nepal most biogas plants (99%) use cattle dung from cows, bullocks oxen and water buffalo exclusively as the feedstock. Other animal dung and vegetable matter finely chopped up could also be used, (refer chapter 1 and 10) but because DCS's experience is mainly with cattle dung this chapter will only refer to it as the feedstock material.

9.1 Slurry Consistency

Slurry is made by mixing the dung with water to make it fluid. Most people use a dung to water mixture of 1:1 and it works well. However, DCS research, as recorded in Vol II Ch.3 shows that a mixture ratio of 2:1 can be used with no significant benefit in that for the same daily gas production the digester volume can be reduced by 25% and 50% less water is required, a big advantage in water short areas.

Cattle dung, when excreted has about 18 to 20% dry matter content, the remaining being moisture. This figure can be altered quite quickly due to sun drying or rain absorbtion. DCS used to use a hydrometer for measuring the moisture content of slurry. When the slurry was thin (1:1 ratio) it was difficult to get an accurate reading due to the viscosity of the slurry. With thicker slurries (2:1 ratio) it was more or less impossible to get a reading. The only reliable way to measure the dry matter content (called Total Solids : TS) is to take a sample of the slurry, weigh it, dry it in an oven at 100°C for 24 hours and weigh the residue.

$$\text{Total solids} = \frac{\text{weight of dried sample}}{\text{weight of original sample}} \times 100\%$$

Under village conditions of making the slurry it has been found that a 1:1 ratio gives a TS concentration of 7% to 9% (hydrometer reading 1.045 to 1.190). A 2:1 ratio gives a TS concentration of 12% to 13%.

DCS research (Vol. II Ch. 3) has shown that TS between 6 and 14.5% has negligible effect on gas production in steel drum, concrete dome or tunnel plants. Too thin a slurry, i.e. less than 6% in unsatisfactory because the slurry will seperate out into three layers inside the digester - leaving solids at the bottom, water in the middle and floating vegetable matter on the top. If too thick a slurry is used, i.e. over 14.5% it will not flow easily and the gas bubbles cannot pass through the slurry easily. In both cases the gas production is noticeably reduced.

9.2 Slurry Mixing

Mixing of the slurry for small plants is locally often done by hand, but it can also be done by feet or by a slurry mixing tool (Fig.

5.2). For large plants a mixing machine (Fig. 5.3) is commonly used. Whatever method is used it is essential to mix the dung water thoroughly until there are no lumps. If there are lumps then gas production will be reduced because the gas producing bacteria do not have free access to the food in the lumps.

When mixing the slurry care should be taken to avoid the following things being included and getting into the digester.

- Earth or sand, etc. (picked up with the dung). It will fill up the bottom of the digester in time and reduce the effective digester volume.

- Straw or grass etc. Any that is in the slurry while it is being mixed can be removed by using one's fingers or a sieve. If it is not removed it will float to the suface of the digester, especially if the T.S. is less than 10%. Thick scum in a digester causes reduced gas production and where a gas drum is used, it restricts the drum's free movement.

- Sawdust or peat moss etc. These are impossible to remove once mixed with the slurry and can cause very serious clogging and scum problems.

- Oil, soap, detergent. Water mixed with these things should not be used for making the slurry as they can kill the bacteria and stop gas production.

9.3 Starter Bacteria

The bacteria which make methane gas exists 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 but the process can be speeded up by adding some urine (max 3%) or pig dung (max. 10%) and mix it with the slurry.

9.4 Filling the Digester

Digesters should be filled quickly to avoid unnecessary air getting at the slurry as the methane bacteria die in the presence of air. Dung can be collected for sometime prior to filling the plant. It must not be allowed to dry and become hard during this time because once dried it is impossible to mix into a slurry.

Slurry is mixed, as described above, in the inlet pit and allowed to flow into the digester. While filling a digester with a centre dividing wall, care must be taken to fill both compartments equally, otherwise the centre dividing wall will collapse of uneven pressure. Therefore drums are not fitted until the plants are filled in order to be able to see the slurry levels in both compartments.

In cement dome and tunnel plants the main gas valve and a tap are left open to let the air escape until the plant is filled with slurry. For satefy reasons it is recommended that the gas tap opened is one at a condensate trap.

Slurry is fed into the digester until it reaches :

Steel Drum plants	-	outlet level
Concrete dome plants	-	half way up the slurry reservior
Tunnel plants	-	level of bottom of the main floor of the slurry reservoir.

If there is any water lying at the bottom of the digester before it is filled with slurry, this will not matter. The slurry should be made as thick as possible while still of a flowing consistency (it must be free of all lumps). This will mix with the water in the digester and once it is of the correct consistency the remaining slurry can be made to the normal consistancy.

When the digester 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 water trying to get in. The slurry wil not leak out through any small cracks in good brickwork because the fibres in the cattle dung wil block them up.

9.5 Starting the Plant

Where a water removal device with dipper pipe is used about 1/4 litre of water should be poured down the dipper pipe to form the gas seal. The special dipper for the new gas outlet for the tunnel plant requires about one litre.

While a steel drum plant digester is being filled the drum should be given a final coat of paint and damaged paintwork should be especially well covered to prevent rust starting. After filling the digester the steel drum is placed in position over the central guide. The main gas valve and burner taps are onto the deflecting ledge. Then all taps and valves are closed.

Similarly once cement dome and tunnel plants are filled all the gas taps and valves are closed. Patience is needed for the gas storage volume to fill with gas. Depending on temperature, it can take 5 to 20 days.

When a steel drum is full of gas, surplus gas will bubble out from under the edge of the drum. With cement dome and tunnel plants the gas is allowed to form until the slurry comes out of outlet or gas starts to escape by bubbling out from the gas storage space throught the reservoir.

The first gas produced usually has a high percentage of carbon dioxide CO_2 in it and often it will not burn. It can also have air mixed in with if the procedure given above is not followed properly and so there could be a danger of an explosion. Therefore it is recommended that all the first gas is allowed to escape in the same manner as described above for letting the air escape. There should be no naked flame and no smoking while the gas is escaping. The second lot of gas will, in almost every case, burn well. Occasionally there is still too much CO_2 and only the third lot of gas will burn.

It should be noted that once a biogas plant is full, no further slurry should be added until the gas storage volume has been filled three times with burnable gas, or after 15 days, whichever is longer. Good burnable biogas indicates that the bacteria populations have stablized. This procedure is essential. Failure to follow it is a common cause of low or no gas production or gas which does not burn (too much CO_2) when starting a plant.

All pipework needs to be flushed with gas by opening the taps in turn until there is a definite smell of gas and then closing them again. Burners and lamps are operated and adjusted as given in Ch.7.

9.6 Operating the Plant

The main task is to feed in the correct amount of fresh slurry daily and, when necessary, to remove condensate from the gas pipes using the condensate taps and water outlet devices. How to make the slurry is given above and suggested daily feed for the three types of plant is given in the respective chapters 2, 3 and 4. Sometimes the suggested figures cannot be used or need to be altered, e.g. when there is a shortage of dung. In these cases gas production can be calculated using the formulae given in Ch. 5.

The daily mixing of the correct amount of dung with correct amount of water to obtain the correct slurry consistance is important. The volume of slurry can be easily measured in the inlet pit.

$$\text{Volume} = \frac{\text{Length (cm) breadth (cm) x depth of slurry (cm)}}{1000}$$

Then the answer gives the volume in litres.

Methane bacteria do not like changes. If it is found that over a period of time, too much, too little, too thick of too thin a slurry has been used, then it should be corrected. If it is a big change it should be corrected in stages over a period of time. A major alteration in the feed made at one time can have an adverse effect of the bacteria and instead of an increase in gas production there can be a temporary reduction.

With tunnel plants using 2:1 dung water ratio it is recommended that each day the new slurry is seeded with bacteria by using one bucket of old slurry taken from the outlet of the plant. This speeds up the methane production process.

Care must be taken when considering putting in extra slurry in a plant. If the retention time is less than about 40 days and the temperature is low then there is a strong possibility that all gas production wil stop. The equations that can be used for working out the effect of addition slurry are given in Ch. 5.

Having taught a person how to make the slurry correctly it also is important to explain not to spoil the good work by washing out the inlet tank with an extra bucket of water and letting this run down the pipe into the digester.

It is generally considered beneficial to mix the slurry in the digester to release gas bubbles and break up any scum in the digester. In the steel drum plant this is easily done when the gas drum is low in the slurry (i.e. after using the gas) by rotating it back and forth for a few minutes once or twice a day. Most dome plants have a mixer fitted and this too can be used in a similar way after the gas has been used.

In the tunnel plant no mixer is provided but a thick slurry is normally used which means scum does not form readily. In both tunnel and dome plants there is some automatic mixing as the slurry moves in and out of the slurry reservoir as gas is alternatively stored and used. Occasionally in Nepal some pig dung is available and added to the cattle dung slurry, using this mixture gives more gas than cattle dung alone. The same is true of night soil and urine are added via an attached latrine. This is due to there being more nitrogen in these materials.

One other operation that needs to be done from time to time is the removal of dried slurry. During dry weather in particular, this tends to collect around the outlet of all types of plant and block it up. It needs to be removed as necessary. Built up dried slurry should also be removed from the sides of the mixing pit and with the floating steel drum plant from between the digester wall and drum.

9.7 Servicing of Plants

Servicing of assessories and appliances is given in Ch. 6 and 7.

Floating steel drum design

Annual painting :

Gas drums need to be painted annually particularly on the outer sides. There is no oxygen on the inside and rust rarely occurs. The lowest part of the sides, which is mostly submerged in slurry, is generally free of rust.

There is no need to remove the drum for painting. Any weights should be removed from the gas holder, the main gas valve closed and the drum allowed to fill till gas bubbles out from under the side. All dung must be throughly washed off using clean water and all rust scraped off using a steel scraper. Then the surface must be cleaned with emery paper or a wire brush. Before painting, the drum must be clean, free of dust and dry. Bare metal should be given a coat of primer (Anti-saline metallic primer). Once this paint is dry the whole drum should be painted with a top coat (high build black bitumen paint), the sides being particularly well covered as this is the part which suffers the worst from corrosion. The gas should not be used for 24 hours in order to let the paint dry.

Scum Removal :

A thick layer of scum can prevent the free movement of the drum and can be a cause or reduced gas production.

In a well run plant it may never be necessary to remove scum. However, at a carelessly operated plant, where straw, grass, sawdust, etc., are mixed in with the slurry and especially one using thin slurry, it could be necessary after six months.

First of all it is necessary to remove the drum. The main gas valve is closed and the drum allowed to come up to its maximum height. There must be no smoking or naked light. The drum is lifted off over the central guide using the handles provided, and set down at the side of the digester. The scum can now be removed from the top of the digester. While the drum is off, the inside should be cleaned and the condition of the paint work checked. It does not usually need attention but if there are any signs of rust it should be repainted before replacing the drum it is very important to let all the air escape as described earlier in this chapter under "starting a plant".

Repair :

If drums are not painted regularly, then rust, particularly on the sides, will quickly become a serious problem. If one or two small holes are found they can be repaired using an epoxy resin such as "Araldite". If the drum has a few holes it is most likely that soon many more will appear. Neither welding on of patches or cutting out defective pieces and replacing them has been found satisfactory. Rust continues under the patch where it cannot be painted and in the badly rusted old steel, even under new paint. The only thing to do is to replace the whole drum.

Dome Plants:

One or two domes have cracked and leaked gas due to poor quality cement being used. The whole plant must be emptied (the contents can be stored in a pit for reuse after repairs), cleaned out and repaired. The repairs depend on the seriousness of the crack. It could involve more plastering, or removal of old plaster and replastering. So far it has never been necessary to replace a dome.

Scum breakers have broken off on a number of occasions but they have not been repaired. As farmers do not complain of gas production after the breakage it is questionable if they are really needed. If scum were a problem it would be necessary to remove the slurry in order to get at the scum to remove it.

Tunnel plants:

A limited number of these plants have been built. So far the plastic lining has never had to be serviced and scum has never been a problem. An advantage with this plant has been the thicker slurry used which prevents scum forming so readily. If the plastic lining had to be repaired or scum removed it would be necessary to remove the slurry from the plant first of all.

9.8 Operational problems and remedies

Starting Problems

Problem	Possible Cause	Remedy
Gas drum does not rise (floating steel drum plant). or Pressure does not rise (cement dome and tunnel plants).	Lack of time	In cold weather (20°C) it can take 3 week to start a plant. Have patience!
	Feeding in slurry while waiting for first gas to collect.	This is a common fault. No slurry should be fed until the third time the gas storage has been filled with burnable gas. This allows the right kind of bacteria to develop and the pH to correct itself.
	Very few bacteria.	At least 20 litres of slurry from a working plant should be put down the inlet followed by one lot of new slurry to push the bacteria fully into the digester.
	Burner, light or condensate tap open.	Close it.
	No water in dipper pipe (condensate trap)	About 1/4 litre water should be poured into the dipper pipe (1 litre for special tunnel plant gas outlet). Any excess can be removed using the dipper bucket.
	Leak in gas taps, piping or gas storage.	Locate and repair.
First gas produced will not burn.	Wrong kind of gas.	The first gas should not be burned. It may have air mixed with it and could explode. Frequently the first gas has a high percentage of CO_2 and so does not burn. Usually the second lot burns. (Also refer "Feeding in slurry...." above).
	Air in the gas pipe.	Allow it to escape until there is a definite smell of gas.
	Wrong bacteria (Foul smell).	Add lime till pH is 7. Do not add fresh slurry until burnable gas is being produced.

General Problems

Problem	Possible Cause	Remedy
Gas drum (or pressure in dome and tunnel plants) goes down quickly once main gas valve is opened.	Burner, light or condensate tap open.	Close it, or them.
	No water in dipper pipe (condensate trap).	Add water as given above.
	Major leak in pipework.	Locate and repair.
Gas drum (or pressure in dome and tunnel plants), rises very slowly.	Temperature too low.	Gas production is always reduced in cold weather. Ideas to increase gas production are given in chapter 10 Remove scum. No straw, grass, sawdust etc., should be put into gas plants.
	Thick scum on top of slurry.	
	Daily slurry wrong. Too thick or thin or too much or little.	Correct amount and consistancy should be added daily. Gas production should correct itself in a few weeks.
	Washing out mixing pit with extra water and allowing this or rain water enter the digester.	Do not let extra water enter the digester.
	Slurry mixture suddenly changed a lot.	Slurry mixture should not be altered too much at one time.
	Putting chemicals, oil, soap or detergent into slurry.	Feed daily with dung and water only. After 2 to 6 weeks it should correct itself.
	Gas leak.	Locate and repair.

General Problems (Cont'd.)

Problem	Possible Cause	Remedy
Gas will not burn.	Wrong kind of gas (probably too much CO_2) due to putting in too much slurry or too much urine per day.	Let gas escape. Correct the amount of slurry and urine fed in daily. It may take some weeks for the gas plant to correct itself.
	Air in gas pipe.	Allow it to escape until there is a definite smell of gas.
Slurry does not flow into digester.	Sieve in inlet pipe (if fitted) clogged.	Remove, clean and refit.
	Inlet pipe blocked.	Clear blockage by pushing pole down inlet pipe.
	Slurry too thick.	Correct consistancy.
Digester pit overflows (Drum plant)	Outlet pipe blocked.	Clear blockage by pushing pole down outlet pipe.
Slurry reservoir overflows (Dome and Tunnel plants).	Slurry outlet slot blocked.	Clear. Slurry often dries in the overflow slot and blocks it especially if it is not bell mouthed (Fig. 5.1).
Slurry does not come out of plant.	Outlet too high.	Lower the outlet level.
	Porous masonary used to build digester or serious cracks formed.	Empty plant, if walls cracked, repair them. If masonary porous then plaster (replaster) inside of digester.

General Problems (Cont'd.)

Problem	Possible Cause	Remedy
	Burners (Stoves)	
Burner flames are long and weak, start far from the flame ports, do not stay alight.	Incorrect primary air aupply.	Place cooking vessel on stove and adjust primary air supply with air adjuster.
	High pressure gas.	Partially close gas tap till flame is normal.
Flame pulsates.	Condensate (Water) lying in main gas pipe.	Remove water from water traps. If the problem continues, then water is lying in part of the pipe from which it can't drain. The pipe must be relaid at a slope of 1:100 and an extra trap fitted if necessary.
Flame small.	Gas jet in burner partially.	Clean jet with sliver of wood or bamboo. Do not damage or enlarge jet.
	Flame ports partially blocked. Water in gas pipe.	Clean out. Remove water from water traps.
	Low gas pressure: Drum: scum preventing free movement of drum. Drum too light.	Turn drum to break up scum and remove dried slurry between sides of digester and drum. If necessary remove drum and clear away scum. Add weights to gas drum.
	Dome or Tunnel: Gas outlet blocked with slurry.	Open end of gas outlet. Clean outlet with rod holding face to one side of pipe to prevent it getting splashed once pipe starts clearing itself under gas pressure! Refit, ensuring joints are gas tight.
	Gas pipe or valve blocked with slurry.	Dismantle pipe line near gas outlet and clean pipe and valve. Refit, ensuring joints are tights.

General Problems (Cont'd.)

Problem	Possible Cause	Remedy
No gas at burner.	Main gas valve closed. Burner tap blocked.	Open. Certain insects build nests with mud in open ended pipes or gas taps. Clean out with a sliver of wood.
	Condensate (water) blocking main gas pipe.	See "Flame pulsates" above.
	Gas outlet, or nearby pipework and valve blocked.	Clear blockage.
		See "Flame small - Dome or Tunnel" above.
	LAMPS	
Light is poor.	Gas adjuster requires adjustment.	Adjust until mantle glows brightly. Now mantles take time to burn, form the correct shape and to allow the flame to go inside the mantle. Only then will the mantle burn brightly.
	Low gas pressure.	See "Burners: Flame small: low gas pressure" above. Most lamps require a minimum of 75 mm W.G. to burn brightly.
	Obstruction in lamp ventury.	This is a common problem. Clean out thoroughly with bit of cloth wrapped around pencil.
Mantle break frequently.	Wrong type or size of mantle. Gas pressure too high.	Use correct type and size to suit lamp. Adjust pressure with gas tap. Open gas tap slowly.
No gas at lamp.	Gas jet in lamp blocked.	Gas adjuster should be operated to clear the jet.

For other possible faults which are common with burners as well, refer to that section.

9.9 Safety

General :

Biogas when used as instructed, is safer than other gases commonly used in houses. It can only burn when there is 9 to 17% biogas mixed with air which are narrower limits than other gases. If all the air is removed from the gas plant and pipes before use, both at the time of installation and any repairs (as explained earlier in this chapter) the gas plant cannot explode because the pressure of gas is greater than atmospheric and therefore air cannot enter the system. For this reason flame traps are not used in gas pipes in Nepal.

Leaks in the house pipe work :

If gas is smelt in the house, it is certain here is a serious leak. Doors and windows should be opened to let the gas dissipate and fresh air come in. The main gas valve should be closed and there should be no maked flames, either lamps or fires, nor smoking until the smell of gas has gone. The first thing to check is that all gas taps for lamps and burners are closed. The main gas valve can be opened and attempts made to locate the leak by smelling where the gas is coming from. Soapy water can be put on suspected leaks, often at taps or joints, and if bubbles form then there is definitely a leak. The full proceedure for finding and repairing gas leaks is given in Ch.6.

9.10 Entering a Digester

Care must be taken if, for any reason, a person must enter a digester. Biogas is not poisonous, but it does not contain oxygen so anyone breathing it can suffocate. Biogas is slightly heavier than air and will lie at the bottom of a digester and only slowly mix with air and disapate.

All the slurry should be removed from a digester pit before anyone enters it, as it will continue producing biogas. To make sure there is no gas lying at the bottom of the pit, a small animal such as a frog, chicken or rabbit is lowered down and watched. If, after 5 or 10 minutes when the animal is brought out, it seems to behave normally it indicates that there is enough air in the digester and it is safe to enter. Should the animal faint or lose consciousness it indicates a lack of air and it is not safe to enter until the gas been disapated. This will take time but can be speeded by blowing in air, e.g. with a winnowing machine. Alternatively the gas can be lifted out in buckets and poured away so that it cannot re-enter the plant by flowing down the inlet or outlet. As the gas cannot be seen it is difficult to tell the effectiveness of this operation. If a worker feels dizzy while working inside the digester or finds it hard or uncomfortable to breathe he must leave <u>immediately</u> and rest in a place where there is good air circulation. There should always be a second person to pull out a worker should he faint in the digester.

Chapter 10 IMPROVEMENTS ON BIOGAS PLANT PERFORMANCE M.M. Lau-Wong

10.1. Identifying the Problem

The majority of instances of plant malfunctioning encountered in Nepal are caused by mechanical problems, such as leakage in valves and piping and crack in digester pits (Ch.9). Occasionally though, the microbial process itself can go awry, and guidelines are given in this chapter for troubleshooting and rectification.

Plant malfunctioning can affect gas production in two ways :

(1) Reduction in the quantity of gas output,and

(2) Decline in the quality of the gas ------- low methane content with a large proportion of incombustible or undesirable gas.

The symptoms and causes of common problems are summarised in Table 10.1. Most problems can actually be avoided if the plant operators are aquainted with the ABC of biogas production. For plants that function normally, gas production can be enhanced by manipulating substrate (feed) input or operating conditions as described in the following section.

10.2 Quantity of Feed Input

Interestingly, the causes of low gas production we frequently encounter are quite obvious and can easily be overcome. Farmers usually add considerably less amount of gobar (cattle or buffalo dung) than recommended and complain about insufficient gas. It is also common that they add more water for mixing than necessary. If water is excessive such that slurry solids fall below 4 to 5% by weight, stratification occurs as the denser solids separate from the liquid and settle to the bottom. Furthermore, extra water input can decrease the retention time of slurry in the digester to such an extent that the slurry is much unexhausted as it leaves the plant as effluent. Efficiency is thus reduced, and in severe cases when the dilution rate is too high, wash-out of the micro-organisms can occur (Ch. 14). In areas where water shortage is a problem, the recommended water to substrate ratio should be carefully observed so that wastage can be prevented.

10.3 Quality of Substrate

Carbon-nitrogen balance :

The quality of the substrate or feed determines the amount and nature of the gas produced. In the Indian subcontinent, gobar is a popular feedstock for biogas plant. Gobar, though plentiful, is

Table 10.1 : Diagnostic Chart for Process Malfunctioning

Cause	Symptoms	Diagnostic tool/treatment
Mechanical problems	Little or no gas	See Ch.9
Input quantity (water or substrate) insufficient or disproportioned	Gas reduced. If water in excess, stratification occurs	Daily input weighed or measured and adjusted to recommendation
Quality of input poor or nutrient overdose	Quantity of gas and/or methane content low	Check CN ratio. If ammonia or urea too high, adjust level
Microflora imbalance; usually too many acid-formers and too few methanogens	pH low or acidic (below 6.5). Gas reduced, foul or incombustible, being low in methane	pH easily detected with pH indicator paper. Lime or other alkali can be added to increase pH.
Biogas microflora not established	Long lag time at start-up, gas foul/ incombustible	Seeding of new plant with slurry from operating plant
Indigestibility of feed	Gas reduced. Little change in feed as seen in effluent	Check lignin content of feed. If straw is used, cut to small size and add required nitrogen
Gas trapped by scum formed by fibrous feed	Gas reduced. In drum plant, scum visible at surface	Before addition, fibres removed or reduced in size. If scum is severe, clean out plant
Toxicity from chemicals such as soap, pesticides, antibiotics, or high level of nutrients.	Little or no gas, microflora inactivated or exterminated	Feed and water checked for contamination. Digester slurry may have to be replaced entirely with fresh slurry.
Temperature of slurry unsuitable	Gas reduced. Over-flow of slurry in displacement plants infrequent	Temperature measured at outlet. Increase temperature by insulation and heating methods.

nevertheless the product of animal feed that has passed through the digestive tract once. In this process, the easily digestible nutrients are removed leaving the more recalcitrant materials like lignocellulose behind. Gobar is therefore deficient in nitrogen, especially if the animal feed is poor, and the methane content of the biogas produced rarely exceeds 55%. Furthermore, if gobar is left exposed for a long period, considerable amount of nitrogen can be lost in the form of ammonia, as much as up to 40% in a few days.

Other types of materials such as poultry, pig and vegetable waste, water hyacinth, algae, molasses, animal urine, and night soil have been investigated for their potential as substrate or supplement (Subramanian, 1977). Poultry waste, pig waste (Kwon and Kim, 1978), night soil, and water hyacinth, all having higher nitrogen content than gobar, showed promising results. However, adoption of high gas yielding materials is practically limited by their availability and people's attitute towards using them. Pigs are only raised by people of certain castes in Nepal and night soil is considered unclean.

Addition of vitamins and a rich nitrogen source such as yeast extract stimulates the growth of methanogens, but their high costs and unavailability in poor rural areas inhibit their use as supplements. Much emphasis, therefore, should be put in the search for local materials that are rich in nutrients, abundant in quantity, but are not yet gainfully utilised. Examples are animal urine (nitrogen rich) and straw (carbon rich). Combination of these materials is necessary to give the gas plant a 'balanced diet'.

In fermentation, bacteria require atoms of carbon and nitrogen in the ratio of 30 to 1 (or 26 to 1 by weight) for metabolism and assimilation. To determine a balanced diet, the proportions of each material in the substrate mixture can be calculated provided that the carbon and nitrogen contents of the individual materials are known (see Section 10.4). A resulting carbon-nitrogen or CN ratio between 20 and 30 by weight is acceptable. Table 10.2 gives the CN ratio, C%, and N% of some potential substrates for biogas plant.

Lignocellulosic residues are deficient in nitrogen but rich in carbon. However, most of the carbon cannot be readily utilised by being bound in the lignocellulosic complex. Under the anaerobic condition inside a biogas digester, lignin is not decomposed and its contribution of carbon should therefore be ignored. Total carbon can be determined by combustion and subsequent measurement of carbon dioxide, and total nitrogen can be measured by Kjeldhal method. The following example illustrates how the CN ratio can be calculated for a high lignin feed like cattle dung.

Calculation of the CN ratio of cattle dung

Lignin content	=	12% of DM (dry-matter)		
Carbon content	=	43% of DM		
Nitrogen content	=	1.2% of DM		
Unavailable carbon	=	carbon in lignin	=	5.2% (assuming 43% carbon in lignin)

Carbon available = 37.8%
and CN ration = 31.5

The CN ratio of 31.5 for this particular gobar sample is slightly outside the desirable range. Grain fed cattle tend to produce dung richer in nitrogen and consequently a lower CN ratio.

Table 10.2 : CN Value.Carbon and Nitrogen (% of Dry-weight) of Potential Biogas Plant Substrates

Material	CN ratio	%N	%C	% water	Comments
Gobar (Cattle/ buffalo dung)	20-30	3-4 1-2	35-40	72-85	Grain or grass fed, dung fresh. Straw fed
Horse dung	25	2	58	70-75)	Dung drier if old,
Sheep dung	20	3.75	75	68)	especially when
Pig dung	14	3-4	53	82)	air humidity is
Poultry dung	8	3.7	30-35	65)	low (House, 1978).
Human faces	6-10	4-6	40	75-80	
Human urine	80	15-18	13	95	
Water hyacinth	15-23	1.3-2.6	24-35	93-95	Air dried. Values vary with stages of growth and habitat. (Gopal and Sharma, 1981).
Rice straw	47.2	0.56	40	5-10	Calculated from data in VanSoest and Roberston, 1978.

10.4 Addition of Urine

Urine which has about 2% urea is a cheap and readily available source of nitrogen. In cow sheds cattle urine can be collected in cemented ditches and fed directly into gas plants. Human urine and night soil can also be utilised by the attachement of latrine. The number of users of the latrine should be controlled so that the input volume does not exceed the plant capacity and urea is maintained below its inhibitory level. Calculation for a plant fed with cattle dung and human urine is illustrated below. By varying the assumptions, the number of latrine users can be ostimated for different conditions.

Calculation of the number of latrine users for a gas plant fed with cattle dung and human urine

Assume daily input for a steel drum plant (14m^3 nominal daily gas production) to be 300kg cattle dung of 20% DM and urea not exceeding 1% of the dry matter of the mixture.

Contribution of carbon from urine being negligible,

Carbon available from mixture = 300kg x 20% x 37.8% = 22.7kg
(from Section 10.3, cattle dung has 37.8% available carbon)

Nitrogen from mixture = nitrogen from dung + nitrogen from urine
= 60kg x 1.2% + 60kg x 1% x 46.7% = 1kg
(Urea has 46.7 which is acceptable).
CN ratio = 22.7 which is acceptable.

Now urine comprises 2% urea (20g/l) or 0.93% nitrogen (9.3g/l).

If one person contributes 1 litre urine or 20g urea per day,
Number of latrine users = 0.6kg (urea from urine) 20g
= 30 persons

This is a conservative estimate, since the amount of urea tolerable is somewhat higher.

10.5 Pretreatment of Lignocellulosic Substrates

Lignocellulosic materials such as cereal straw and stalks decompose with difficulty, but their abundance at harvest time has prompted much effort to tap this reserve of energy and carbon. Pretreatment is often used to increase their digestibility. Supplemented with nitrogen they can serve as feedstock for animals or fermentation processes such as a biogas process. Pre-treatment methods include:

1) Physical or mechanical reduction of size -- grinding, chopping, and milling disrupt the crystallinity nature of cellulose fibres and expose more surface area to chemical and enzymic action. Usually this is the initial step followed by chemical or enzymic degradation.

2) Chemical degradation -- using alkalis, acids, or oxidising agents. Sodium hydroxide remains to be the most inexpensive and effective agent. For review, see Lau, 1979.

3) Steam and pressure -- inefficient unless accompanied by heat or chemical. One should be cautioned though: if pretreatment conditions are too severe, lignin is broken down to low molecular weight units which are inhibitory to the microflora (Han and Callihan,, 1974).

Pretreatment with chemicals, steam, or pressure incurs expenses and requires equipment and training of personnel. Moreover, the excess of acid or alkali used has to be neutralized before fermentation. These complications can only be justified for big commercial operations and community plants for which technical assistance is available. For small-size domestic plants, one should simply go as far as chopping or grinding the straw residue to a smaller size (no longer than 1 cm long) to prevent the accumulation of a gas-trapping scum on the slurry surface. Nitorgen should also be supplemented in the form of urea, urine, or other compounds, since the CN value of straw is high. A typical CN value of rice straw is 47, excluding the lignin fraction.

10.6 Composting Material as Substrate

Other methods of pretreatment of lignocellulosic residues include the use of microbes and enzymes. Under the anaerobic condition inside a biogas digester, decomposition of lignocellulose proceeds slowly while lignin is not degraded at all. Attempts were made to elucidate an anaerobic microflora that degrades lignin at mesophilic temperature but unsuccessful (Wohlt et al., 1978; Hackett et al., 1977).

Nonetheless, lignin is decomposed aerobically and residues can first be degraded to a limited extent outside the digester. Successful composting is marked by transformation of the fibres from a rigid to a flaccid texture as bonds are broken and carbon consumed; at this point, the material should be fed into the gas plant before further exhaustion.

Methods for building compost are numerous. It can be elaborate involving built-in channels for ventilation (McGarry and Stainforth, 1978), or it can simply be a pile of residues with manure sandwiched in between different layers. Composting material can be straw, grass, stalks, stovers, or vegetable matter. The compost pile should be kept moist by watering; a slight concave top prevents runoff of water. Decomposition can be accelerated by the addition of manure of effluent from biogas plant, and occasional turning or stirring of the heap for aeration as the process is mediated by aerobes like fungi. By packing the material loosely less than a metre high, decompostion is also achieved but takes a longer time. If the initial pH is not neutral, it should be adjusted to 7 or slightly alkaline with lime.

Composting can be facilitated by inoculation with lignin degrading fungi such as Trichoderma viride and the use of cellulase enzymes. As compost materials are usually rich in carbon but deficient in nitrogen, nitrogen-fixing bacteria such as azospirillum can be inoculated directly. These bacteria can be mass produced cheaply in a maunure-soil carrier and are normally used for inoculating seeds of cereal crops (Subba-Rao, 1978). Direct inoculation of nitrogen fixers to the digester slurry, however, will not be effective since the percentage of free nitrogen gas in the digester is low.

As considerable amount of heat is generated from aerobic decomposition, composting can serve the additional purpose of heating and insulation in winter if built at ground level directly above underground gas plant.

10.7 Toxicity

Besides the basic elements: hydrogen, oxygen, carbon, and nitrogen, micro-organisms require other elements such as sulphur, phosphorus, metals, and trace minerals for growth. Metal and trace elements are benefical at low concentration, but become inhibitory or toxic at higher levels. Alkaline cations such as sodium, potassium, calcium, magnesium, and ammonium were found to be stimulatory at levels below 200, 400, 200, 150, and 200 mg/l, but start to become inhibitory at levels above 3500, 2500, 2500, 1000, and 1500 mg/l respectively (Jewell et al, 1978; McCarty, 1964). Heavy metals such as copper, zinc, and nickel are toxic at levels exceeding 1 mg/l. A sulphur source of about 0.85 mM concentration is essential, but at a level of 9 mM all inorgnic sulphur compounds other than sulphates are inhibitory to both cellulose degradation and methane formation, hydrogen sulphide being the most potent of all (Khan and Trotter, 1978).

Since pesticides and herbicides are used in some agricultural fraction and can remain on crop residues used as substrates, their harmful effects on anaerobic digestion were studied (El-Halwagi, 1980). When no other causes of plant malfunctioning can be traced, it is worthwhile to check if the feed, both substrate and water, has been contaminated by pesticides, herbicides, antibiotics, or other substances harmful to the microflora. Water used for mixing may have been taken from streams polluted with chemical wastes from a factory upstream, or may contain soap or detergent from previous washings. Chlorinated hydrocarbons such as chloroform and carbon tetrachloride are extremely toxic. In severe cases of contamination, all the slurry may have to be replaced.

10.8 Control of pH (acidity-alkalinity) Level of Slurry

In anaerobic digestion, different groups of micro-organisms have different functions and their own preferred environment. Acid-formers enjoy an acidic environment (pH 4 to 6) while methane-formers prefer a neutral or slightly alkaline pH. In a normal process, pH is maintained between 6.5 and 7 --- a reasonable compromise --- by the buffering actions of carbonates and bicarbonates of ammonium formed during the process. But when imbalance occurs, one group of bacteria, usually the acid-formers, predominates. As a result, the slurry becomes too acidic for the methane-formers and methane production declines. This problem is more commom at the initiation of new plants that have not been seeded with actively fermenting slurry from an old one. Gas if formed is foul or incombustible, and the slurry pH drops below 6.5.

Fortunately, this situation can be easily rectified by the addition of alkali if detected early enough. Lime or calcium oxide is the cheapest alkali and can be added to the outlet mixing pit of dome and tunnel type plants. The pH should be monitored constantly with a pH indicator (paper or meter) until neutrality is reached. Further input of substrate should be withheld until the gas produced becomes combustible. This may take several days to a week. Soda or sodium bicarbonate can also be used. It is more expensive but more soluble than lime. Other alkali like sodium hydroxide, potassium hydroxide, and ammonia are more expensive and less readily available.

10.9 Microflora -- Seeding, Recycling, Inoculation with Specific Cultures

The quality and quantity of biogas depend as much on the nature of the substrate as the microflora. A balance of the right groups of bacteria is essential for an efficient process. Cattle dung normally has the right mixture of rumen bacteria for methane generation. However, especially during start-up of gas plants, the process can go awry. As a safeguard, new plant should be seeded with slurry (about 2% inoculum) from an operating plant. At start-up, normally there is a lag period before gas is produced; pH drops initially and then increases as the process stabilizes. Without seeding, the lag period can take up to a week depending on the temperature. But with seeding, it can be reduced to one or two days.

Mixing is limited in plug-flow reactors especially if the slurry is thick. To decrease the lag time for fermentation of daily fresh input, it can be inoculated with effleunt from the same plant in the mixing pit. In other words, the biogas microflora which is abundant in the effluent recycled back into the plant.

Attempts have been made to isolate micro-organisms beneficial to biogas production from waste and sewage. These cultures can then be used for inoculation (Ch. 14).

10.10 The Temperature Effect

Temperature is a very important parameter affecting the performance of biogas plant. In the Terai or the southern plains of Nepal, digester temperature drops from a summer maximum of 31°C to a winter minimum of 20°C, with a concomitant decrease in gas production of 40 to 50%. Winter in temperate regions is more devastating. Various methods have been devised to increase the digester temperature in winter; these include insulation, composting, solar heating of plant and influent, erecting of green house, and utilization of external and waste heat (see Ch. 18). These mehtods or their combinations should be adapted to make the best economical use of local materials and facilities.

Experiments in the capital Kathmandu (1324m altitude) showed that with composting alone; slurry temperature of dome plant increased by 3°C and gas increased by an average of 54% throughout the winter. For underground gas plants, composting may work well up to an altitude of at least 2000 meters. Gas plants above ground are more difficult to insulate but can possibly be covered with specially weaved straw mat. Water can be preheated in buckets before mixing; its transparency enables radiation to penetrate easily, whereas opaque slurry stops radiation near the surface.

Daily influent should be retained in the inlet pit covered with a plastic sheet until about 2:30 p.m. By absorbing the solar radiation, the slurry temperature in the inlet can be increased by as much as 9°C on a sunny day and 4.5°C on a cloudy day. The pit should be large but shallow, so that the radiation can penetrate most of the slurry. A slurry depth below 7.5 cm is desirable (Vol. II, Ch. 6).

In areas where geothermal heat sources are present, gas plant can be built in their vicinity and water from hot springs and geysers can be channelled for internal heating of digester.

10.11 Agitation

The need for agitation in digester is a topic of contention. There are two kinds of agitation, each for a different purpose.

The first kind is merely used for breaking up scum and usually involves a metal contraption fixed near the surface of the digester slurry. Upon rotation, it breaks up scum of straw or fibres accumulated at the surface thereby releasing trapped gas from the slurry. However, if long strands of straw in dung are removed before feeding, a scum breaker is not necessary. In fact, most of the scum breakers were installed are not functioning because of breakage of the rotating bar outside the gas plants.

The other type of agitation involves the installation of an impeller or stirrer that penetrates deep into the slurry. Its mixing action enables a more uniform distribution of micro-organisms, influent, metabolic procucts, toxic materials, as well as heat inside the digester. Scum layer if present can be dispersed and settling of solids can be prevented. Installation and continuous operation of impeller, however, are expensive, and the increase in gas yield is not substantial enough to justify the economics of its installation. In displacement digesters, the ascent of gas bubbles, thermal convective current, and displacement action of slurry may render extra agitation unnecessary. Mining has one disadvantage though : it stirs up helminth or parasite eggs, thus reducing their time and the chance of their extermination inside the digester.

Chapter 11 THE ECONOMICS OF BIOGAS SYSTEMS M.M. Lau-Wong

SECTION 1: ANALYSIS TECHNIQUE

11.1 Why Bother about Economics?

In Third World countries, the development of renewable energy resources such as biomass, solar and wind energy is now in vogue. Where resources are scarce and funding difficult to come by, analysis tools are indispensable for comparing the worth of these numerous alternatives so that investment can be made wisely.

An economics study is a vital part in the planning of a project, not its aftermath. Data from the actual implementation of the project would certainly make the study more precise, but preliminary analysis should commence as soon as basic information is acquried. A good analysis identifies constraints and risks, points out courses of actions for enhancing the chance of success of the project, and above all indicates whether the project should be undertaken at all. If the economics appears promising, field tests can be devised not only to check technical feasibility, but also to collect more social and economic data in the local situation. As testing proceeds, important factors which are initially overlooked can be included in the analysis, the direction can be modified to maximise benefits, and if necessary decision can be made to forgo the project. However, one must bear in mind that such analysis is only a tool for evaluating projects: it should never usurp the place of sound judgment in decision making. Financial as well as social, organisational, administrative, and technical considerations serve the basis for decision and gathering of these facts is a time consuming but essential process.

In project analysis, national planners in particular are interested in the total return or benefits to the society as a whole, regardless of who confers them or who receives them. The tool applicable in this case is economic analysis described in section 11.4.

Ultimately, the test of the product is its acceptance in the market. Individual and joint investors are most concerned about the financial returns in their venture - whether they have made the most lucrative deal and get the best return for their investment. Financial analysis is a tool for determining this and it simulates the reasoning or evaluation process of the prospective investors. Nonetheless, even if an undertaking is shown financially sound, the attitudes of different income groups in a society towards adopting new technology can still be drastically diverse. In developing nations, it has been observed that well-off farmers and middle-class income earners are more open to innovation, whereas the poor are more reluctant to risk the little they have, since failure in the venture would mean total disaster. Therefore, to choose among alternative project for maximising social and economic return, it is crucial to identify and understand the various forces at work in the target group or area.

11.2 Techniques for Comparing Costs and Benefits

An obvious method for determining whether a project would give a desirable return on our investment is to compare the costs and benefits. There are many analytical techniques for measuring project worth but no one that is best for all cases. Three common measures of project worth are listed below :

1. Benefit-cost ratio
2. Net present worth
3. Internal rate of return

These are discounted measures and to understand how they are used one must first grasp the concept of "discounting". If we lend our money out to someone, we expect to get interest for the use of that money. Suppose $1000.00 is borrowed for one year at an interest rate of 10%. At the end of the year, we expect to receive 1100 (=1000 x 1.10) from the borrower. Thus $1100 at the end of one year is equivalent to $1000 at present, i.e. it has a present worth of $1000/-. If the loan is extended for another year, the amount due at the end of the two years is $1210 (=1100 x 1.1). Note that compound interest is involved since the borrower must pay interest on the amount ($1100) that would have been paid at the end of the first year. Our calculation shows that $1210 two year from now has a present worth of $1000/-. Similarly, the amount due for $1000 borrowed for five years is : $1000 x 1.10 x 1.10 x 1.10 = $1610.51 and the present worth of $1610.51 five years in the future is therefore $1000. This method of reducing a future amount to its present worth is known as discounting : the "interest" rate used,in this case 10%, is known as the discount rate. The longer the period and the higher the discount rate, the smaller is the present worth. Since most project lasts for more than one year, the actual timing of costs and benefits can make a big difference in their attractiveness. The way to compare projects with different future cost and benefit streams (i.e. cost and benefit spread over a number of years) is to discount future benefits and costs to their present worth.

Now let us turn to the definitions of the three measures of project worth mentioned above.

(1) Benefit-cost ratio = $\dfrac{\text{total present worth of benefit stream}}{\text{total present worth of cost stream}}$

the benefit and cost for each year of the life of the project being discounted individually to the beginning of the project and then summed up. If this measure is applied, a project will be accepted when benefit-cost ratio is greater than one.

(2) Net present worth = total present worth of benefit stream - total present worth of cost stream

Project will be accepted when this is positive. As in the previous measure, acceptance means that the project can recover all investments and earn a return on investments equal to or higher than the discount rate.

(3) Internal rate of return = the discount rate required to make the net present worth zero.

A project is considered attractive if the internal rate of return is higher than the desired return rate, not attractive nor accepted if otherwise.

Now the question arises : what should the discount rate be ? The discount rate is generally taken to be equal to or higher than the lcoal interest rates on loans. It varies from place to place and in India and Nepal, a value of 15% is reasonable (for further discussion, see World Bank, 1975).

Once the discount rate is determined, the computation for benefit-cost ratio and net present worth is relatively straight forward. The internal rate of return, unfortunately, can only be found by trial and error. It is the discount rate that reduces the net present worth to zero and is always rounded to the nearest whole percentage. It may be helpful to the reader at this stager to go through the example in section 11.6 before proceeding further.

When presented with inexclusive alternative projects, they should be ranked according to their internal rate of return. Benefit-cost ratio and net present worth are poor indicators of ranks and their use may lead to erroneous judgment.

In selection among mutually exclusive projects, a project with higher cash flow is more attractive than one with low cash flow since implementation of both is impossible. In this case, net present worth, being an absolute measure, will give the right choice. On the other hand, internal rate of return may give the wrong choice since small projects may have low net present worth despite high return. Benefit-cost ratio is likewise unreliable for choosing mutually exclusive projects.

Finally, how long is the project life ? This has to be determined beforehand since the analysis has to be carried out over this period. Generally in an agricultural project, project life is taken as the period the major capital items can last. In industrial and manufacturing project, obsolescence of the project can terminate its economic life earlier. Therefore in analysis, a usual practice is to choose a period comparable to the economic life of the project. Note especially that the discounting techniques described here have already taken depreciation into account. At zero internal rate of return or the breakeven point, capital is already recovered as gross benefit equal gross cost.

11.3 Determination of Costs and Benefits in Financial Analysis

An analysis undertaken from the perspective of any party involved in a project - be it the government, a private agency, the contractor, or an individual - is called a financial analysis. The party concerned is interested in knowing the returns of its contribution. Therefore in doing financial analysis for any one party, it should be stressed that the costs incurred and benefits accrued are the ones for that particular party.

One common mistake seen in economics study of development project is the comparison of costs and benefits "before" and "after" the implementation of the project. In fact, the comparison should be "with" and "without" since the situations "before" the project and that "without" the project can be quite different and give rise to different costs and benefits.

Identifying cost:

Costs are normally easier to identify than benefits. During the preparation or installation period, costs may be incurred from services, labour, equipment, and supplies. During operation, costs may include labour, maintenance, repair and any forms of input and servicing required. If the project eliminates some form of labour, for instance in the case of biogas which may eliminate labour involved in collecting firewood, the cost of such labour shoudl logically be subtracted form the operation cost (or added to the benefits, which amounts to the same thing). This is also an illustration of counting costs "with" and "without" the project. Another illustration - if a project of growing cash crop is initiated on land used traditionally for growing food grains, the value of the production forgone (in this case food grains) should be included as costs or deducted from the benefits.

Obviously, taxes and repayment of loans are part of the costs whereas subsidies reduce costs.

Identifying benefits:

The benefits from an agricultural project can be measured from increased output or production. The product can be consumed on the farm or sold, but in either case it should be valued at its market price. Benefits can take the form of saving as well. For example, the use of biogas for cooking eliminates or reduces the consumption of other kinds of fuel such as firewood and kerosene. The benefit accrued should therefore be the saving on firewood or kerosene valued at their market prices. In some places in the Terai (Southern plains of Nepal), firewood can be gathered from the jungle free. However a price should still be assigned to reflect labour cost incurred in gathering wood.

A salvage value of equipments and other assets at the end of their service or economic life should be estimated and included in the benefit at the right time.

11.4 Determination of Costs and Benefits in Economic Analysis

Economic analysis considers the profitability of a project to the whole society. In contrast to financial analysis, it does not worry about income distribution and capital ownership; it does not matter who actually receives the benefits.

For instance, a nationwide biogas programme helps to reduce the consumption of firewood, thereby preserving forest and inducing the cascade effects of checking soil erosion and lowering of water table, and eventually leading to increase in productivity of the land. All these effects are benefits to the society and should be taken as such in a complete economic analysis. In financial analysis, however, these are not usually considered because from a biogas plant owner's perspective, it is actual cash returns that matters, be it in the form of savings or income. Even if economic analysis indicates high returns to the society, the system will not appeal to individual or community ownership if financial returns are low.

Identifying costs and benefits:

Cost and benefits can be identified in the same manner as described in the previous section. There are a few important exceptions, though. In financial analysis, market prices are always use, whereas in economic analysis, "Shadow prices" are used to reflect real social and economic value for goods, services and discount rates.

Artificial prices of commodities may be a result of many factors -- price control, low foreign exchange rates in developing countries that unrealistically elevate the purchasing power of their currencies, insufficient or incorrect information, etc. The time value of the commodity or shadow price is one that would exist under "free competition in a free market". In practice, however, estimation of shadow price is often open to controversy. Still a few guidelines can be offered. Where the domestic market is protected world market prices can be used instead of domestic prices.

In shadow pricing labour, it can be considered as the cost to the society for transferring labour from its usual occupation to the project. If labour is short, the shadow wage can be taken as the market wage. If a labourer is unemployed nothing is lost by the society by transferring him to work in the project and the shadow wage is zero. In most cases where unskilled labourers are involved, they are probably under-employed already and their shadow wage may range from zero (no employment available) to say half of the market wage. Skilled labour can be taken at their market price since full employment is likely.

In economic analysis, all transfer payment such as taxes are not considered as costs (or benefits). Subsidies must also be excluded and the price adjusted to reflect the true cost. Costs are also incurred from any extension services run by the government or development agencies for promotion of the product involved. These costs may not affect the private investor and can be neglected in financial analysis, but they represent additonal burden to the society and should be considered in economic analysis.

Secondary costs and benefits:

Besides its primary functions, a project may have indirect effects on the society and the people involved in it. These indirect effects or secondary effects are often elusive and difficult to quantify. One illustration is the installation of a biogas system for hulling rice.

The rate of hulling by an engine run on a biogas-diesel mixture is much faster than the traditional method, and what used to be hard work for village women is now taken over by machines run by men. The women now have more time for leisure or other income-earning activities (secondary benefits). On the other hand, hulling may polish the rice to such an extent that most of the vitamins and proteins are lost - a nutrition problem for the society (secondary cost).

In developing countries where unemployment and under-employment persist, a new project creates jobs thereby increasing purchasing power of the people. As they spend their income, more jobs are created and the chain effect of employment creation ensues. Other secondary benefits are less obvious. Once villagers are involved in development projects, they may be more open to innovations (or opposite if they have had bad experience with the development project). They become "progressive", more willing to learn, and will attempt to attain a better life for themselves and for their children. The project itself may provide opportunities for training of the local people, for better utilization of rural resources, whether material or human.

Besides reducing consumption of firewood and possibly deforestation, a biogas system produces many other secondary benefits. Women are released from the time-consuming chore of collecting firewood. Cooking is easier and cleaner - no more polluting fumes from firewood; no more soot covered pots and pens. Healthwise and time-wise, a biogas system appears to improve life for a rural woman. If nightsoil is used as feed for the gas plant, there is the additional benefit of treating a health hazard, and at the some time it is converted to a valuable fertilizer.

For a project that involves a community, success can promote cohesiveness and further cooperation. Taking part in a development project and demonstration of the effects can confer prestige and dignity to people, a factor impossible to measure but which nonetheless plays a vital role in motivation. As shown in these illustrations, secondary effects are complex and usually defy quantification. However, they represent real costs and benefits, and as far as possible important effects should be identified and quantified and treated in economic analysis. In financail analysis, their inclusion is not necessary.

11.5 <u>Sensitivity Analysis</u>

When evaluating a proposal or a set of proposed options, one has to make assumptions and predictions. Since all estimates are subject to uncertainty, a decision can be made more sensibly if sensitivity analysis is applied. Sensitivity analysis is simply making probable changes in estimates of elements such as fuel cost, labour, and maintenance to see how much the measures of project worth are affected. If a certain element can take on a wide range of values without affecting the outcome appreciably, the outcome is regarded as insensitive to uncertainties of that particular element. If however even a small change in the estimate of an element alters the outcome significantly, the outcome is regarded as sensitive to changes of that element. The application of sensitivity analysis is demonstrated in the following sections for various biogas systems.

SECTION 2 : ANALYSIS OF VARIOUS BIOGAS SYSTEMS

11.6 Financial Analysis for a Domestic Biogas Plant

So far, the most common application of biogas in Nepal is still domestic - for cooking and lighting. Biogas replaces the traditional fuel such as firewood for cooking and kerosene for lighting; the savings on these fuels are to be counted as 'benefits'.

Measuring Costs and Benefits :

Measuring costs is straight-forward and the breakdown is given in table 11.1. In measuring benefits, the most crucial factor lies in the availability of biogas throughout the year. The gas replaces its equivalent of fuel, the price of which can be obtained readily from the market.

First, prediction must be made on the quantity of gas available in different seasons of the year. Based on field data (Lau-Wong, 1984), the following prediction can be made for lower hilly regions below 1300m.

Season	Digester temp. °C	Daily gas production m^3 (STP)
Summer, 91 days	30	2.97
Rest of the year, 274 days using composting etc.	25	2.06

Gas available per year = 2.06x274+2.97x91 = 834.7m^3 (STP)
911.1m^3 (25° C)

When gas is insufficient in the cooler months, preference is usually given to cooking. Based on the calorific values and efficiencies of firewood, kerosene, and biogas, the benefits on savings is estimated (Table 11.2).

In enumerating the benefits of biogas, the value of effluent as fertilizer has often been emphasised. However, one must note that dung has a value itself and can be used as fertilizer if not fed to the gas plant. Although the form and concentration of nitrogen (basic nutrient for crop) are altered, its total quantity is basically unchanged. Proper field trials should still be conducted for comparisons; but for the purpose of this analysis, one can assume that the cost of dung as fuel or fertilizer and the benefit of effluent as fertilizer cancel each other out.

Salvage value is almost nil since the plant is basically brickwork underground.

Computation :

Having determined the total costs and benefits, the next step is to choose a discount rate: 15% is normally used for Nepal where the present bank fixed-deposit interest rate is around 13%. Given the discount rate, the discount factor for each year can be easily obtained from Discounting Tables (Gittenger, 1973). The present worth of costs and benefits are then computed for each year by multiplying the cost or benefit of that year by the corresponding discount factor. They are then summed up over the project life to give the total worths of costs or benefits.

Using the Butwal (Terai) firewood price of 0.6 NRs/kg, the benefit-cost ratio and the net present worth are calculated and shown below Table 11.3. To find the internal rate of return, trial and error method must be used. At a rate of 14%, the total present worth is 149 NRs, but at 15% it becomes - 126NRs. Therefore the internal rate of return, to the nearest percentage, is 15%, which happens to be the same as the discount rate. Firewood price varies from 0.25 to 0.45 NRs/Kg in the hills, with a weighted average of 0.36 NRs/kg (Campbell, 1983). If we use this average value, the internal rate of return comes out to be only 3%.

Discussion :

The market price of firewood varies considerably in different locality in Nepal and has risen much in the last few years. At a Butwal (Terai) firewood price of 0.6 NRs/kg, the benefit-cost ratio is almost 1 and the internal rate of return is 15%. But using the hill average price of 0.36 NRs/kg, the benefit-cost ratio (0.73) is below 1 and the net present worth is negative, indicating that a domestic plant is not worth installing. The internal rate of return is only 3%, much less than the 15% discount rate; the farmer can get higher return by investing his money elsewhere, eg. by putting it in a bank which gives at least 13% interest. The firewood price of 0.6 NRs/kg seems to be the cut-off point; any price falling below this would make a domestic plant unattractive.

At 0.6 NRs/kg, firewood is still a cheaper source of fuel than kerosene, the former being 0.93 NRs/1000 kcal (effective) and the latter 1.12 NRs/1000 kcal (effective). In doing financial analysis in different locations, therefore, the price of the cheapest or most commonly used fuel should be sought and applied.

The discount rate chosen should also reflect the local condition. If it is higher than 15%, the benefit-cost ratio and the net present worth will be reduced making the project less attractive. Note that the internal rate of return is still the same, unaffected by the discount rate chosen.

Besides the price of fuel, the other sensitive factor affecting the project's benefit is gas availability. since temperature-drop in winter can reduce gas production drastically (40 to 60% reduction for a 10°C drop), the benefits correspondingly decrease as well. Care should therefore be taken to get realistic estimates of gas production before proceeding with the analysis.

11.7 Financial Analysis of Domestic Plant with Credit

Since the installation of a self-financed domestic plant is financially unattractive in the hills, let us now examine the impact of credit financing on the analysis.

Through the Agricultural Development Bank of Nepal (ADB/N), farmers can take loan at 11% interest repayable over 7 years. If he does that, the financial picture actually looks worse than if he installs it with his own money. At the hill firewood price of 0.36 NRs/kg, the benefit-cost ratio is still below 1 and the net present worth is negative, while the internal rate of return drops below zero! The reason for this is obvious: the interest rate is simply too high. Until a year ago, the interest rate used to be 6%. If interest free loan is given, the benefit cost ratio is almost 1 and the internal rate of return is 12% (Table 1.4), making the biogas installation more reasonable.

Now consider the case when subsidy is available for hill installation. At 41% subsidy, the benefit-cost ratio is 1 and the internal rate of return 15%, the cut-off rate.

These results are significant for the formulation of strategy for biogas development and promotion. Installation and material costs should be reduced or subsidised (both amounting to the same thing). Without subsidy, the present interest rate on loan is too high; interest-free loan would definitely make the system more attractive. However, to get subsidy or low interest loan from the government or donor agencies, they must first be convinced of the intrinsic value of the system, since subsidy and loan are expenses to the society afterall. An economic anaylsis wil therefore be performed in Section 11.10.

11.8 Financial Analysis of Income Generating Milling System: Comparison of Biogas and Diesel

Diesel run engine is a popular device for rice hulling and flour milling for small local entrepreneurs. Adapted engines are available commercially from India to take a fuel mixture of biogas and diesel or just diesel alone. If the owner has enough animals, he can have a biogas plant installed and save an appreciable quantity of diesel besides having gas for cooking. However, the high capital costs of a biogas plant may make this option less attractive. In the following analysis, an attempt is made to compare the financial attractiveness of the two mutually exclusive alternatives: milling using a biogas system or an exclusively diesel system.

Gross income for mill :

Let us consider the case of using biogas from a steel drum plant (nominal gas production: $14m^3$) for milling. To get a fair idea of what a typical mill will earn, data on expenses and income have been collected from two such systems in Bhaluwe and Tikhuligarh, both in the Terai of Nepal. For fear of taxation, owners tend to overstate expenses and understate income. Direct questioning usually draws farfetched answers. To get more reliable information, cross checking and indirect questioning from different approaches are often needed.

The quantity and type of grain brought to the mill depend on the season. Business for a typical year is shown in Table 11.5. The gross income for a diesel or a biogas/diesel system is 18,240 NRs.

Fuel requirement :

Using diesel alone, the fuel requirement is 0.2 l/HP, hr. With biogas, diesel is still needed for ignition, but as much as 80% is saved being replaced by biogas ($0.433m^3$/HP, hr) -- a claim made by the Kirloskar engine manufacturers. However, in almost all occasions we encountered, engine operators never opened the gas valves fully. Measurements at Bhaluwe indicated that only about $0.32m^3$ of biogas was used per HP per hour; in other words, the engine was run on 40% biogas. Their reasons for doing so are obscure; probably they feel that the engine runs better and the gas lasts longer. Any gas remaining can be used for cooking or lighting which is a financially sound option for a large gas plants, though not for small domestic plants as previous analysis showed.

The fuel requirements for both diesel and biogas/diesel systems are shown in Tables 11.6 and 11.7.

Cost and Benefits :

Costs and benefits for both systems are shown in Tables 11.8 and 11.9. The additional benefit of a biogas system is the availability of gas for cooking and lighting, especially during the months of August to October when business is slack.

Savings on kerosene can be calculated from Table 11.6. Since $1.87m^3$ gas (25°C) is equivalent to litre of kerosene (at 5 NRs/R), and 0.26 $7m^3$ gas to 1 kg of firewood (at 0.6 NRs/kg) (Table 11.1). The saving on kerosene is

$$2.8\ m^3/day \times 90\ days\ /\ 1.87\ m^3/l \times 5\ NRs/l = 675\ NRs$$

The savings on firewood = $(3.2 \times 120 + 90)\ /\ 0.267 \times 0.6$
= 2481 NRs.

Therefore, total savings on fuel = 675 + 2481 = 3156Rs and total benefits for a biogas milling system is

18,240 + 3156 = <u>21396 NRs</u>

While that of a diesel system remains to be <u>18,240 NRs</u>.

Sensitivity analysis and discussion :

At a discount rate of 15%, both biogas and diesel systems for hulling and milling are acceptable - with benefit-cost ratio greater than 1 and net present worth positive. If the biogas system is community owned, a 50% subsidy can be obtained from the Agricultural Development Bank, Nepal, for the biogas plant, thus making this option more competitive.

The financial returns, as would be expected, are extremely sensitive to the amount of grain brought in for hulling and milling. For the period following harvest, the mill would be definitely busier than the period before harvest. Unless facilities are erected for storing grain, the mill owner has to be content with fluctuating business. Since storage facilities incur extra costs and purchasing of a stock of grain requires capital, these investments are usually only made in bigger enterprises.

Before installing a rice and flour mill, it is therefore essential to survey the market first to see if potential business is enough to bring the desired returns.

How efficiently diesel is used is another critical factor affecting the economics of both systems. The mill operator usually waits until several customers have arrived before starting the engine, so that idling time of the engine is minimised.

When presented with the alternatives of a biogas milling system and a diesel one, which is more appealing to investors? To make a realistic comparison, one must realize that there are two sensitive factors affecting the returns in the biogas system - the daily gas production and the market price of firewood. Normally if the digester temperature can be maintained at 28°C with heat exchanging device, there should be enough gas for rice hulling and flour milling with excess for cooking as well. However, low winter temperature coupled with mismanagement of the heat exchanging system (such instances have unfortunately occurred) can reduce gas production to such an extent that the mill has to be run solely on diesel for part of the time.

The other sensitive element in the comparison is the market price of firewood.

In villages, prices can vary from 0.25 NRs/kg to 0.45 NRs/kg, with a weighted hill average of 0.36 NRs/kg (Campbell, 1983), while in cities the prices are even higher. Using the Butwal price of 0.6 NRs/kg, the internal rate of return of the biogas milling system is the same as that of a diesel system (21%); however the biogas system may be preferred since the net present worth is 6320 NRs more. The price of 0.3 NRs/kg fuelwood is the cut-off point when both systems give the same net present worth. A wood price above that would make a biogas milling system more attractive than a diesel one.

Introduction of subsidy or loan (even at 11% interest) for biogas would definitely make such system more favourable. As long as the firewood price is high and digester temperature is favourable, a biogas milling system is as good as a diesel milling system. In the event of shortfall of diesel, a biogas milling system will be more appropriate, and since diesel is an import, savings on foreign exchange on import of diesel will be a benefit to the society.

11.9 Financial Analysis of a Biogas Irrigation System - and Its Comparison with a Diesel One

A community biogas plant for irrigation has just been installed in Madhubasa, a Magar village in the Terai (Ch. 12.) Here, water for irrigation has been a continuous problem. Despite constructing and joining an additional well to an existing well, the water delivery rate plummets from 10 l/s during the monsoon to 3 l/s in the hot dry season.

This sets the limit for the land area that can be irrigated. To determine this and the water and pumping requirements, the initial step is to calculate the evapotranspiration losses for each crop. The calculations are summarised in Table 11.10.

In the past when irrigation was non-existent, only one main crop, paddy, was grown. With irrigation, another crop such as wheat can be grown in winter. Dividing the water available (520m^3/day) by the peak water demand (21.4mm/day), the irrigated land area for paddy comes out to be 3.6 bigha or 2.4 ha. Similarly for the winter wheat crop, the area is 9.6 ha. Note that shortage of biogas for running the engine would not be a limiting factor for determining irrigated land area, since the villagers will resort to running the engine on diesel alone.

If the villagers are extra careful in the use of water, more land area can be irrigated. At this point it is difficult to predict the water application efficiency and a 65% value is assumed, 70% being a high value.

Benefits :

Table 11.13 gives the extra gross profit from the two crops - paddy and wheat. Note that for paddy extra profit is obtained from the difference of the irrigated and rainfed crop.

The villagers plan to use any excess biogas for lighting ten lamps. The savings on kerosene per day or the two growing seasons are given in Table 11.10. For the rest of the year, gas is sufficient for lighting 10 lamps 7 hours daily. Annually, this is equivalent to 4968 NRs when expressed in terms of savings on kerosene.

Discussion of results :

A biogas irrigation system yields high benefit-cost ratio of 1.43 and an internal rate of return greater than 50% at 50% subsidy. Even without subsidy, the internal rate of return is greater than 50%, indicating that installation of the system is worthwhile. An irrigation system run on diesel was analysed in the same manner. The results are summarised in Table 11.14.

Without subsidy, biogas system which gives the additional benefit of lighting appears less attractive than a diesel system since it has a lower net present worth. With 50% subsidy, however, the picture for biogas looks much brighter. In fact, with only 6% subsidy a biogas system would give the same net present worth as a diesel system. The subsidy may very well worth it since utilization of biogas reduces reliance of the country on the import of diesel.

Now that both systems are shown to be acceptable, a loan borrowed for financing the costs would only make them more attractive to investors, even at 11% interest (over a period of 7 years) which is the current rate for agricultural loans.

Since most of the profit come from the wheat crop. The analysis is sensitive to the yield of wheat. A yield of 2 t/ha instead of 2.5 t/ha would bring the internal rate of return of a biogas system down from over 50% if no subsidy is given, while that for a diesel system still remains about 50%. The economics is extremely sensitive to the actual area irrigated as well. The cropping pattern should therefore be adjusted to optimize the use of water.

11.10 Economic Analysis of Domestic Biogas System

As previous analysis indicates, a domestic biogas system for cooking and lighting is financially unattractive in the hills unless subsidied. Since resources for subsidy are derived ultimately from the society itself, the socio-economic benefits should be weighed against the costs of the system in an economic analysis.

Costs and Benefits :

Cost are identified as in the case for financial analysis except when shadow prices are used (Table 11.11).

Quantification of the socio-economic benefits, on the other hand, is extremely difficult if not impossible. The most obvious benefit often quoted in literature is the prevention of deforestation. But to what extent? Theoretically, the benefit would be equivalent to the economic value of the amount of firewood a biogas system can save. This value is probably reflected in the cost of deforestation to the society as shown below. So far the damage done by deforestation has not been successfully quantified in monetary terms.

1) Loss of top soil

Land erosion, a serious problem in Nepal, normally takes the form of top soil and nutrient loss; sometimes whole chunks of land are removed. It is the consequence of natural as well as human causes; deforestation caused by inexorable demands for fodder and fuelwood is only but one of the culprits. Unrestrained defoliation by the high livestock population, overgrazing of pastures, chopping trees for fuelwood, land clearance for cultivation, human settlement or roads are all damaging forces working together, accentuating the problem. Since these causative factors of soil erosion are neither independent nor additive, it is impossible to isolate the portion contributed by deforestation through excessive cutting of fuelwood even though a value can be assigned to the loss of land or nutrient. Moreover, the effect of deforestation is not only erosion; loss of forest cover can affect rainfall and lower the water tables as well. Thus, it is infeasible to quantify the cost of deforestation from fuelwood cutting as loss of top soil.

2) Decrease in land productivity

Another approach is to equate the cost with decrease in crop yield caused by depletion of nutrients and top soil (Steven, n.d). Over the last 20 years Nepal has been suffering a decline in crop production. (Agri. Stat. Di.). Since soil erosion caused by deforestation induces damages other than declining crop yield, and the latter is a result of not only erosion but other factors such as lack of agricultural inputs, this approach will fail to give a reliable estimate of the cost of deforestation.

3) Market price

The market price of firewood which has soared in the last decade varies with locality. The price probably reflects well the demand and supply of that area but is far from representing the true cost of deforestation. If forest is accessible, the price if any, will be unrealistically low.

4) Cost of afforestation

What value should then be assign to fuelwood? Since the cost of deforestation to the society is beyond quantification, a different approach is to assign value based on the cost for <u>afforestation</u>.

Studies revealed a decline in forest area from 6.4 million ha in 1964 to 4.1 ha in 1980. Later estimate showed a reduction of more than 700,000 ha between 1975 and 1980, an average loss of 14,000 ha forest annually (National Planning Commission). Targets have been set in the Sixth Plan (1980/81-85/86/) to afforest a total of 71, 427 ha, which comprises both new plantations and protected forests. The investment on new forests is US$360 or 5040NRs per hactare (Asian Dev. Bank, 1982).

Now between the time of investment and the first harvest of fuelwood, there is obviously a time lag depending on the species of tree planted and the climate. If the lag time is taken to be 5 years and discount rate 15%, the worth of the investment at the <u>first</u> year of harvest would be 1.15^5 x investment = 2 x 5040 NRs/ha/ha = 10080 NRs/ha. Since from the first year onwards there will be harvest of wood <u>every</u> year, this value of 10080NRs/ha is equivalent to an installment of 1511 NRs/ha (10080/6.67) every year from the first year to infinity. The dividing factor 6.67 is actually the compound interest factor at 15% (the discount rate used here) and can be readily obtained from Compound Interest Tables (Gitenger, 1973). Given the annual productivity of the forest, the afforestation cost per kg of fuelwood can then be determined. A conservative annual yield of $5m^3$ (2750kg)/ha leads to a cost of 0.55NRs/kg fuelwood (1511/2750), and a domestic plant saving 2380kg fuelwood (see Sec. 11.3) will accrue a benefit of 1309NRs per year.

If an annual yield of $10m^3$ fuelwood/ha is attached, the benefit accrued will be 655 NRs per year.

Other indirect benefits :

The secondary benefits of a biogas system are described in Sec 11.4. From data in 'The Status of Women in Nepal', man and women in a household share the workload for fuel collection, both spending about equal time of 1/2 hr daily. In this analysis, it is assumed that 1 hr is saved from the elimination of wood collection and 1/2 hr for cooking when biogas is used.

Another secondary benefit is the elimination of smoke pollution from wood stoves. Although women do almost all the cooking and are more prone to eye and lung irritation, the expenses in health care do not necessarily run higher since these problems are usually left unattended.

Their vitality might be decreased, though, with less work output, but this again is hard to measure. Smoke from burning firewood, on the other hand, has been reported to have some value afterall --- it kept out insects that gnawed into the wooden beams of ceilings. However, an attempt is made here to include the more significant entities (Table 11.11).

Discussion of results :

In the above analysis, the benefits of a biogas plant in terms of savings on firewood is measured by means of the cost of afforestation to the society. With an annual productivity of $10m^3$/ha for afforested land, the benefit-cost ratio is below 1 and the internal rate of return only 9%. But with a lower productivity, say $5m^3$/ha, these values jump to 1.19 and 23% respectively. This big difference shows how sensitive the outcome is to the actual productivity of forest land. In fact, an annual yield of $7m^3$/ha will bring the cost of firewood to 0.39 Rs/kg and the benefit-cost ratio to 1. These results have important implications. If forest productivity can be maintained above $7m^3$/ha, which is a target not difficult to achieve, afforestation scheme would cost less to the society than biogas systems. The benefit from afforestation will be even greater if the lag period can be decreased by planting fast-growing species. However, one must bear in mind that this analysis for biogas uses the cost of afforestation and not the true cost of deforestation itself, which can be tremendous if damages caused by landslides and floods (not only in Nepal, but also in India and Bangladesh) are included. If that is the case, domestic biogas systems may very well have high enough socio-economic returns to guarantee its place in the development of reneweable resources.

It should be pointed out that in afforestation there is an inevitable lag between time of investment and the beginning of harvest, whereas for biogas the effects are immediate. Probably the best strategy is to implement both programmes simultaneously provided that resources are available. Theoretically, the livestock population in Nepal can provide enough feedstock for one small domestic plant per household. The distribution of animals unfortunately does not permit that. If however, gas plants are installed for families that possess enough animals, there will be less competition for firewood with the less well-off villagers, and depleted forest in the locality will recover more rapidly.

11.11 Summary

At its present cost, domestic biogas system for cooking and lighting is acceptable in places where fuelwood price is high, such as in the capital Kathmandu and some towns in the Terai. The Butwal (a town in the Terai) price of 0.6 NRs/kg is the cut-off point at which the benefit-cost ratio is almost 1. In the hills where the fuelwood price is lower, with an average of 0.36 N Rs/kg, a 41% subsidy is required to bring the same returns.

Since subsidy comes ultimately from the society itself, it cannot be justified unless the social and economic benefits of biogas outweigh its cost to the society. One oft-cited benefit is the conservation of forests by replacing fuelwood which, according to a survey done by Tribhuvan University in 1975, accounts for 93% of domestic fuel consumption. As explained in the analysis, the cost of deforestation proves extremely difficult to quantify. Nevertheless, economic analysis showed that if the economic value (which may be very different from its market price) of fuelwood hits 0.39 NRs/kg, the benefit-cost ratio becomes 1 at a discount rate of 15%. In other words, if the economic value of fuelwood is above 0.39 N Rs/kg, a <u>subsibized</u> domestic biogas programme should be considered.

In our economic analysis, a comparison of biogas system and afforestation was made. If forest productivity can be maintained above $7m^3$/ha.yr., which is a target not difficult to achieve, afforestation scheme would cost less to the society than biogas system. However, in afforestation, there is an inevitable lag between the time of investment and the first harvest, whereas for biogas the effects are immediate. Since fuelwood shortage is imminent, the best strategy for the country is probably to implement both programmes along with the development of other renewable sources of energy such as hydroelectricity.

For income generating activities, such as rice hulling and flour milling, a biogas system (which supplies fuel for cooking as well) is as competitive as a diesel one, provided that the digester temperature can be maintained at or above 28°C and fuelwood price is higher than 0.3 NRs/kg. As the analysis shows, the comparison is extremely sensitive to fuelwood price and gas production, the latter being strongly dependent on temperature. Either system by itself is financially viable but sensitive to the amount of grain brought in for hulling and milling and how efficient the fuel is used. Therefore before installing a rice and flour mill, it is essential to survey the market first to see if potential business is enough to bring the desired returns.

As for using biogas for irrigation, the internal rate of return is high (above 50%) even without subsidy. Using diesel, the rate of return is higher than 50%). In fact, with only 6% subsidy, a biogas system would give the same net present worth as a diesel one. The subsidy may be worthwhile since utilization of biogas reduces reliance of the country on the import of diesel thereby saving foreign exchange. The economics is extremely sensitive to the actual land area irrigated. If water supply is limited, the cropping patterns should be adjusted to optimize the use of water and maximize the irrigated area.

In conclusion, the returns are high if biogas is used for income generation and irrigation. For domestic purposes such as cooking, an afforestation scheme would cost less than a biogas one. However, if latrines are attached to biogas plants for the treatment of human waste, the socio-economic value of biogas plant would definitely increase. This is actually the practice in China where waste processing is the primary objective and biogas is only a by-product. In Nepal, the idea of using gas derived from human waste is repugnant to most people. Unless this cultural barrier is overcome, domestic gas plant using cattle dung will have very limited practicality.

Table 11.1 Capital and Recurring Costs for a Domestic Plant (dome type CP 10)

Capital cost	NRs
Plant installation plus accessories	10,246
Annual Recurring costs	
Labour for operation (1/2 hour/day at 1 NRs/hr) - hauling water, mixing slurry, etc.	183
Repair and maintenance (2 gas taps or gas valves and parts for lamps) *1	150
Compost or straw insulation for winter, plus plastic for passive solar heating of effluent	100
Total	433

Note :

* 1 The government minimum wage is now 10.40 NRs/day or 1.30 NRs/hr, since plant owner may be operating plant himself or use existing help, no extra labour will be hired and financially will cost him less.

* 2 In the first year after installation, Gobar Gas Company provides full guarantee, therefore repair and maintenance should be excluded from the first year's costs.

Table 11.2 Savings on Fuel

Fuel	(A) Calorific value	(B) Efficiency	(C) Quantity of fuel/yr.	(D) Efficient k.cal/yr.
Biogas (54% CH4)	4628.6 kcal/m³ (25°C)	52%	911.m³ (25°C)	2,192,901
Firewood	4300 kcal/kg	15%	2380kg *1	1,535,031 (70% of biogas)
Kerosene	9000 kcal/l	50%	1461 *1	657,870 (30% of biogas)

1.87m³ gas (25°C) = 1 litre kerosene
0.27m³ gas (25°C) = kg firewood

(C) = (D)/(A) x (B), assuming 70% of the gas replaced wood for cooking and 30% replaced kerosene for lighting.
Price of kerosene is 5NRs/l, savings/yr = 146 x 5 = 730 NRs
Price of firewood : 0.6NRs/kg (Butwal), savings = 2380 x 0.6 = 1428NRs.
0.36NRs/kg (hill), savings = 2380 x 0.36 = 857NRs.

Table 11.3 <u>Financial Analyais - Domestic Dome Type Plant</u>
(in constant 1983 NRs)

Year	Total cost	Present worth 15%	Discount factor d.f. for 15%	Total benefit	Present worth 15%	Increment benefit or Cash flow	Present worth d.f.		Present worth d.f.	
							14%	14%	15%	15%
1983	10,529	9,160	.870	2,158	↑	-8371	-7341	0.877	-7283	0.870
84	433	↑	.756	2,158		1725	↑	↑	↑	↑
85	433		.658	2,158		1725				
86	433	sum= 1797	.572	2,158	sum= 10831	1725	sum= 7490	sum= 4.342	sum= 7157	sum= 4.149
87	433		.497	2,158		1725				
88	433		.432	2,158		1725				
89	433		.376	2,158		1725				
90	433		.327	2,158		1725				
91	433		.284	2,158		1725				
92	433	↓	.247	2,158	↓	1725	↓	↓	↓	↓
TOTAL		10,957	5.019	10,831			+149	5.219	-126	5.019

Benefit-cost ratio at 15% = 10,831/12,284 ∓ 0.99
Net present worth at 15% = 10,831 - 10,957 = -126 Nrs
Internal rate of return = 15%

Table 11.4 <u>Measures of the Worth of Domestic Biogas Plant with and without Credit Financing</u>

Financing	benefit-cost ratio	net present worth, NRs	internal rate of return, %
(A) <u>Firewood price = 0.6 NRs/kg (Butwal)</u>			
without credit	0.99	-126	15
loan 11% 7 year	0.98	-256	11
(B) <u>Firewood price = 0.36 NRs/kg (hill average)</u>			
without credit	0.73	-2992	3
loan 11% 7 year	0.72	-3121	below 0
interest-free	0.98	-168	12
loan subsidy 41%	1	0	15

Table 11.5 Typical Business for Mill

Month	No. of Month	No. of hrs. engine run per day	Quantity/day Rice. muri	Wheat. pathi	Gros income per period NRs.
Nov-Mar	5	4	15	8	10,200
Apr-Jul	4	4	12	10	6,960
Aug-Oct	3	1	1	8	1,080
				Total	18,240

Note : (1) 1 muri paddy is about 50 kg. Hulling charge is 4 NRs/muri and maximum hulling rate is 6 muri/hr.

(2) 1 pathi wheat is about 3.2 kg. Milling charge is 1 NRs/pathi and maximum milling rate is 12 pathi/hr.

Table 11.6 Fuel Requirement for Biogas System

Month	Diesel Required Liter		Gas Required per day m^3	Gas left for		Equivalent of	
	per day	per period		Cooking m^3/day	Lighting m^3/day	Fuel wood kg	Kerosene litre
Nov - Mar	2.24	336.0	8.8	-	-	-	-
Apr - Jul	2.24	269.0	8.8	3.2	-	12	-
Aug - Oct	0.56	50.3	2.2	8.0	2.8	30	1.5
	655.3 (or 3604 NRs at 5.5 NRs/l)						

Table 11.7 Fuel Requirement for Diesel System

Month	Diesel Required, litre per day	per period
November - March	5.6	840
April - July	5.6	672
August - October	1.4	126
Total		1638 (or 9010 NRs at 5.5/l)

Table 11.8 Biogas Systems - for Hulling and Milling

Captial Cost		NRs
Plant Installation plus accessories (dome type '500 cft')		37,515
7 H.P. dual fuel engine (Kirloskar)		10,500
Rice Huller plus accessories No. 8		2,500
Flour mill plus accessories 16"		2,500
Heat exchanging device plus accessories and pump		1,500
	Total	54,515

Annual Recurring Costs

Labour for plant operation (1hr at 1 NRs/hr.) mixing slurry etc.		365
Labour for operating engine, huller and mill (350 NRs/Month, less during slack season)		3,500
Maintenance and repair (350 NRs for engine 950 NRs for huller, 850 NRs for mill running below 4-5 hr each day, 250 NRs for plant and heat exchanger)		2,250
Diesel		3,604
Mobil oil (2 l/month at NRs/l)		672
	Total	10,391

Financial Analysis (in constant 1983 NRs)

Year	Total cost	Present Worth 15%	Total Benefit	Present Worth 15%	Increment Benefit	Present Worth 20%	Present Worth 21%
1983	64,756*	56,338	21,396	↑	-43,360	-42,735	-42,428
1984	10,391	↑	21,396		11,005	↑	↑
1985	10,391		21,396		11,005		
1986	10,391		21,396		11,005		
1987	10,391	Sum =	21,396	Sum =	11,005	Sum =	Sum =
1988	10,391	43,112		107,387	11,005	43,876	41,863
1989	10,391		21,396		11,005		
1990	10,391		21,396		11,005		
1991	10,391		21,396		11,005		
1992	10,391	↓	21,396	↓	11,005	↓	↓
			1,000 (Salvage)	247	1,000	227	208
Total		99,450		107,634		1,009	-154

Note : * Maintenance and repair for gas plant (estimated 150 NRs) covered by installing company for the first year.

Benefit-cost ratio at 15% = 1.08
Net present worth at 15% = 8,184 NRs
Internal rate of return = 21%

Table 11.9 Financial Analysis for Diesel Hulling/Milling System
(In constant 1983 NRs)

Capital Costs	NRs
7. H.P. diesel engine	10,500
Rice Huller plus accessories	2,500
Flour mill plus accessories	2,500
Total	15,500

Annual Recurring Costs	
Labour for operating engine, huller, and mill	3,500
Maintenance and repair	2,000
Diesel	9,010
Mobil oil (2 l/month at 28NRs/l)	672
Total	15,182

Year	Total cost 15%	Present Worth	Total Benefit	Present Worth 15%	Increment Benefit	Present 21%	Worth 22%
1983	30,219	26,693	18,240	↑	-11,979	-9,895	-9,823
1984	15,182	↑	18,240		3,058	↑	↑
1985	15,182		18,240				
1986	15,182		18,240				
1987	15,182	Sum =	18,240	Sum =		Sum =	Sum =
1988	15,182	62,990		91,547		9,868	9,492
1989	15,182		18,240				
1990	15,182		18,240				
1991	15,182		18,240				
1992	15,182	↓	18,240	↓	↓	↓	↓
			1,000	247	247	148	137
Total		89,683		94,805		121	-194

Benefit cost ratio at 15% = 1.02
Net present worth at 15% = 1,864 NRs
Internal rate of return = 21%

Table 11.10 Irrigation Requirements by Crops

Month	Rice Growing season					Wheat growing season				
	5*1	6	7	8	9	10*1	11	12	1	2*1
Co-efficient of transpiration, k	1.1	1.1	1.07	1.0	0.95	.28	.5	1.1	1.1	.25
% of daily day-time hour of year total, P	0.31	.32	.31	.30	.28	.26	.24	.23	.24	.25
Average temperature, °C*2	31.8	29.1	29.0	29.2	28.3	26.3	21.8	16.3	6.2	17.2
Average rainfall, mm*2	23	483	425	353	218	28	–	–	1	19
CALCULATIONS FOR GROSS IRRIGATION WATER REQUIREMENT (GI)										
1) Evapotranspiration, E*3 mm/month	231	226	212	192	168	44	64	118	122	30
2) Percolation loss (7mm/day) mm/month	210	210	210	210	210	–	–	–	–	–
3) Effective rainfall mm	23	360	345	200	145	–	–	–	1	12
Net irrigation (NI), = (1)+(2)+(3), mm/month	418	76	77	203	233	26	64	118	121	18
Gross irrigation mm/month	643	117	118	312	358	40	98	182	186	28
(GI=NI 65% efficiency) mm/day	21.4	3.9	3.9	10.4	11.9	1.3	3.3	6.1	6.2	0.9
PUMPING REQUIREMENTS										
Water pumped/day, m^3*4	523	104	104	260	296	135	327	596	605	96
Pumping time/day, hr*5	11.2	2.2	2.2	5.6	6.3	2.9	7.0	12.7	12.9	2.1
Biogas Production/day, m^3*6	14.5	14.5	14.5	14.5	14.5	8.5	8.5	8.5	8.5	8.5
Pumping with biogas/diesel, hr*7	6.9	2.2	2.2	5.6	6.3	2.9	4.0	4.0	4.0	2.1
Pumping with diesel alone, hr	4.3	–	–	–	–	–	3	8.7	8.9	–
Biogas in excess, m/day	–	9.9	9.9	2.7	1.3	2.4	–	–	–	4.1
Diesel required, l/day*8	6	0.55	0.55	1.4	1.6	0.73	4	9.7	9.9	0.53
Lighting (0.142/light, hr) light-hr day	–	70	70	19	9	17	–	–	–	29
Replacement of kerosene for lighting, l.	–	5.3	5.3	1.4	0.7	1.3	–	–	–	2.2

Notes :

1. For wheat half-month; for rice 10 days including water for land preparation and nursery.

2. Climatic data for Janakpur (Sharma, 1974)

3. Blaney Criddle method = E = K x p (0.46 T+8) x 30mm/month; T in °C

4. Water pumping requirement/day = irrigated area (ha) x GI (mm/day) x 10^3m plus 10m^3 for village consumption. Irrigated area is 2.4 ha for the rice and 9.6 ha for wheat.

5. Pumping capacity of 13 l/s or 46.8m^3/hr
Pumping time/day = water pumped/day + 46.8

6. In the Terai, digester temperature in the summer can reach 30°C and in winter, with insulation and solar heating of influent, a temperature of 25°C is attainable (since gas plant is a long distance from the engine, heat exchanging is impossible). With 300 kg gobar and retention time of 74 days, the corresponding gas productions are 8.5m^6 and 14.5m^3.

7. With the engine consuming 0.42m^3 biogas/HP, hr, maximum pumping with biogas is feasible for (gas production/0.42 x 5) hour per day.

8. 5 HP engine running on biogas/diesel mixture requires 0.25 l diesel/hr and on diesel alone requires 1 l/hr.

Table 11.11 Costs for a Biogas Irrigation System

Capital Costs	NRs With subsidy *	Without subsidy
Gas Plant :		
Installation of plant plus appliances (includsing 2 lights)	18,758	37,515
8 lights (350 NRs/light)	1,400	2,800
Piping for lights (200m at 18 NRs/m)	1,800	3,600
Irrigation system :		
5 H.P. engine plus pump set	10,500	
Engine house	5,000	
Water tank	800	
	38,258	60,215
Annual recurring costs		
Maintenance for engine and plant : installation etc.	2,000	
Diesel (183 l for rice, 727 l for wheat, at 5.5 NRs/l)	5,005	
Mobil oil (2 l/month at 28 NRs/l)	672	
Labour for gas plant operations (1½ hr/day at 1 NRs/hr)	548	
Labour for irrigation (60 hr for rice, 1053 hr for wheat; 2 persons at 1 NRs/man-hr)	3,308	
Seed	1,766	
Chemical fertilizer	8,707	
Extra labour for paddy and wheat crop (Table 11.13)	6,768	
Total	28,774	

Note :

* 50% subsidy, except for farmers' labour and irrigation system

Table 11.12 Input Requirement for Rice and Wheat Crop

	Seed requirement			Fertilizer requirement *2		Labour	Irrigated crop Extra labour required
	kg/ha	NRs/kg	NRs/crop	NRs/ha	NRs/crop	NRs/ha	NRs/crop
Paddy*1	50	2.00	240	572	1373	950	240*3
Wheat*1	50	3.18	1,526	764	7334	680	6528
			1,766		8707		6768

Note :

*1 = Irrigated paddy, 2.4 ha
Irrigated wheat, 9.6 ha
*2 = Source: Shibata San, 1980
*3 = Extra labour required for paddy crop/ha
= labour for irrigated crop (950 NRs/ha) - labour for rainfed crop (850 NRs/ha)

Table 11.13 Gross Profit from Extra Crop Yield

	Yield t/ha Irrigated	rainfed	Price NRs/kg	Irrigated area ha	Gross Profit NRs/crop
Paddy	3.0	2.0	1.50	2.4	3,600
Wheat	2.5	-	1.80	9.6	43,200
					46,800

Table 11.14 Comparison of Biogas Irrigation Systems Run on Biogas or on Diesel Alone

System	Benefit-cost ratio at 15% discount rate	Net present worth NRs	Internal rate of return, %
Biogas			
No subsidy	1.28	51,441	50
50%	1.43	70,543	50
Diesel	1.34	53,370	50

Table 11.15 Economic Analysis - Costs and Benefits of a Domestic Biogas System

Capital Costs	NRs
Plant installation plus appliances (including extension done by installing agency)	10,246
Materials centributed by farmer (brick and sand)	805
Labour contributed by farmer (shadow price, taken as half the unskilled labour wage)	360
Total	11,411

Annual recurring costs	
Labour for operating plant (half the minimum wage : 0.5 hr/day x 365 x 1.30 NRs/hr x 0.5 = 119)	119
Repair & maintenance	150
Compost/insulation for winter etc.	100
Total	369

Benefits			
Savings on labour - fuel collection, 1 hr/day at 0.65 Rs/hr	238		
- cooking and dish cleaning 1/2 hour/day at 0.65 Rs/hr	119		
Kerosene 146 l (5 Rs/l, the market price is used since it is not subsidized)	730		
		Wt. of wood	Wood cost (Rs/kg)
Firewood - afforestation estimate, yield 5m³/ha	1,309	2,750	0.55
7m³/ha	932	3,850	0.39
10m³/ha	655	5,500	0.27

Afforestation yield, m³/ha	5	7	10
Benefit-cost ratio at 15%	1.19	1	0.86
Net present worth at 15%	1,894	1	-1,389
Internal rate of return, %	23	15	9

Chapter 12 A PRACTICAL GUIDE TO COMMUNITY BIOGAS

A. Bulmer

The thrust for establishing community biogas plants has been to make biogas technology available to lower income groups of people. At present only the top 10% to 20% of farmers in Nepal have the resources to install a family sized plant for themselves. The ideal is that poorer people coming together will be able to match in money and livestock what the rich can provide on their own.

The application of this ideal has to be grounded in the reality of each situation and success depends on giving due weight and study to the words: "poor people coming together".

12.1 People

The people are the focus of our concern.

We should be people orientated: technology must not be allowed to dominate, but should be arranged to fit around the real needs of the people for whom it is intended, at a level at which they are able to understand and cope with.

We should be realistic: people want to go their own way, but they may be willing to work together for one activity, if they profit from it.

There have been few examples of successful community biogas projects. There may have been a lack of realism about the part self-interest plays in the lives of the poor. As an economic group, they have no greater willingness to cooperate than any other. Their willingness to take part in collective action, as opposed to the self-sufficient life-styles of the rich, is not based on any ideals, but on their proven experience that they can benefit by working together. So biogas technology must be presented in such a way that the people as individuals will benefit from the project individually, if they cooperate in it.

12.2 Community

A "community biogas project" is defined, for the purposes of this discussion, as "a cluster of individuals, whether urban or rural, who share in part ownership of a biogas installation".

There is a distinction between "group ownership", involving a self-selecting group of 4 to 10 people, and "village ownership", which implies that all the people in a village or local neighbourhood are involved (up to 100 people). In practice, group ownership seems to be more successful, but this discussion includes both patterns.

12.3 Questions Before a Plant is Planned

Why is our organisation involved in a community biogas project?

The motives of the implementing organisation and members must be considered. Is- community biogas part of a larger programme? When rural development is "in fashion", community projects are often used to justify less fashionable work. Outside pressures from funding organisations, a desire for prestige or political advantage or the need to spend grant money before the end of the financial year, all can distort an otherwise well planned programme.

Are we setting up a community biogas programme in order to help ourselves or in order to help the people of the community?

Failures in community biogas projects often lie with the implementors, not the community or the technology. It is important to understand the pressures under which we are operating and not to allow them to distort our planning and implementation.

Are we willing to commit ourselves to the people of the community?

If we are involved in setting up a community biogas project, we must find the right community with which to work. This is a job that the implementors must do themselves. We must stay in the community for several nights, eat their food and accept their hospitality. if we are foreigners of a different culture to the villagrs, from a different nation or tribe or caste, we must be prepared to become familiar with, and accept, the social and cultural traditions of the community in which we are to work. We must understand what the people are saying, their way of expressing themselves.

There is no substitute for time spent with people, meeting them informally, getting to know them, so that we cease to be "The Expert" from outside, but are seen as someone who cares and listens.

12.4 How will the Project be Financed?

Poor communities do not have the capital to pay for a community biogas plant. Therefore another organisation (not necessarily the implementors) must provide capital, as a loan, a direct subsidy or a mixture of the two.

The people of the community must have a financial commitment to the project. They must provide input to the construction of the plant, such as free labour for the digging of pits. They should take part of the cost as a loan, so they have a stake in the successful operation of the system.

A careful economic analysis must be made of the project. In Nepal, we recognise that biogas technology must be partially subsidised to be financially feasible. The level of the loan component depends on the ability of the people to pay back the loan, and this must be assessed.

The project itself should generate an income that is sufficient to pay back the loan and also to give the people a useful profit.

Whatever approach is followed, it is vital that the decisions are made before meeting the people of the community. It will be one of the first questions that the people will ask, and they need a simple and direct answer (in writing if necssary). Misunderstandings must be avoided, such as reactions of "Oh, but we thought ....." and "But, when you first came, you said .....", in the future.

Who will provide the capital finance, for both loans and subsidy?

It is better for the implementors not to be responsible for providing finance, especially loan finance. National Agricultural Credit Schemes have plenty of experience with giving loans and collecting repayments and it is good to give the responsibility to them. Our energies should be directed into building a system that works and for which the people are happy to pay.

12.5 How will Technical Follow-up be Provided?

Assuming that the necessary expertise, designs, materials and transport facilities are available to build the plant, provision should also be made to follow-up and maintain the plant, once it has been built.

In Nepal, a previous programme involved the building of 3 community plants. A year after the implementation, a survey was done (Bulmer 1980) which showed that one of the major causes of failure was inadequate maintenance provision. A community plant is more vulnerable than a family plant, as no one person is responsible for repair work. In the above cases, lights and cooking stoves were broken and the users tried to get them repaired, but the implementors of the project were unable to give an adequate response. In a short time the users lost interest in the system and it stopped operating.

Do we know of previous attempts to set up community biogas projects in or near our area?

We need to learn from other people's successes and failures; they are less expensive to us than our own. We should visit other community biogas plants, talk to the users and the implementors and read any reports they may have written. We may even need to make our own assessment and report on their work. Learning from others will warn us of any pitfalls to avoid and stop us making the same mistakes. It may even give us ideas that we had not thought of.

12.6 How is a Community Selected?

There are many factors to be taken into account when selecting a community with which to work. If a community has been recommended by someone else, a government official or a local politician, we must analyse their motives for the recommendation. We may be aiming to help a certain category of people, a particularly poor or disadvantaged group. We may have certain geographical or environmental aims, such as setting up a plant in an area of deforestation, to encourage the use of alternative cooking fuels to wood. Communication is a factor: do we want to be able to reach the community quickly and easily from a nearby town? This may distort our other aims, as the poorest people usually live in the least accessable areas.

Do we want to choose a community that has already shown a spirit of cooperation or one that has already expressed an interest in biogas technology? People who are already motivated are much easier to work with.

When the criteria have been established, we should contact people with good working experience of the area in which we intend to work, such as community health workers, agricultural extension agents, for their advice and suggestions.

12.7 Questions on Going to a Community

The number of people in a visiting team, and its composition by sex, age etc., can affect the initial impression the people of a community receive, depending on the local culture. An individual visitor may be less threatening than a team. The mode of transport (ranging from helicopter, through jeep to foot) also affects initial impressions. It may be better to leave a vehicle away from the village, so that the people's first sight of us is on-foot. The time of the visit is also a factor, people are more likely to talk and listen if they have no work to do.

Should someone introduce you to the people?

In some places, it is better to work through local political, development or even religious agencies, when contacting communities.

The initial contact will be formal; a time of explaining our purpose and discovering the possibilities. If the situation looks promising, then arrangements to return for a longer stay can be made. Facing a stranger, villagers will close ranks and only the influential ones will speak. In many places, the women will not even be visible. It may take several visits before the real feelings of everyone can be expressed.

12.8 Collecting Information

Much information is required to make a full and careful assessment of the feasibility of a biogas system for the community, and time and patience are required to gather it. Answers to questions should be written down, but the appearance of a notebook during conversations can make a villager wary. Information should always be cross-checked with another person; villagers do not always tell the truth about themselves to outsiders. Answers about land holdings and income may reach the tax authorities. The local tea shop or the next door villages are places where alternative versions of a story may be found.

The core of the information should be :

Location : Postal Address;
Map relating the village to the wider area;

		Relationship to local services, roads, government offices Map of Village.
People	:	Number of households; People in each household, by age and sex; Literacy.
Relationships	:	Family Lineage; Caste, tribal and linguistic links; Religious affiliations.
Economic	:	Occupations and typical incomes; Land holding; Ownership of capital goods.
Livestock	:	Type, number, sex and size; Daily quantity of dung available.

12.9 The Political Dimension

The pattern of authority and decision making in the village is one of the most important items to information, but is the most difficult to assess. We are interested to know how the villagers are likely to cooperate together in the project.

We must find out :

Leadership	:	Who the leaders are; What is the basis of authority: wealth, charisma, education, religious status?
Factions	:	Under which leader to different villagers align themselves and for what reason?
Disputes	:	What is the past history of court cases, land disagreements, family antagonisms, personality clashes?
Cooperation	:	What have the villagers done together in the past, that demonstrates a spirit of togetherness?

A history of cooperative ventures is the most important sign for which to look: building a village well, making a road, running a local school, having a common grain store. The more telling ventures are those that require sustained effort: maintaining the road, paying a teacher's salary. Sharing together in religious festivals is an indicator, but a less significant one.

12.10 The Test

Now we have collected all the information on the community that we need. The villagers seem interested in the community biogas project, and we are hopeful that they are willing to cooperate on it. The next stage is the Test.

The Test is a principle in the methodology of 'The Village Reconstruction Organisation', run under the leadership of Michael Windey S.J., in Guntur, Andhra Pradesh, India. He sees it as an essential stage in any community development process, to determine the real commitment of the people to a project.

The people should be challanged to complete a specific task, within their capabilities. They could be told to repair an approach road, so that materials could be brought to the site, or to dig the first 2 m depth of the digester pit. They must organise this job among themselves and come to the office to tell us when they have finished. They must not be supervised during the test, it is a test of their ability to a job by themselves, and also that they have more than a polite interest in the project.

If the people come to a specified place to tell us that they have finished the task, then we can continue with the project. If they never come, then we should look for another community with which to work.

12.11 The Management Committee

If the community passes the test, the next stage is the management committee. It must have authority and be recognised by all the members of the communiy. The form it takes must be agreed by the villagers, with help from the implementor.

Who should be on this committee?

How committee members are chosen depends on the cultural assumptions of both the villagers and the implementor. It may be by democratic process or by consensus. The committee may include representatives of the less advantaged groups, such as women and the landless. It should have enough power to ensure that decisions concerning the project are made fairly.

We can point out to the villagers the areas in which cooperation is required and the likely points of contention, but they must decide on the measures required to meet these demands.

The frequency of meetings, the creation of posts of chairman, secretary, and treasurer and other committee matters must be decided by the villagers, with guidance rom the implementor. Simple training may need to be given in taking minutes, doing accounts and running meetings.

12.12 Technical Aspects

The emphasis of this chapter is on the community, rather than on the technology. There is a big difference between community ownership and individual ownership of a biogas plant. The individual owner only needs to answer two socio-economic questions: "Have you enough cattle to feed a biogas plant?" and "Can you afford the price?"

How does biogas fit into the life of the community?

When the subject of biogas technology is explained to the villagers, they will need to know what they can use it for. Can biogas technology answer a need that the villagers already have? A supply of energy is a basic requirement for living, but the villagers must understand in detail how a biogas plant could make their own lives easier.

The different possibilities for the use of biogas should be explained to the villagers as clearly as possible. The use of pictures or a small model may help them to understand this new concept for them. If it is possible to take a group from the village to see other biogas installations, and especially other community biogas systems, they will grasp the possibilities more quickly.

The villagers must decide for themselves how they want to use the system, but they must be given as much information as possible, so they can make a meaningful decision.

12.13 The Uses of Biogas in the Community

Biogas has been traditionally used for cooking and lighting; domestic uses which save money, but do not earn an income. We believe that a new dimension can be introduced if the gas is used to earn an income for the villagers. The advantages of this approach focus on the areas where community biogas is most vulnerable: in the taking of responsibility for running and maintaining the system.

If a biogas plant is used to earn money, there is a strong incentive for all the people in the community to keep it running, to keep the money coming in.

If the gas is used for a single major purpose, such as running an engine, the people can concentrate their efforts on ensuring that this is maintained properly. If other equipment, such as lights, fail, the purpose of the plant is not lost.

Also this approach offers a means of reaching poorer communities. If the economic analysis has been done accurately and the correct subsidies are available, then poor people can repay the cost of a loan for the biogas plant from the income it generates.

In principle, there are many ways in which biogas can be used to earn money (see Chapter 8). In Nepal, there are only two ways that have been tested or studied in depth: grain milling and irrigation pumping.

12.14 The Use of Biogas for Milling in a Community

Several community plants have been set up in Nepal that use the biogas to run a dual-fuel engine to drive grain milling equipment. The joint owners of these systems seem to be happy with the profits that they earn. The income seems to be enough to cover the loan repayments for the whole system (most have received a 50% subsidy for the biogas plant).

How will a community mill be run and organised?

An operator is needed to look after the engine and milling equipment full-time: to maintain it, to ensure adequate stocks of fuel, oil and spare parts and to repair it if it breaks down. It is better to send a member of the village away for training in this work, if at all possible, than to employ an outsider.

Another person will be employed in organising the customers and taking payment for milling services (given in cash or in kind, a proportion of the grain being milled). This job may also be full-time and should be done by a member of the community whom others trust.

A third person should have the responsibility of checking the income each day and of keeping detailed accounts of earnings, expenses and profit.

It is important that all the members of the community feel confident that their interests are being protected. There are too many cases of cooperative ventures in which the treasurer has run away with the money. We must ensure that the management committee faces up to such matters at an early stage and makes proper arrangements to safeguard against misuse of funds. They should also ensure the security of community cash and grain.

12.15 The Use of Biogas for Community Irrigation

One community biogas system in Nepal has been set up to run an irrigation pump, but it has not been running long enough to confirm our economic assumptions: that they will make a good profit from the system.

The first question to be settled is: where is the water? Is there enough water throughout the year available from a nearby river, shallow well, bore hole, to make irrigation pumping an economic proposition? The implementor may need to ask help from irrigation engineers to answer this question.

The positions of: the source of water, the lands to be irrigated and the village and the cattle sheds, must all be considered in choosing a site for the plant. Often a source of water is away from both the village and the land. The water must be brought to the land along a suitable canal or pipe. If the biogas plant is near the pump-set, to which it is supplying gas, the cattle dung may have to be carried a long way each day. If the biogas plant is in the village, where security is better, then the biogas must be transferred to the engine. This can be done with a long pipeline of a suitable size (see Chapter 6), but pipelines are expensive. Biogas can be transferred in a large plastic balloon, but this is easily damaged.

The villageres must be presented with all the possibilities and the advantages and disadvantages of each, so they can make their own decision.

Will biogas used for irrigation pumping help all members of the community?

Irrigation will help those with land; the more land a person has, the more benefit he receives. We must help the management committee face up to these issues. If everyone in the community is to take part in the project, they must all receive some benefit from it.

A careful analysis should be made of people's land holdings and where each person's land is, in relation to the canal that will bring the water.

How will people who have no land, or whose land is not in the irrigated area, benefit from the project?

There are several ways in which this question can be answered. People can be each given 'credits' for the gas or the water, which they can sell to others. An arrangement can be made where those who might not otherwise benefit may rent land in the irrigated area from others. It may be decided that those who will not benefit from the water should not take part in the scheme at all. These decisions must be made before the installation work is started.

An irrigation pump is only used when the crops need water, but the biogas plant is producing gas all the time. Should the gas be used for some other purpose, such as cooking and lighting as well? If this is done, then gas will not be available for this other purpose during the irrigation season.

As with milling, an operator for the pump-set should be trained to run and maintain the equipment.

12.16 The Use of Biogas for Community Cooking and Lighting

Most individually owned biogas plants are used for domestic purposes, so community biogas plants are planned with domestic use of the gas in mind. Organisationally, this way of using the gas can be the most complicated.

Again, the villagers and the management committee must make many decisions before the plant is built. All the villagers in the scheme must have equal access to the gas. If the gas supply is limited, the use must be controlled. Some houses will be further away from the biogas plant than others, but they must not receive less gas.

Who has the responsibility for maintenance of the community facilities? For the individual family stoves and lights?

Maintenance people can be trained and supplied with tools and spare parts, but how will they be payed? Who pays for the spare parts?

The failure of cooking stoves and lights, without quick repair, is the quickest way to ensure a community effort fails.

12.17 Running the Biogas System

The villagers must make sure that effective arrangements are made to feed the plant with sufficient dung every day to produce the biogas required. The arrangements must be seen to be fair, those who supply less dung may need to compensate in another way, such as giving labour. someone must be responsible for ensuring that everyone gives as much as they have promised.

In some places cow dung is dried and used for burning. Are all the villagers convinced that putting the dung in the biogas plant is a better use for it? It is often difficult for people to change their habits.

Arrangements must also be made to share the slurry that comes out of the plant in a fair way. it can be dried and stored for future use as fertilizer, or it can be put into the irrigation water. Who benefits?

The fairest system is that people should receive back, as slurry, what they put in, as dung. This may be difficult to do when putting slurry in the irrigation water. In this case, credits may need to be given for fertilizer, as well as gas.

The maintenance of the plant must be planned for. How will the cost of maintenance be covered? Who is responsible? The implementors must ensure that expert technical help is available, if it is needed, and that the people know how to find it.

12.18 Adding Latrines to Community Biogas

One benefit of a community biogas system is that latrines can be added, thus improving the sanitation of the village, and also the gas production from the plant. However, the introduction of latrines adds a further set of complications, for which planning must be made by the villagers.

The defecating habits of the people need to be considered. The help of a woman, such as a community health nurse, is useful in this discussion with the people. The people need to be convinced that latrines will help them, by improving the health of the village. Again they must change their habits, and this is difficult.

If latrines are added to the plant, the siting of the biogas installation must be well planned. People demand privacy for using the toilet. The latrines must also be well planned, especially as there is a limit to the water that can be added, to give the correct total solids in the plant.

Some people feel that the use of night soil in a plant somehow 'taints' the gas for cooking.

Latrines need to be cleaned, but who will do it and how will they be compensated or paid? How will cleanliness be maintained?

One night-soil biogas plant has been built in Nepal, with 18 latrines, for an urban community as a sanitation measure. Many people used the facility, so it soon was overloaded. Cleaning the latrines became a problem, as poor quality gas was produced, so it could not be sold to pay the caretaker, as was planned. It has now been abandoned (Bulmer, 1980).

12.19 Evaluation

Community biogas plants are complicated, and we need to learn as much as we can about setting them up. An evaluation of how each plant is working is not only valuable to the implementors, but also to others interested in this area of development. The more this type of information can be shared, the fewer failures we may have.

Chapter 13 BIOGAS EXTENSION D. Fulford

The extension of biogas technology to a large number of people in a developing country is a task that many planners have underestimated. There are extension programmes in several countries in Asia (Subramanian, Eggeling): Korea (30,000 plants in 1979), Taiwan (7,500 plants in 1975), Philippines (400), Thailand (200) and Pakistan (100) (Ellegard), but they have not always been as successful as the planners hoped. Even in China (7,000,000 digesters in 1978) and India (89,828 plants in 1980) (Ellegard), the failure rate of the plants built has been fairly high (up to 50% in China - Tam; 30% in India - Moulik).

Most of these extension programmes have been started by government agcncies. The Indian programme, for example, is organised mainly by the Khadi and Village Industries Commission, a central government funded organisation set up to encourage rural development in India. some of the state governments also have their own programmes, such as PRAD in Lucknow in Uttah Pradesh.

The Chinese experience has been slightly different, partly because of the way in which government is organised. The commune system is very involved in every aspect of people's lives, including government, so the idea of biogas technology was able to spread rapidly and people were able to obtain information and help easily. Although the collective system has facilitated the fast growth of biogas technology in China, the main driving force has been a new freedom for families to own things privately, including biogas plants and pigs (Thery).

In Nepal, the national biogas programme was launched by the Department of Agriculture of His Majesty's Government of Nepal (HMG/N) in 1975. The responsibility for continuing this programme lies with a private limited company, the Gobar Gas tatha Krishi Yantra Bikash (Pvt) Ltd., (the Gobar Gas Company). This company was set up by the Agricultural Development Bank of Nepal (ADB/N), the Fuel Corporation of Nepal and the United Mission to Nepal (UMN) in 1977. The organisation of the company was based on an extension programme started by DCS as part of the national effort (Fulford).

13.1 Organisation of Biogas Extension

Any extension programme has several components, all of which must be working effectively for the programme to succeed. The technology used in the extension programme must be well tested and proved before it is made available to large numbers of people. The technology must be sold to customers, who have to be convinced of its value and of their need to purchase it. A sales campaign should be linked to good publicity for the technology, via popular newspapers and radio. It is more difficult to persuade customers to purchase a technology of which they have never heard.

Few people in a developing country such as Nepal have capital available to buy a technology as expensive as biogas. Finance must be available to give customers loans to pay for their plants. An organisation is then required to recover loan repayments and interest from the customers; a job best done by a bank.

The technology must then be installed in the places where it is to be used. Staff must be trained in installation and also how to teach the customers to use the equipment and how to do simple routine maintenance. An essential feature of the programme in Nepal has been follow-up: regular visits to customers who have purchased biogas plants, to check on problems and to put them right.

A major component, which is sometimes neglected, is that of planning and management. Staff must be hired and trained, and money must be available to pay them, before it can be earned from work under the programme. Supplies must be purchased, stored and transported to the different sites where biogas plants are being built. Close links need to be set up between the sales staff and customers and the loan officers and construction staff, to insure that the customer gets what he pays for, and pays for what he gets, in good time. Yearly plans must be realistic, taking into consideration potential markets, installation capacity, material supplies and bottle necks, transport problems etc., as well as the past year's achievements. Extension programmes often grow more slowly than planners forecast.

These various components have different demands. Good, well proven technology requires research and development, which is expensive and best organised and financed by national research or academic institutions or by international aid agencies. Research and development workers need good access to the work of field staff. Good publicity also requires national or central direction and organisation. Journalists and sales staff are better at publicity than researchers.

Loan finance is best provided by a national or regional bank, as it is specialised work and requires a good supply of funds, very good administration and a high degree of confidence, both from the local people and the government. If subsidies are to be given to cover part of the cost of biogas plants, as in some countries, they should be administered by government, although the banks can act as agents.

The work of selling to customers and of constructing biogas plants should be organised at a local level. Each area of country has its own peculiarities and problems, that are best understood by the people of that area. This is especially true of technologies, such as biogas, that relate to rural areas, which are far more diverse than urban ones. If the construction programme is organised centrally, many different local offices are required, which is expensive to administer. If several different sales and construction teams are set up, which can act independently, but relate to the centre via a licensing system that ensures quality control, the administrative overheads can be reduced.

Follow-up should be organised centrally, especially as it should relate to the work of research and development. It is best done, though, by people who know a local area, such as by the construction or sales teams. These people may be reluctant to report failures caused by their own bad workmanship.

Thus the organisation of a biogas extension programme is very complex and may involve several very different types of organisation, such as: a university, a publicity agency, a bank, several small construction firms and a government department. The work of such diverse groups needs to be coordinated and monitored.

13.2 Planning and Extension Programme

Careful planning is an essential feature of any successful programme. The senior management and technical staff, who are to be responsible for running the programme, should be hired and trained before detailed plans are made. They should be involved in planning the programme they are to administer.

The aims of the programme must be stated clearly, in terms of measurable quantities: eg. the number of biogas plants built each year, the number of construction workers trained to what level. The assumptions behind these aims must also be clearly stated: eg. "Biogas is an acceptable source of fuel to rural people", and in a way that can be easily tested during the programme. All development programmes are based on a series of assumptions about the environment and about the feelings and attitudes of the people who are to be helped. If these assumptions are incorrect, the success of the programme is at risk.

Each component of the programme: technology, finance, publicity, management, follow-up etc. needs to be carefully planned, both as a separate feature, by people experienced in these areas, and in relation to each other. Managers, technicians, financiers and publicity agents need regular coordinating planning meetings to ensure all the different sets of plans fit together well. The form of management structures, especially the clear demarkation of responsibilities for decision making, need to be decided early in the planning process, so that each member of staff knows exactly what they are to do and how to do it.

Plans need to be practical. The early part of the programme should include feasibility studies, market surveys and economic analyses, based on data from the areas where biogas plants are to be sold, to ensure the programme is realistically designed. A pilot programme, building a small number of biogas aplants in a limited area, is a valuable way to give insight into possible problems for the future. It also provides training for staff and the testing of management structures and technical approaches.

Plans need to be flexible and constantly reviewed. Regular evaluation is an essential part of the programme, so that achievements can be tested against targets and reasons for poor performance can be identified and corrected. If some previously unidentified circumstance arises (eg. a change in political emphasis), the plans need to be changed quickly enough to allow for it, so the running of the programme is not adversely affected.

The planning process should not be rushed and it needs to be adequately funded. Adequate spending of time and money at an early stage may save mistakes that could be very expensive in terms of both time and money later on. Initial budgets should be fairly large. It is far easier to obtain grant money at the beginning of a new programme than at a later stage, especially if money is required to put right mistakes. Grant money must be available for administrative and runnings costs. Staff must be paid while they are being trained and making plans, before they can earn money for the programme from the work they are doing.

13.3 Construction Programme

The initial priority in a biogas extension programme is good, proven technology. Much of this book is devoted to technical designs for this reason. Designs of equipment that are to be built for customers must not only work at the test-site level, but also be well proven in the field. Therefore, in setting up the technical component of the programme research and development staff must plan how they are to field test all the equipment that they are to use, once the prototype designs have been developed.

A second priority is the training of construction staff, who can only learn how to build biogas plants by actually doing the job themselves, with guidance from trained staff. These requirements suggest that a pilot programme is an effective way to start. A limited number of biogas plants (10 to 30) can be built for customers in a defined geographical areas and these plants can be used to train construction workers and to test the technology. While customers must pay the market price for the plant that they receive (calculated on the basis of a full scale programme), adequate guarantees and compensation must be available in case of failures due to inadequate technical design or lack of skills in the builders. The early customers will tend to be the more go-ahead people, who would have a better understanding of the problems involved. They should be willing to accept failures, as long as they themselves do not lose out because of them. If a pilot plant fails, it must be repaired, or replaced by a new one, paid for by the programme. As a last resort, the price paid for the plant may be refunded to the customer, with an extra fee, to compensate for the trouble caused.

The budget for this pilot programme should thus include a 100% guarantee fund for each plant built under it. Also provision should be made for regular visits (eg. 4 visits in the first year after the plant is built) by research and development staff, to discover any design or construction faults that need to be put right. This pilot programme will be relatively expensive and cannot earn a profit. It will give a good indication of the real costs of building biogas plants and provide a basis for economic analyses and pricing for the on-going programme.

As staff skills develop and as the technology becomes reliable, the pilot programme will merge into an on-going extension programme, centred about the pilot area. The guarantee fund will provide the basis for an on-going fund which can be used to repair plant failures. A proportion (5 to 8%) of the price of each plant should be set aside in this fund as an insurance against faults caused by bad workmanship or errors by the construction staff. If the guarantee period is made the same length of time as the loan period, the bank providing finance can be sure of getting the repayments from happy customers.

13.4 Organisation and Staffing

The construction programme is best organised on a local level.

As the extension programme moves into a new geographical area, staff should be recruited from that area. They can be trained by working alongside experienced staff in an area that already has an established programme. While the movement of staff from an established area into a new one allows flexibility in the programme organisation, it can breed dissatisfaction in the staff. This approach can be costly if relocation and compensation payments must be made to these staff to keep them happy.

Each area (selling perhaps 50 to 100 plants a year) sould be responsible for its own management and budgeting. Once a programme is established in an area (within 4 years), it should become self-financing: salaries of staff and other overhead costs coming from the sales of biogas plants. This commercial approach to biogas plant construction should lead to greater efficiency and lower costs, as staff recognise that their earnings depend on their own efforts (Fulford). As it takes time to set up a commercial concern, each area team must be provided with enough working capital to set up their programme and run it for 3 to 4 years until they make a profit. These area teams can be registered as private limited companies, with either cooperative or individual entrepreneur ownership.

Each biogas plant takes 1 to 2 weeks to build, therefore construction staff must spend much of their time in the field. Field allowances must be paid to these staff as compensation for living away from home, even though the customer will often provide food and lodging free to them. Good training and planning are essential to keep these costs low, as they can rise very rapidly if the work is done slowly, or if frequent visits have to be made to remote sites to bring materials that might have been forgotten. Construction staff should be trained in customer relations and in sales techniques as they spend much of their time among customers and their neighbours, who are also potential customers.

Quality control is an essential part of the extension programme. different systems can be devised: eg. the construction workers can be paid a bonus for each plant they have built, if it is still working well after 9 months or a year. Each plant should be inspected before it is filled with slurry. Inspections can be done either by a senior member of the construction team, or by sales or follow-up staff. The best advertisement for biogas technology to potential customers is an effective working plant nearby and a happy owner explaining its merits.

13.5 Sales and Follow-up of Biogas Plants

While salesmen can be part of the commercial area construction programmes, this approach increases overheads and makes a biogas plant expensive to the customer. A better approach may be to use agricultural extension workers or specialist salesmen, paid from a central government or international aid agency. The same applies to staff responsible for follow-up, who could be the same staff as the salesmen, doing both jobs. Some form of incentive scheme is required that encourages sales and follow-up staff to do their job properly. This type of field work is impossible to supervise, so staff must be paid on proven results. A bonus can also be paid to anyone who sells a biogas plant, such as a construction worker or a loan officer at the bank.

13.6 Biogas Extension in Nepal

In Nepal, DCS has discovered some of these principles by using them and proving that they worked. Other principles have been found by trying the opposite, which did not work. DCS effectively started with a pilot extension programme by building 95 biogas plants within 50 km of Butwal. This was done under a national programme organised by HMG/N in the Nepali Agricultural Year of 2033 (1975/76). 95 plants were too many for the first year of a programme, as technical faults did arise and funds were insufficient to put them right. The steel drums started to corrode and DCS's first attempt to repaint them did not solve the problem. About half of these corroded drums have now been replaced, but not all of them, as funds have been difficult to obtain for this work.

The first 12 concrete dome plants and the first 6 tunnel plants built for customers were provided with 100% guarantee funds, although most of the design faults proved to be minor and inexpensive (mainly leaking gas taps).

Another 100 biogas plants were supposed to have been built by the Department of Agriculture, HMG/N, using agricultural extension workers (Junior Technical Assistants) as supervisors. The JTAs were supposed to sell plants to farmers, obtain supplies from central workshops, hire local masons to build the plants and to arrange loans from ADB/N. Neither the JTAs or the masons received much training in the building of biogas plants. Many of the plants had technical problems and a proportion failed (34% - Pyakuryal, Coburn). In some cases, the loans had not been used to build biogas plants, but to build build houses or for other purposes.

After the Agricultural Year, the DCS biogas extension programme was formed into a private limited company, which started selling and constructing biogas plants on a national scale in 1976 (2034). The sudden expansion from an area programme to a national one put great strains on the new company, which was already under-financed. The Gobar Gas Company has had to pay for all the work of sales and follow-up as well as covering all the overheads of central coordinating office. Only research and development and some publicity work was funded by an outside grant through DCS..

The Company has steadily increased sales most years (Table 13.1), but not as fast as planned. It has not been able to make a profit. If the cost of a central coordinating offic and of extension agents/salesmen/ follow-up staff were to be covered in another way, such as by a government or international aid agency , then the company's profitabilitity could be greatly improved.

The sudden expansion meant that staff from the Butwal area programme had to be promoted and sent to take charge of other areas before they were properly trained or had gained sufficient experience. Technicians were made managers with no management training at all. As staff have gained experience and received some on-the-job training, as time and work have permitted, this weakness is being overcome, but only slowly.

Other problems faced by the Gobar Gas Company have been linked with the supply of materials, especially cement and steel. Since there is

Table 13.1 Biogas Plants Built in Nepal

International Year	Nepali Year	Plants Built by: Gobar Gas Co/DCS	Others	Type SD	CP	TP
1974/75	2031	3	6	9	-	-
1975/76	2032	95	85	180	-	-
1976/77	2033	55	15	70	-	-
1977/78	2034	131	-	131	-	-
1978/79	2035	126	2	126	2	-
1979/80	2036	111	-	91	20	-
1980/81	2037	149	-	63	86	-
1981/82	2038	234	-	31	199	4
1982/83	2039	280	-	13	265	2
1983/84	2040					
Total	10 years	1184	106	714	572	6

often a shortage of these supplies in India, a licensing and quota system has been introduced for the export of them to Nepal. This means that careful planning and management is required to ensure that the correct quantities of materials are available at the right time. Money is also required to pay for these supplies, when they become available, so good cash flow management is essential.

Considering the lack of management training and experience in the staff of the Gobar Gas Company and also the high demands on management made by the economic environment in Nepal, the performance of the company has not been bad.

The follow-up work of the company has been effective. The failure rate of biogas plants in Nepal by the Gobar Gas Company is estimated to be only 5%. All of these failures are steel drum biogas plants, most built in the Agricultural Year by DCS, using low quality steel.

The future of biogas in Nepala looks better. HMG/N is taking a close interest in the benefits that biogas technology can offer to the country's economy. The Department of Agriculture has started offering subsidies to farmers, as they recognise that biogas plants can improve the fertilizer value of cattle dung, especially if that dung is not being burnt as fuel. As artificial fertilizer becomes more expensive and difficult to obtain, this aspect is gaining in importance.

No research and development programme is ever really complete; there are always new ideas and improvements to be tested. The programme described in this book has been finished, as far as DCS is concerned, but the work is still being continued under the Research Wing of the gobar Gas tatha Krishi Yantra Bikash (P) ltd. While a full description of their work and results would require another book, a brief review of the directions of their research is given.

Chapter 14 FURTHER IDEAS FOR BIOGAS IN NEPAL D. Fulford

14.1 Alternative Feedstocks for Biogas Plants

A dependence on cattle dung alone as a feedstock for biogas plants limits the gas available, especially for poorer farmers who may only have one or two animals. Cattle dung is essentially partly digested, ground up vegetable matter, so experiments are continuing with the use of raw vegetable matter as a feedstock for dome type plants (Devkota).

Feedstocks being tested include: water hyacinth, corn cob, banana leaves, rice straw and a weed called 'banmara' (Eupatorium species), which grows widely in Nepal, but which few animals will eat. Four CD10 biogas plants are being used as batch digesters for these tests: loaded once every two or three months. Between 10 and 40% of slurry from a working digester is added as a seed to supply the populations of bacteria to start the digestion process.

The results look fairly hopeful, especially if the vegetable matter is mixed with cattle dung and the carbon: nitrogen ratio is kept between 20 and 30. Banmara, especially, has a high nitrogen content, for plant material, so gives reasonable gas production. However, certain practical problems make the use of vegetable matter difficult.

Large amounts of vegetable matter are difficult to compress into a digester pit, especially if they are unprocessed. Total feedstock concentrations of only 20 to 50 kg/cu.m. could be achieved 9compared with 70 to 130 kg/cu.m. for cattle dung slurry) (Devkota). Hand chopping of vetetable materials with a knife is a very slow and laborious process and would not be accepted by local farmers. It is also inefficient, as it is difficult to reduce all the pieces to a size below 10 mm long (Chapter 10).

A machine is required to chop vegetable matter. A chaff cutter would work for dry materials, but would not cut soft, wet matter, such as water hyacinth or partially composted leaves. A device similar to a large domestic meat mincer could be used.

If vegetable matter is fed continuously into a digester, it usually forms a scum layer on the top of the slurry. Finely ground materials tend to float to the surface of the slurry and stop the gas escaping. Researchers at the Jyoti Solar Energy Institute in Gujurat, India, suggest that vegetable matter should be fed to the top of a digester (Lichtman). Oxygen in the plant cells makes fresh materials float to the top anyway, but if it is fed lower down in the plant, it brings partly digested material to the surface with it. The oxygen in the fresh material should be consumed by the acid forming bacteria at the surface of the slurry, so the vegetable matter can sink, but the partially digested material remains at the surface as a scum. It may also be that the introduction of oxygen-rich material into the methane producing middle layers of the digester disrupts the activity of the methanogenic bacteria. If fresh vegetable matter were introduced at the surface of the slurry, a population of oxygen tolerant bacteria should form in the place, which will consume the oxygen and allow the material to sink.

Scum formation can also be reduced by increasing the viscosity of the slurry. If the solids content of the slurry is increased to around 130 kg/cu.m. at 25°C, the mobility of scum and other vegetable matter in the digester is reduced (Jewell), so it is less likely to float to the surface. However, a thicker slurry is more difficult to mix and to introduce into a biogas digester.

A design for an Archemedes screw type slurry pump/mixing machine is shown in Figure 14.1. A model of this pump has been made, but a full size prototype has not yet been made or tested. If it worked, it would offer a solution to all of the above problems. It could be fitted so that the outlet of the pump was just below the surface of the slurry (Fig. 14.2), thus introducing the thick, fresh, well mixed feed into the correct region of the digester.

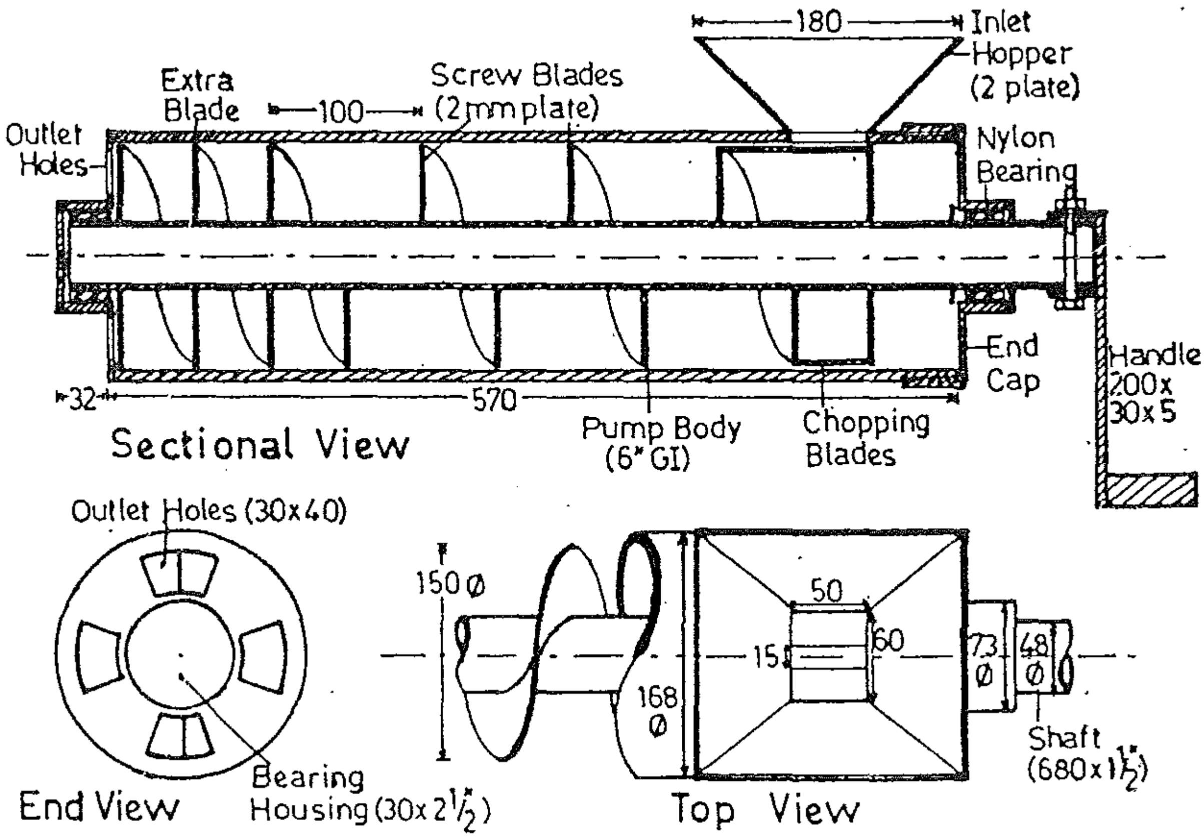


Fig. 14.1 A Suggested Design for an Archemedes Screw Slurry Pump

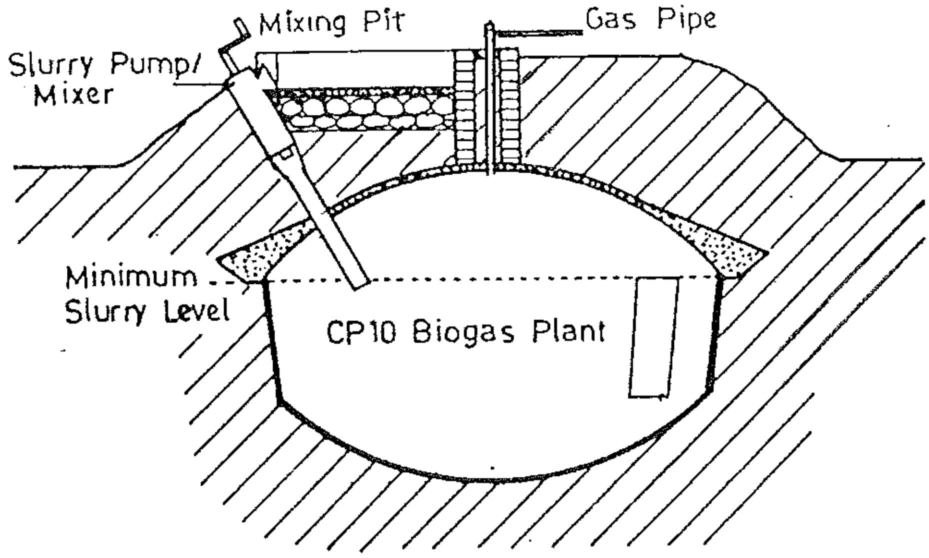


Fig. 14.2 Use of Slurry Pump to Introduce Feed into Biogas Plant

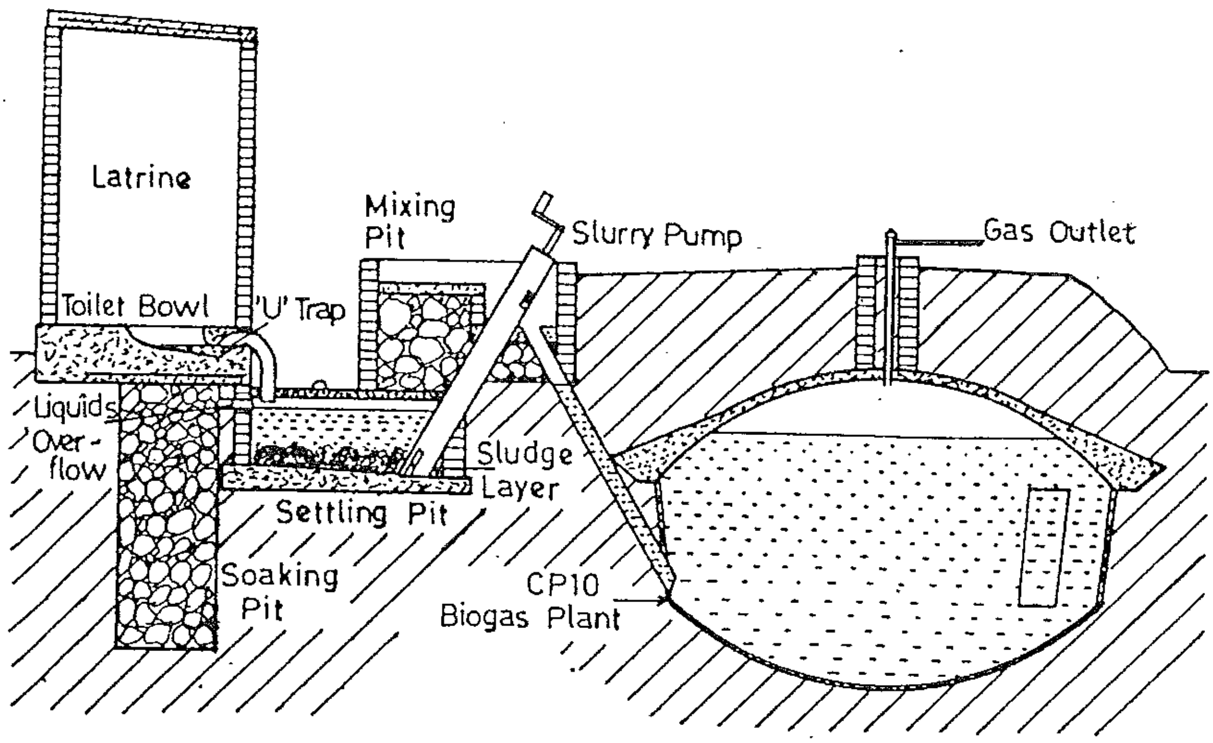


Fig. 14.3 Use of Settling Pit and Slurry Pump with a Latrine

14.2 Use of Latrines with Biogas Plants

While the addition of a latrine to a biogas plant is becoming more acceptable to the more modern Nepali people, minor technical problems have prevented their construction in some places. People do not want to touch night soil, so it must be gravity fed into the plant. The base of the mixing pit is at least 0.5 m above ground level. the bowl of an Asian (squatting) type toilet must be placed below floor level, so the outlet (if a 'U' trap is fitted) coms about 0.4 m below floor level. Thus the floor of the latrine must be about 1 m above the ground if the system is to work effectively, and slurry from the plant is not to come into the latrine.

If the night soil is to be mixed (eg. in a mixing machine), before it is fed into the biogas plant, the latrine may be 2 m above ground level. The night soil plant in Tansen (Chapter 2) was sited on a slope so it was below the latrines, so this was possible. In other sites, it would be very difficult to site a latrine so high from the ground. There have been several requests for cesspits to be adapted, so that the biogas can be collected. If both the cesspits and the latrines have been built, this would be impossible to do.

A further problem is that water used to flush the latrine can dilute the slurry. If a syphon type flush system is used, the solids content from the latrine may be only 2%. If urine is also included, the total solids may be reduced to 1% or less.

A possible solution is the use of a settling tank. If the wastes from the latrines are left in a tank for 24 to 48 hours, the solid material should sink to the bottom and form a sludge layer. The excss water can be wasted through an overflow in the top of the tank into a soaking pit; a hole in the ground full of stones, which allows the water to soak into the surrounding soil. An Archemedes screw slurry pump can be used to lift the solid sludge from the settling pit to a point where it can be fed into the biogas digester. This hand operated pump can also be used to mix the night soil, as it is pumped (Fig. 14.3). The pump would have to be made from a corrosion resistant material, or coated with a strong paint, such as epoxy, as night soil is very corrosive. High Density Polyethylene, which can be welded with a hot air gun, could be used.

14.3 Extended Dome Biogas Plant

The growing popularity of community biogas plants has indicated a gap in the range of designs that are being produced in Nepal. The largest dome design is the CP20 plant, which produces between 3.5 and 5 cu.m. gas per day, depending on feed and temperature. The largest steel drum plant, the SD500, produces between 8 and 12 cu.m. of gas a day. The disadvantages of the drum design, especially the difficulty of transport for such a large drum to a remote area, suggest that a larger size o displacement digester is required. A CP50 plant was designed, but the digester pit would have to be so deep (4.8 m) that it would be very difficult to dig, especially if the spoil had to be removed through the slurry outlet.

A better solution is the Extended Dome design (EP), which is a hybrid between the dome and tunnel designs. The gas storage volume is made as a partially cylindrical tunnel (4 m wide) closed by domed ends (each effectively half a CP20 dome). While the roof could be made in a way similar to that of the dome designs, by casting it over a mud mould, the digging of a large chamber underneath the roof would be laborious. If several plants are to be made to this design, a steel form (Fig. 14.4) should be made, which allows the roof to be cast after the digester pit is dug and lined with brick masonry (in a way similar to that for the brick lined tunnel plant).

If the central tunnel section is made 4 m long (Fig. 14.5), the total internal volume is about 54.6 cu.m. (EP50 plant). This tunnel section can be made different lengths, by including more or fewer sections of form, to give a range of sizes of biogas plant (up to EP95 or more). For these larger plants, the slurry reservoir has a large surface area. The main area of the reservoir can be covered by another length of tunnel, reducing the amount of steel reinforcing rod required.

14.4 Construction Details for the Extended Dome Design

The principles of construction follow the same lines as for the dome design (see Ch.3). A suitably shaped hole (depth 920) is dug, with the guidance of a template (Fig. 14.6). The edges of the hole should be lined with bricks (placed at 45°), to act as a foundation for the dome. If the ground is of questionable quality, this foundation should be 1-1/2 bricks, or even 2 bricks, wide (Volume II, Chapter 7).

The digester pit is then dug and lined with bricks: put flat on the floor and laid as a half brick wall at the sides. A row of full bricks at the base of the walls, helps to spread the load on the floor and another full row at the top acts as a ledge. The metal form is bolted together in place on this ledge and the gas outlet pipe (Fig. 14.6) is put in place. The surface of the form is coated with a paste of mud and water, so the concrete does not adhere to it.

The whole roof must be cast at one time, within one day, so enough labourers, masons and materials must be available and prepared to do this. A small cement mixing machine would ease the job for larger sized plants. The concrete (1:3:3 mix) should cure for at least 7 days, kept damp with sacking that is regularly wette. The form can be unbolted and removed, once the dome is strong enough.

Table 14.1 Dimensions of Different Extended Dome Designs

Plant Type	L (m)	S (m)	B (m)	Total Vol m³	Dome Vol m³	Digest Vol m³	Working Vol m³
EP20	0	0	2 320	22.944	5.439	17.505	20.225
EP35	2 000	1 000	1 800	38.748	10.043	28.705	33.727
EP50	4 000	2 000	1 400	54.552	14.647	39.905	47.229
EP65	6 000	3 000	1 400	70.356	19.251	51.105	60.731
EP80	8 000	4 000	1 400	86.160	23.855	62.305	74.233
EP95	10 000	5 000	1 400	101.964	28.505	73.505	87.735

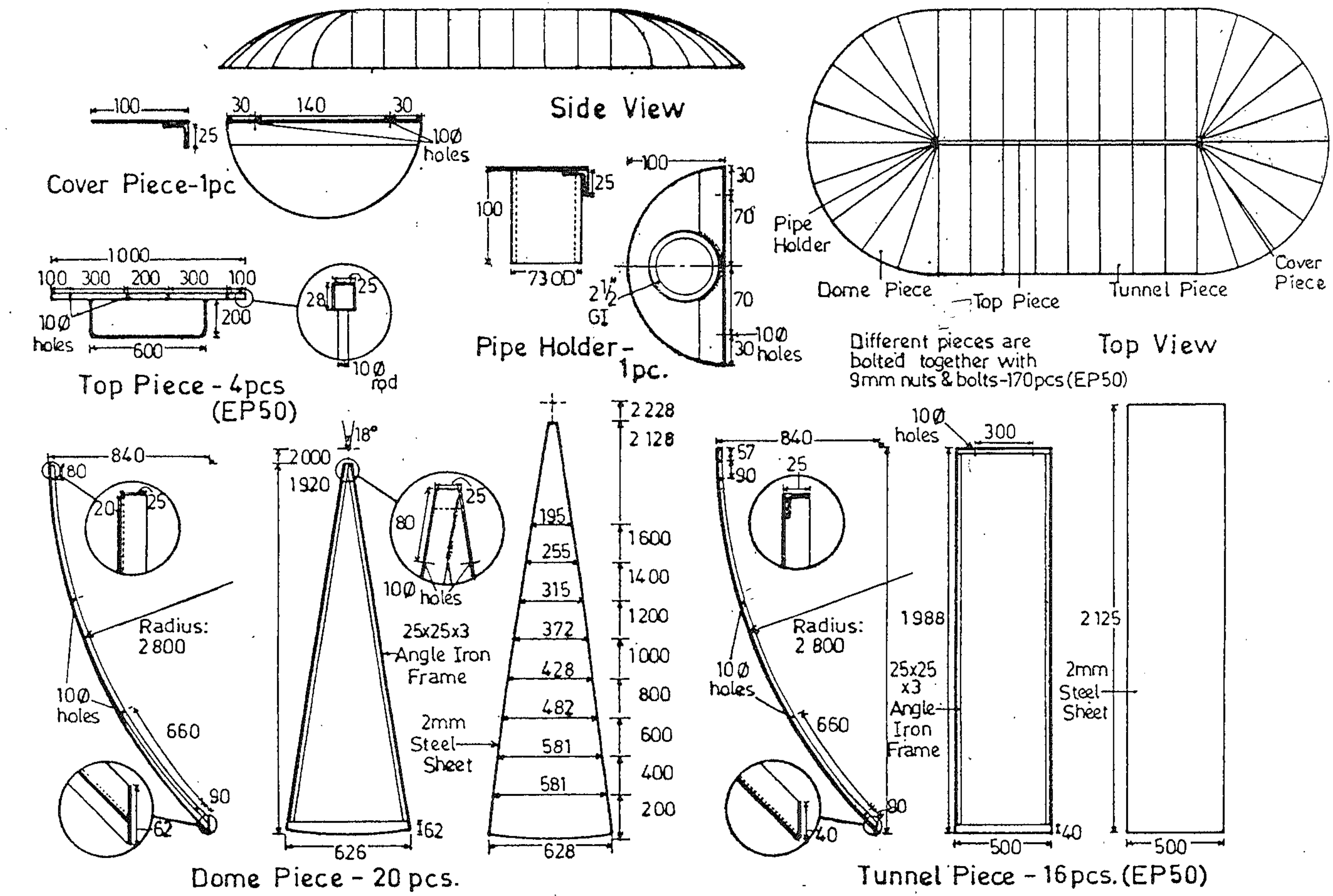


Figure 14.4 Steel Mould for Extended Dome Biogas Plant

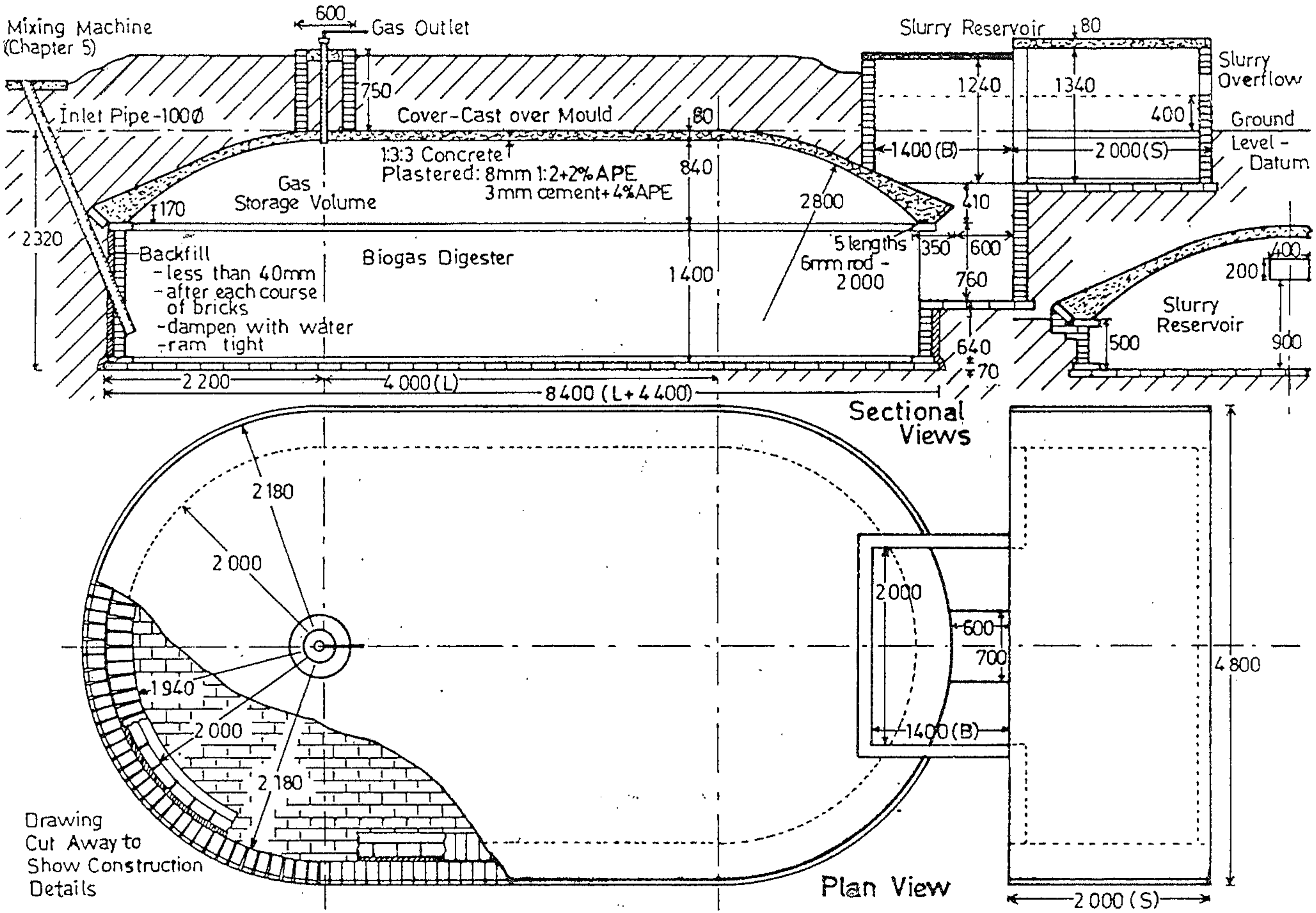


Figure 14.5 Extended Dome Biogas Plant (EP50)

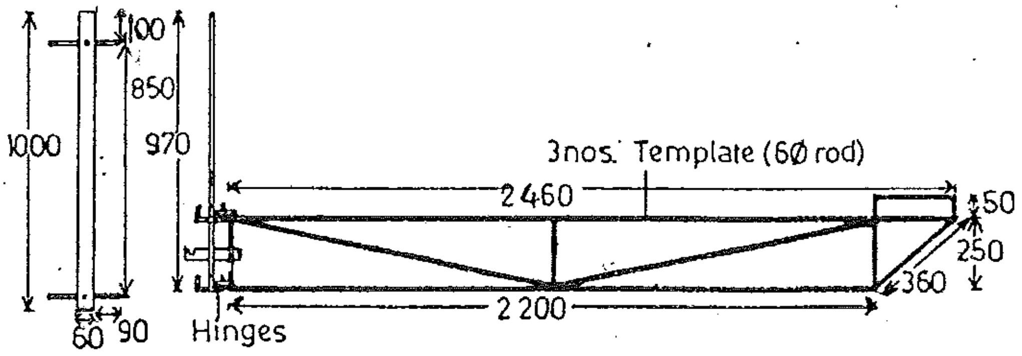


Fig. 14.6 Steel Template and Gas Outlet for Extended Dome Plants

The inside of the dome is carefully cleared of mud, dampened with water and plastered with mixtures of cement, sand and acrylic emulsion in the same way as dome plants (8 mm of 1:2 with 2% paint + 3 mm of cement with 4% paint). If the bricks and outside soil are likely to be porous and leak slurry, the inside of the digester pit can also be plastered (1:1:6 of cement, lime and sand).

The cover over the digester pit is made in the same way as the digester pit roof, except that the inside need not be plastered. For these larger plants, a mixing machine should be used to mix the slurry. A conventional mixing machine (see Chapter 5) or a larger version of the Achemedes screw machine could be used.

Table 14.2 Characteristics of Extended Dome Biogas Plants

Plant Type	Work Vol m^3	Ret. Time day	1:1 Mix			1:1/2 Mix		
			Dung kg	Water lit	Gas m^3	Dung kg	Water lit	Gas m^3
EP20	20.2	78	130	130	4.02	170	90	5.36
EP35	33.7	77	220	220	6.78	290	150	9.03
EP50	47.2	79	300	300	9.31	400	200	12.41
EP65	60.7	76	400	400	12.29	530	270	16.38
EP80	74.2	74	500	500	15.26	670	330	20.35
EP95	87.7	73	600	600	18.24	800	400	24.31

14.5 Practical Experience with Extended Dome Plants

At the time of writing, one extended dome plant has been built, an EP50 biogas plant. The steel mould system for the roof worked well, the roof proved easy to make and the mould could be removed without too much difficulty. The inside surface of the roof proved to be a little too smooth for good plastering, so it was scrubbed with a wire brush and roughened with a chisel, to provide a key for the plaster. This plant will be carefully followed-up, as will the other EP50 plants that are now on order from the Gobar Gas Company. As the technology involved in this design is an extension of a technology that is known to work well (that of the dome plants), the staff of the Gobar Gas Company do not expect any problems to occur in these plants.

Table 14.3 Material Quantities for Extended Dome Plants

Materials	EP20 Plant	2 m Tunnel (T)	EP50 (EP20 + 2T)	EP95 (EP20 + 5T)
Bricks	3,000	1,100	5,200	8,500
Cement kg	950 (22)	700 (16)	2,350 (54)	4,450 (100)
Sand lit	2,400 (70)	1,500 (44)	5,400 (156)	9,900 (285)
Gravel lit	1,400 (41)	1,200 (35)	3,800 (110)	7,400 (212)
Steel rod	130 m (6mm)	-	100 m (6mm)	100 m (6mm)
Gas Outlet	1 m	-	1 m	1 m
Inlet Pipe	2.7 m	-	2.7 m	2.7 m
Mix machine	1	-	1	1

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