A TECHNO-ECONOMIC ANALYSIS OF BIOGAS PLANTS

A Project Thesis

By

Dilip Kumar Paul
B. Sc. Engg. (Mechanical)

AUGUST 1999
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
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Submitted to the Department of Industrial and Production Engineering, Bangladesh University of Engineering and Technology, Dhaka, in partial fulfillment of the requirements for the degree of Master of Engineering in Industrial and Production Engineering.

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Approved as to the style and content by:

1. 19/9/99
Dr. A. N. Mustafizul Karim — Chairman
Associate Professor
Department of IPE, BUET
Dhaka, Bangladesh

2. 19-9-99
Dr. Md. Abdur Rashid Sarkar — Member (External)
Director, Centre for Energy Studies
BUET, Dhaka
Bangladesh

3. 19-9-99
Dr. Golam Mohiuddin — Member
Professor and Head
Department of IPE, BUET
Dhaka, Bangladesh

AUGUST 1999
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DHAKA, BANGLADESH

CERTIFICATE

This is to certify that this work has been done by me and it was not submitted elsewhere for the award of any degree or diploma or for any publication.

19/9/99

Supervisor

Author

DEDICATED

TO

The memory of my GRANDFATHER

and all those who were killed along with him

in the Liberation war - 1971

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The Author

ABSTRACT

Renewable energy sources are playing a vital rolc in the developed as well as the developing countries to meet partially the need of global energy. Long term sustainable development requires a gradual shift towards renewable sources of energy that are more evenly distributed and environmentally less destructive than fossil fuel sources. In this respect, biogas plant could be one of the renewable sources of energy that offers Bangladesh with the prospect of increasing its energy supplies in a self-reliant way along with attended economic, social and security benefit.

Biogas plants of different sizes have been installed in different parts of Bangladesh. There are three different types of biogas plant - (i) Fixed dome biogas plant (ii) Floating cover biogas plant and (iii) Bag design biogas plant. Floating cover biogas plant has higher initial capital cost and shorter working life. Bag design biogas plant incurs higher capital cost and low gas delivery pressure than fixed dome biogas plant. Considering relative advantages and disadvantages of the different types of the biogas plants, the fixed dome plant is mainly used in the country. The technology of biogas plant is very simple. Gas is generated from the plant by anaerobic digestion of cow-dung/animal dung in the absence of air. The biogas is currently used for cooking, lighting and as fertilizer on the land. The plants are not very costly, the major share of costs are incurred at the initial stage. The operating and maintenance costs are quite low.

The present work attempts to study some technological parameters of commonly used fixed dome biogas plant and identify a tecno-economic viable size of biogas plant. Cost figures relating to plant fabrication have been collected from various sources and other cost items were estimated on the basis of available information. It has been found that fixed dome biogas plant is very suitable in the context of Bangladesh. It has also been observed that economic viability of biogas plant increases with the size of biogas plant. Sensitivity analyses were performed to identify the limiting conditions under which biogas plant would be functioning economically. Through this study, technological suitability in the context of prevailing situation, economic viability, and future scope of biogas plants have been

evaluated. The findings of this study could give some directions and guidelines for future planning and implementation of biogas plants in Bangladesh.

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Introduction

1.1 General

Economic growth and development are neccssary to reduce poverty and human deprivation in the developing countries. Such growth and development also offer a way of limiting unsustainable population increases; any constraints on growth could be counter productive [1]. Thus developing countries are keen on achieving higher growth and exports. Inherent in their plans for economic expansion is the positive relationship between energy and GDP (Gross Domestic Product). In low-income countries generally, commercial energy consumption is growing at 3.6 percent annually compared to a GDP growth rate of 2.5 percent [2]. Commercial energy consumption is expected to continue to rise more rapidly than the growth of national economies of developing countries. The proportion of developing countries' national budgets dedicated to promoting commercial energy is very high. Such a large allocation for energy is at the cost of many other aspects of development [3].

In recent years most of the emphasis of energy devclopment is exclusively on electricity and oil in the developing countries. The high dependence of developing countries on traditional biomass fuel is often neglected. In developing countries about 38 percent of total energy is provided by traditional biomass fuels [4] and in countries like Bangladesh the share of traditional biomass fuels can be as high as 75-90 percent [5].

The current pattern of commercial energy oriented development has led to very large increases in the consumption of electricity and oil, resulting in inequities, external debt, and environmental degradation as has been experienced by many developing countries. Large proportions of the rural population and urban poor continue to depend on low quality energy sources such as firewood for cooking and kerosene for lighting. The conventional paradigm of development characterized by commercial energy supply oriented policies may not be sustainable.

Thus the search is for alternative approaches to energy and development, which include the efficient use of energy and alternative sources of energy, particularly renewables should be made desperately.

1.2 Energy scenario in Bangladesh

Bangladesh is acclaimed to be rich in natural gas. Natural gas is a source of non-renewable energy. Twenty gas-fields have so far been discovered till now and have proved storage of 23.093 trillion cft. Out of this, 13.737 trillion cft is extractable. Presently 48% of the natural gas is used for generating electricity, 31% for fertilizer, 11% in the industry, 2% for commercial use and 8% for household use. Considering the current and future rate of use this gas storage will meet the demand of Bangladesh up to 2015 to 2020 AD [6].

Oil is the non-renewable primary mineral source of energy. But there is not enough oil field explored till today. The only oil field that discovered is in Haripur and having 10 million barrel capacity. Presently, 45000-barrel oil is required everyday in Bangladesh and the major portion of it is imported from the Middle East. In the total demand of oil, 50% is diesel, 25% kerosene, 10% fuel and 8% petrol and Bangladesh has deficiency in diesel and kerosene [6]. The demand for oil and oil-product is increasing at the rate of 2.5 to 3.0 %. The Government has to spend Tk.1400 crores every year for importing 15 million barrel of oil and oil-product [6].

The per capita energy consumption is widely accepted as an index of development of a country. Though the installed total electricity generating capacity of Bangladesh is 3100 MW, Bangladesh Power Development Board has produced a maximum of 2384 MW till 12th November 1998. Now twenty power plants of the country have the generating capacity of not more than 2450 MW. The current demand of electricity per day is 2450 MW; but BPDB is generally producing 2100 MW to 2200 MW. As a result there is load shedding almost everyday. Because of power disruption industrial growth is seriously hindered. Table 1.1 below provides information on per capita GNP, electricity consumption in different countries [6,7]. This shows that electricity consumption in Bangladesh is much lower than even most of the neighboring countries.

Table 1.1 Per capita GNP and electricity consumption

Country	GNP (US $)	Per capita electricity consumption (kwh)
Bangladesh	265	68
Pakistan	440	358
India	330	350
China	370	546
South Korea	4500	2259
Singapore	12890	5218
Taiwan	8000	3870
Australia	19590	9161
USA	22560	12170
Norway	24160	25083

There are legitimate explanations for such a low consumption of energy in the country. Development of this sector was hampered in the past due to several factors, such as the need for emergency rehabilitation tasks following the war of liberation, subsequent global energy crisis and constraints in resources, both financial and indigenous energy sources. Consequently the development of this sector was slow during the first decade after liberation of the country in 1971. It has, however, been possible to increase the generating capacity of the national grid by about 120% over the last few years [8].

Future growth in demand for electricity should be high in keeping with national goals for economic emancipation. This endeavor could be handicapped both due to resource constraints and demands from other competitive sectors of economy. Attempts should, therefore, be made to harness the alternate sources in order to meet the energy requirements of the country. In this respect biogas plant may be considered as a prospective alternative.

1.3 Biogas - a new alternative

Renewable energy sources are playing a very important role in the developed as well as the developing countries. Such renewable energies offer developing countries the prospect of increasing their energy supplies in a self-reliant way at national and local levels along with the attended economic, social, and security benefits [9]. Long term sustainable development in all countries, and particularly developing world, requires a gradual shift towards renewable sources of energy that are more equitably distributed and less environmentally destructive than fossil fuel sources [10].

Table 1.2 World Energy Council projections of 'minimum'/ 'maximum' contribution from 'new' renewable energy (WEC 1993)

	In 2020 'minimum'		In 'maximum' with major policy support	
	MTOE	% of total	MTOE	% of total
'Modern' biomass	243	45	561	42
Solar	109	20	355	26
Wind	85	16	215	16
Geothermal	40	7	91	7
'Small' hydro	48	9	69	5
Oceanic	14	3	54	4
Total	539	100	1345	100
% of total energy demand		3-4		8-12

New projections show that by the year 2025 with the adequate support, renewables could contribute nearly 30 percent of direct fuel use and 60 percent of global electricity supplies [3]. Further projections for 2050 show that much of the world growing energy needs could be met by renewables at prices lower than those forecast for conventional energy [11].

The recent World Energy Council report (WEC1993) makes a conservative projection (Table 1.2) for renewables and, according to the minimum possible scenario for 2020, 'new' renewables would meet 3-4 percent of total energy, amounting to 539 MTOE (Million Ton Oil Equivalent) compared to the 1990 level of 164 MTOE. Under the maximum possible scenario with major policy initiatives, renewables could provide 8-12 percent of total energy by 2020 (1345 MTOE) [3]. These renewable energy sources include biomass, solar, wind, geothermal, small hydro and oceanic energy. According to WEC (1993), under the minimum case or low scenario, biomass is the most important of the renewables and is projected to account for 45 percent of the new contribution by rernewables to world energy by 2020. In the maximum scenario projections, modern biomass will account for 42 percent of the total renewable energy contribution by 2020. Unlike solar, wind or micro-hydroelectric systems, modern biomass energy systems could be set up in virtually any location where plants can be grown or domestic animals are reared. Biomass energy includes energy from all plant matter and animal dung in the form of gas called biogas.

1.4 Sources of energy for cooking and lighting in rural areas

The household in the rural and some urban areas use firewood, twigs, brushwood, crop residue, jute cane, animal dung etc. for cooking. In most of the cases they buy these fuel. The combustion of fuel wood contributes to the depletion of forests. A serious environmental problem is that combustion of fuel wood for cooking leads to indoor air pollution with serious health consequences [12] while the emission of CO_2 from fuel wood used for cooking is estimated to contribute to about 2 percent of global warming [13]. Biogas generated from biogas plant can meet the fuel requirement of cooking without causing any health or environmental pollution.

The kerosene lamp or kerosene pressure lamp is used for lighting in the rural and some urban areas of the country. In the rural areas, biofuel account for 90-95 percent of total energy in Bangladesh. The remaining 5-10 percent mostly kerosene for lighting [14]. The kerosene requirement for lighting can be replaced using biogas fuelled hajack.

1.5 Dissemination of the technology

It is true that a technology can not be widely implemented instantaneously in a society. It undergoes some gradual diffusion process of familiarization to the people to get social acceptance. The biogas technology is no exception. The Government of the People's Republic of Bangladesh has taken some projects of biogas plant for various end-uses such as cooking and lighting. These projects have been implemented through Bangladesh Council of Scientific and Industrial Research (BCSIR) and Local Government and Engineering Department (LGED).

In addition to meeting the heating requirements at micro level, if used in a sustainable way, biogas could lead to no net emission of CO_2 and, in fact, would lead to a reduction of greenhouse gas emissions when used as a substitute for fossil fuels [15].

In spite of its entire attribute, it has some inherent problems such as availability of cow dung and low energy density. Thus the energy output is greatly dependent on the availability of cow dung. Despite of all these shortcomings the biogas plant with low operation and maintenance cost complement and supplement the efforts of the Government for attaining self-sufficiency in the energy sector.

1.6 Aims and Objectives

There have been a number of studies on the techno-economic, social and organizational aspects of biogas technology in developing countries. Different studies indicate that BCSIR has conducted a number of technological assessment of the biogas plant [16]; but no detailed cost economic analysis with respect to plant size has been conducted although a few studies do provide some preliminary indication on their economic viability [17].

The current project work makes an attempt to make a detailed economic analysis of the various commonly used biogas plants now in use in the country. Biogas is not traded, and, therefore, has no market price, hence it has to be valued according to equivalents that are traded [17]. Therefore the aim of the study is to analyze technical and economic performance of the biogas plant of different sizes by estimating the market price of their equivalents i.e. fuel-wood, kerosene and fertilizer. Following are the objectives with specific aim and possible outcome:

I. To make critical study of some technological parameters of commonly used biogas plants.

II. To identify a techno- economic viable size of biogas plant.

Chapter 2

Background Study and Literature Survey

This chapter provides a review of the available work on the technical and the economic performance of the biogas plant.

Biogas programs of China and India are often quoted as examples for initiation of biogas projects in other developing countries. China started its biogas program in 1958 and installed 8 million plants by the end of 1979. Analysis of official Chinese statistics from 1980 shows that, of all the biogas plants constructed until 1979, only about 55% were functioning normally. In India the biogas program was started in the 1960s. A national biogas program was initiated in 1977 and a total of 280,000 biogas plants were installed up to the end of 1984 [18].

On the basis of a review of the experience of the extensive biogas program in China and India the Government of the People's Republic of Bangladesh has initiated a biogas implementation project. During 1980-81, 110 biogas plants have been set up in Bangladesh by Environmental Pollution Control Directorate (EPCD). These plants are of the fixed dome Chinese design with certain modifications. This design requires minimal maintenance. In the Chinese model, inlet and outlet are at the same level. In the EPC model, the inlet is at lower level. This has enhanced the performance of the plants by increasing the speed of digestion. Another improvement that EPC has made on the Chines model is wooden floating arrangement at the inlet and outlet to break the scum and agitate automatically upon charging [19].

Bangladesh Agricultural Research Institute has three biogas plants. Two Indian types are at Jamalpur and Jessore regional stations, and one Fixed Dome Chinese type is at Ishurdi, Pabna. The plants at Jamalpur and Jessore were of the floating metallic drum type, which were constructed in 1980 at a cost of Tk. 7000.00. The Jessore plant has a capacity of

50cft gas a day. This Indian digester eats cowdung and pure water at a ratio of 1:1 by volume. It is necessary to keep the lid on. The Jamalpur plant has a daily production of 100 cft and was constructed in 1980 at cost of Tk. 9000.00 [19]. In both the plants scum is broken by the manual rotation of the floating drum. The problems encountered in both the technologies are as follows:

(a). They are made of mild steel sheeting, not readily available in rural Bangladesh.

(b). Construction requires welding, a skill not wide spread in rural Bangladesh.

(c). The 6 (six) feet diameter drum is hard to transport in rural Bangladesh, where roads are often non-existent.

(d). As the dome is made of metallic structure, there is always a problem of corrosion. As a result, the structure is less durable.

(e). Only slurry or liquid type of charge can be fed to the digester.

The fixed dome plant at Ishurdi is made of RCC with pudloo cement. This type of construction inhibits gas leakage. It was constructed in 1981 at a cost of Tk. 14000.00. The main advantages of this plant are:

(a). It has reasonable bearing capacity.

(b). It can be built anywhere.

(c). Building materials are locally available.

(d). It can be constructed very easily.

(e). Low building cost and good suitability.

(f). Simple structure and the masses are willing to erect it.

Ganoshasto Kendro has a biogas plant of the Chinese fixed dome design slight modification. Pressure of the gas in the tank is monitored by a manometer. The digester has a capacity of 100 cft. The plant is capable of operating a stove and a lamp for one family. EPC has built and operates an Indian type biogas plant of floating drum design at Savar Dairy Farm. The plant has capacity of 200 cft and the cost incurred was Tk. 20000.00 [19].

The main organizations concerned with the biogas demonstration projects are the Institute of Fuel Research and Development, the Environmental Pollution Control Directorate (EPCD), Bangladesh Agricultural University, Mymensingh and Bangladesh Small Cottage Industries Corporation. Up to June 1984, 219 biogas plants had been installed by EPCD of which 110 were of fixed dome plants and 109 were of floating gas holder type plants. Total installation cost of plants was met from government grant [18]. Two photographs of 100 cft plant at Dour, Uttara and 450 cft plant at Kamarpara, Uttara, Dhaka are presented in the appendix-B as Fig. A1 and Fig. A2.

A Danish International Development Agency (DANIDA) study (Kock 1984) reported that out of a total of 249 installed biogas plants, 130 (52%) units were of the floating gas holder type, 112 (45%) of the fixed dome type and 79 (3%) of the bag type design. The users of 87 (35% of total) were surveyed which indicated that 73% of the plants were found to be in operation. The installation cost of a 100 cft floating gas holder type biogas plant varied from Tk.3500.00 to Tk.21000.00 and the fixed dome type varied from Tk.6500.00 to Tk.35000.00 [18].

Considering the relative advantages and disadvantages of biogas plants of different designs, a comparative study was made by the Planning Commission of all thanas prior to setting up fixed dome Chinese biogas plant in each one [19]. Presently, Institute of Fuel Research and Development of BCSIR and LGED are pioneers in the installation of biogas plants. The BCSIR is advocating in the building up of biogas through active participation of the government (by providing subsidy in the form of cash) and the user.

The cost of a biogas plant mainly depends on its size and the design. The biogas programme can be assessed with respect to the acceptance or use levels, the benefits derived, the physical achievement as compared to its potential, and the analysis of the barriers to expansion of the programme.

Economic analysis usually includes calculations of the parameters such as payback period, net present value, internal rate of return, benefit cost ratio etc. For a project to be economically viable, the payback period must be less than its useful life, the net present value be positive, the internal rate of return be greater than the rate acceptable to the society and the discounted benefit-cost ratio should also be more than unity. But any single indicator is not deemed to be sufficient to reflect the overall economic attractiveness of the project. Decision making in this respect will depend on the policy of the country regarding economic indicators and conditions to be satisfied by a given project.

In the context of Bangladesh, most of the projects are in the public sector, for which, there are prescribed procedures for appraisal of projects. According to the criteria set by the Planning Commission, the three indicators used for assessing viability of any project are:

(A). Net present value at a selected discount rate should be positive;

(B). The internal rate of return must be at least equal to a selected discount rate, and

(C). Benefit-cost ratio at a selected discount rate must be greater than unity.

There are differences of opinion in considering a discount rate for appraisal of a project. Planning Commission insists that a new project must meet the above criteria at a discount rate of 15%. On the other hand, international development financing institutions like the Asian Development Bank and the World Bank suggests that an infra-structural project like energy should have a lower discount rate, namely 8-10%. In the present study, therefore, all the analyses are performed for a range of discount rates.

It is often suggested that environmental advantages should be quantified in appraisal of energy related projects. Biogas technology in this respect should have advantages over its alternatives. However, it is difficult to quantify such benefit. The social benefits can be taken care of either by selecting a lower discount rate by assuming governmental support, probably in the form of subsidy.

The biogas programme has been introduced very recently and therefore there is no cost economic analysis presently available in the country. As no study specific to the one conducted by the author has been done, the author would like to mention some of the studies on the economic performance of biogas plant installed in different parts of India.

In the study of P.B.Ghate [20] where two biogas plants (KVIC floating drum design) one of 35 m^3 capacity and the other of 45 m^3 capacity have been provided with a combined gas production capacity of 80,000 litres (2800 cft) a day. The project was commissioned in 1978 and purpose was to supply gas for cooking, lighting through generator or gas lamps and also for pumping safe drinking water. Total initial capital cost was Rs.75061.00 (equivalent to Tk.487896.50) i.e. Tk.174248.75 per 1000 cft as of 1999 (1US$=Rs.7.50 during 1977-78 and 1US$=Tk.48.75 during 1998-99) and the expected life of the project was 20 years. The benefit cost ratio of the project when illumination was provided through lamps was 1.54:1 at 10% discount rate. Discounting cash flow technique was used. Following assumptions were made in conducting the analysis:

(a). Per day availability of cow-dung = 1524 kg.

(b). Gas production in winter from 1 kg of cow dung = 38 litres.

(c). Gas production in summer from 1 kg of cow dung = 55 litres.

(d). The energy content of 28 litres (1cft) of gas is 135 kcal and assuming 60% efficiency of a gas burner the effective heat utilization is 81 kcal per 28 litres.

(e). 1 kg of coal provides 1761 kcal of effective heat if burnt in an open chula with 28% efficiency.

(f). Economic cost of soft coke is Rs. 152.00 per ton (equivalent to Tk.988.00).

(g). 28 litres of gas can be replaced by 0.018 litres of kerosene oil for lighting.

A case study of Pura village [3] in India where Rajabapaiah et al. (1993, 1994) has conducted an economic analysis of the biogas electricity generation system based on the field operation. The biogas plant was a floating drum KVIC design with a mild steel drum gas holder. The biogas plant has the potential to generate 42 m^3 per day (equivalent to 1470 cft) of biogas. The biogas fuels a diesel engine generator system of 5 kW capacity. The cost of electricity (from the centralized system) was estimated using discounting cash flow technique. The capital cost of the biogas plant was US$ 2554.00 (1US$=Tk.48.75) which is equivalent to Tk.124507.50 i.e. Tk.84699.00 per 1000 cft as of 1999.

Ramesh Bhatia et al. (1977) has conducted a study on Energy Alternatives for Irrigation Pumping [21]– where it has been mentioned that the capital cost for a 100 cft and 200 cft Chinese type biogas plant are Rs.1286.00 (equivalent to Tk.8359.00) and Rs.2461.00 (equivalent to Tk.15996.00). In the calculation it has been assumed that 25% of the costs of cement concrete work, brick-work, slab and plaster are unskilled labour.

Review of the available works indicate that:

(a). Biogas can qualify as an alternative for cooking and lighting.

(b). Fixed dome Chinese design biogas plant is very suitable in rural Bangladesh.

(c). The size of the biogas plant should be selected in keeping with the number and size of the household in a village.

(d). Location of the biogas plant should be such that cow dung is available at that particular location.

(e). Cost-economics of biogas technology and its alternatives such as fuel wood, kerosene etc. should be considered in making a proper economic analysis.

(f). Discounting cash flow technique and payback period should be used in economic analysis and different indicators (like NPV, BCR, IRR etc.) of different plant sizes be compared according to the relevant acceptable criteria.

(g). There are uncertainties in different cost components, its future trend. Therefore, calculation should preferably be made for ranges of above parameters. This could eliminate many of the associated uncertainties in cost estimation and analysis.

Chapter 3

Biogas Plant

3.1 Introduction

The decay of organic matter, particularly human, animal and plant wastes, in the absence of air produces an inflammable gas which contains methane and carbon dioxide. The gas is known as biogas and the process as anaerobic digestion or fermentation. Biogas can be used for cooking, lighting, refrigeration and for running petrol or dual fuel engine.

3.2 Types of biogas plant

Biogas technology in the form of two basic designs – the fixed dome (Chinese) and floating cover (Indian KVIC) has been in use in many developing countries for many years. The bag design (Taiwan) is also becoming popular in some countries. The fixed dome design is mainly used in Bangladesh and has been discussed in detail in this chapter. The construction of various commonly used technologies is also briefly discussed.

3.3 Floating Cover Design

This type of digester is most commonly used for treating sewage sludge in developed countries. The design consists of cylindrical reactor with an H/D ratio of between 2.5 and 4.1. The reactor is usually constructed of brick, although chicken wire reinforced concrete has been used. The construction does not have to be as strong as the fixed dome type since the only pressure on the wall is the hydrostatic pressure from the liquid contents. The gas produced in the digester is trapped under a floating cover on the surface of the digester, which rises and falls on a central guide. The volume of the gas cover is approximately 50 percent of the total daily gas production, and the cover is usually constructed of mild steel, although due to corrosion problems other materials such as ferrocement and fiberglass have been used. The pressure of the gas available depends on the weight of the gas holder per unit area, and usually varies between 4 - 8 cm of water pressure [17].

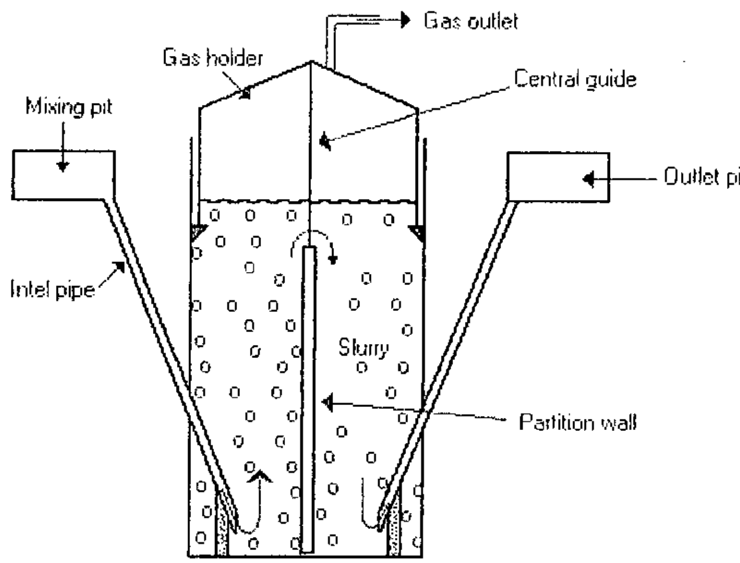

Fig.3.1 Floating cover digester

The reactor is fed semi-continuously through an inlet pipe, and displaces an equal amount of slurry through an outlet pipe. Typical detention time varies from 30 days in warm climates to 50 days in colder climates. The design and operation of such plants are primarily empirical and there is little understanding of the fundamental processes involved.

3.4 Bag Design

The bag digester is a cylinder made up of either PVC, a Neoprene coated fabric (nylon), or red mud plastic (RMP). Inlet feed and outlet pipes, and a gas pipe are integral part of the bag. The feed pipe is arranged such that a maximum water pressure of approximately 40-cm is maintained in the bag [17]. The digester acts essentially as a plug flow reactor, and gas produced is usually stored in the reactor under the flexible membrane, although it can be stored in a separate gas bag.

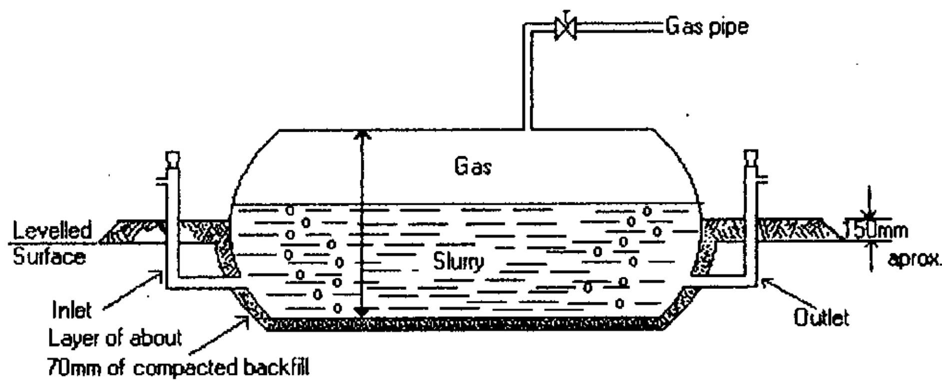

Fig.3.2 Bag digester

The complete membrane is extremely light, and can be installed easily by excavating a shallow trench slightly deeper than the radius of the digester. The basic design was originated in Taiwan as a result of problems experienced with brick and metal digesters.

3.5 Fixed Dome Design

This is the most common digester type, and the basic design originated in China. The reactor consists of a gas tight chamber constructed of bricks, stone, or poured concrete. Both the top and bottom of the reactor are hemispherical, and are joined together by straight sides. The inside surface is sealed by many thin layers of mortars to make it gas tight. The digester is fed semi-continuously (i.e. once a day) and the inlet pipe is straight and ends at mid level in the digester. The outlet is also at mid level, and consists of a fairly large storage tank. There is a manhole plug at the top of the digester to facilitate entrance for cleaning, and the gas outlet pipe exists from the manhole cover.

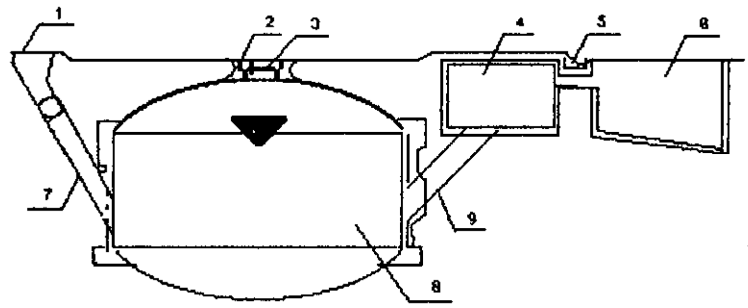

Fig.3.3 Fixed dome digester

1: Inlet 2: Gas pipe 3: Moveable cover 4: Hydraulic chamber 5: Overflow pipe 6: Manure storage tank 7: Inlet pipe 8: Fermentation chamber 9: Outlet pipe.

The gas produced during digestion is stored under the dome, and displaces some of the digester contents into the effluent chamber leading to gas pressures in the dome of between I - I.5 m of water [17]. This creates quite high structural forces, and is the reason why the reactor is hemispherical top and bottom.

3.5.1 Principle of Biogasification / Methano Fermentation

The conversion of biomass to CO_2 and CH_4 in anaerobic methane fermentation takes place by the concerted action of three major metabolic groups of bacteria, namely fermentative bacteria, acetogenic bacteria and methanogenic bacteria. Fermentative bacteria hydrolyse the primary substrates to acetate and other saturated fatty acids, CO_2 and H_2 as major end products. The obligate H_2 producing acetogenic bacteria produces H_2 and acetate and sometimes CO_2 from the end products of the first group. The methanogenic bacteria catabolise mainly acetate, CO_2 and H_2 to CH_4 and other terminal products. Anaerobic fermentation of biomass to methane by the three major metabolic groups of bacteria [22] is shown in Fig. 3.4

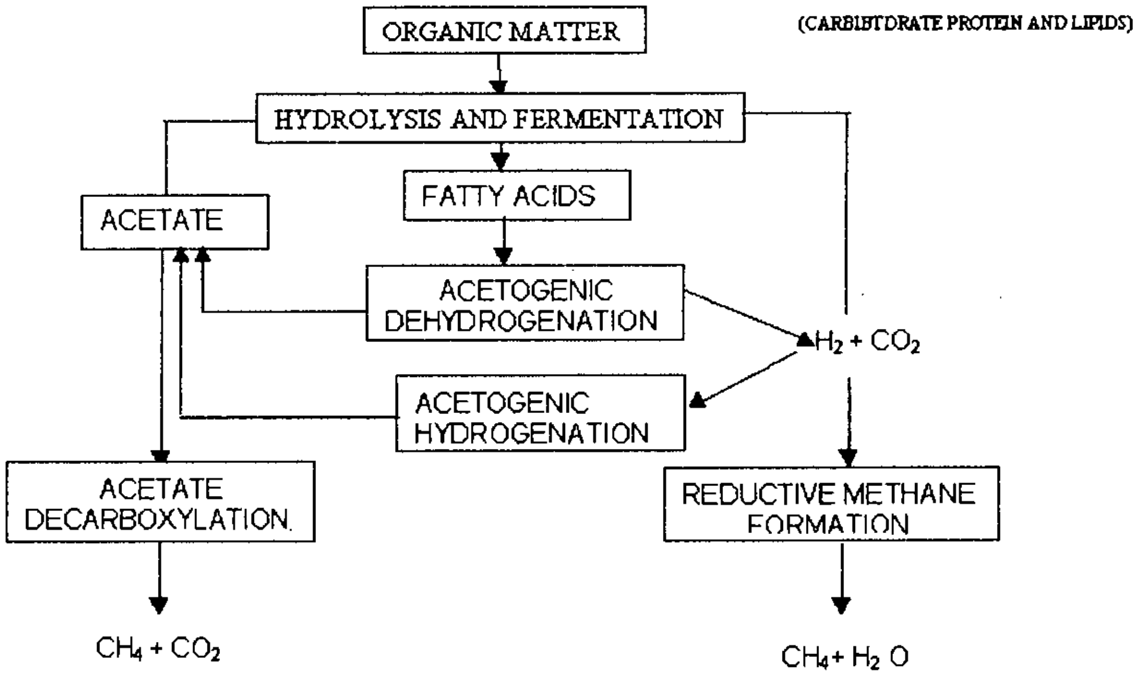

Fig.3.4 Methano fermentation.

Fermentative Bacteria: The fermentative bacteria consist of a number of bacterial species. Most of these are obligate anaerobes, but some facultative anaerobes like streptococci and enteries may also be present. The anaerobic mesophilic species are from the genera, namely Bacteroides, Clostridium, Butyrivibrio, Eubacterium, Bifidobacterium, and Lactobacillus. In the cattle manure digesters, mainly gram negative, non-sporing anaerobes are found. Ammonia usually serves as the main source of nitrogen and is essential for some species.

Methanogens: The presence of methanogenic bacteria is essential for anaerobic degradation, as only these organisms can catabolise acetate and hydrogen to gaseous products in the absence of light, oxygen, sulphate and nitrate.

Methanogens are composed of many different species having quite different cell shapes and structures. But these are the only group of bacteria that derives some energy for their growth through known mechanisms that lead to the formation of CH_4. These grow strictly under anaerobic conditions. Most of them require a mineral salt media with CO_2, ammonia and sulphide as the main carbon, nitrogen and sulphur sources, respectively.

Fermentation of Polysaccharides: Polysaccharides such as cellulose, hemicellulose, pectin and starch are hydrolyzed to sugars and oligosaccharides, which are then taken up by the bacteria and fermented to a variety of products.

The H_2 – producing Acetogenic Bacteria: Ethanol degradation occurs according to the following chemical equation:

$2CH_3CH_2OH + HCO_3^- = 2\,CH_3COO^- + CH^+_4 + H^+ + H_2O$

Fatty Acid Oxidizing and H_2 - producing Bacteria: Fatty Acids are oxidized as follows:

$CH_3CH_2CH_2COO^- + 2H_2O = 2CH_3COO^- + H^+ + 2H_2$

Substrates: Thermophilic Methanosarcina species use H_2 and CO_2 for their growth according to the following chemical equation:

$4H_2 + HCO_3^- + H^+ = CH_4 + 3H_2O$

Only a pure culture of Methanosarcina species is capable of degrading acetate as follows:

$CH_3COO^- + H_2O = CH_4 + HCO_3^-$

3.5.2 Factors Affecting Anaerobic Fermentation of Cow-dung

The major factors which affect the formation of biogas from cattle–dung are: temperature, pH, percentage of C and N, solid organic matters and water in the slurry, retention time, volumetric organic loading rate and nutrients.

Temperature: Anaerobic fermentation of raw cow-dung can take place at any temperature between 8 and 55^0 C. The value of 35^0 C is taken as optimum. The rate of biogas formation is very slow at 8^0 C [22].

pH: The pH of the cow-dung slurry can be varied from 6.8 to 7.8. The pH above 8.5 should not be used, as it is difficult for the bacteria to survive above this pH.

Concentration of C and N: The methanogenic bacteria need both C and N for their survival. But they consume C at a rate 30 to 35 times faster than that of N. The optimum ratio of C: N may be taken as 30: 1. The fermentation should be carried out strictly in the absence of O_2, i.e. under- anaerobic condition [22]

Proportion of solid and Water: Anaerobic fermentation of cow-dung proceeds well if the slurry contains 8 to 9% solid organic matters. As cow-dung contains about 18% solid, the slurry should be diluted with water in the ratio, cow-dung : water = 1:1. The following is the production of biogas from a slurry (where cow-dung: water=1:1):

In summer at 47^0 C- 0.06 m^3 / kg cow-dung added / day.

In winter at 8^0 C- 0.0 3 m^3 / kg cow-dung added/ day [22].

Retention Time: The retention time (RT) of the system refers to the volume of the fluid in the reactor per volume of fluids passing into and out of the reactor per day. At a certain fermentation temperature, the protein and carbohydrate fermenting bacteria grow at a rapid rate and the substrates are rapidly degraded to fatty acids at a short RT. But the fermentation of fatty acids do not occur until the RT is increased by four to six times due to slow growth rate of the fatty acid fermenting bacteria.

Volumetric organic loading Rate: The volumetric organic loading rate is defined as the rate at which organic waste is supplied to the reactor. It can be expressed as the percentage weight of organic matter added each day to the reactor volume. It is related to the RT and the percentage of organic matter present in the feed, according to the following equation:

Reactor loading rate per cent = (Percentage of organic matter in feed)/RT

Nutrients: For methane, fermentation substrate should contain sufficient minerals as nutrients for bacterial growth.

3.5.3 Biogasification of Dairy Animal/Cattle-dung by Anaerobic Digestion

As the required groups of bacteria are already present in the raw cattle-dung and these grow in the digester feed, there is no need of adding any bacteria for the degradation of the dung. The fermentation is conducted closed tanks in the absence of oxygen, which inhibits the growth of other undesirable bacteria present. The digestion is carried out at a slurry temperature of about 38^0 C and pH of about 6.8. The digestion time may vary from 15 to 30 days. In the temperature range of 27-38^0 C, the mesophillic bacteria predominate, while at 52^0 C thermophilic bacteria are responsible for rapid rate of fermentation and biogas production. [22]

On an average, the biogas generated from cow-dung is composed of 60% CH_4 and 40% CO_2 under usual conditions of fermentation. But higher percentage of methane in biogas can be obtained under favourable conditions. Negligible amounts of NH_3 and H_2 S are also present in the biogas. Biogasification continues for an indefinite period under controlled anaerobic conditions for a continuous feeding of organic matter.

3.5.4 Working Principle of Fixed Dome Biogas Plant

Fig. 3.5 shows the hydraulic biogas digester after charging and sealing the cover but before initiation. At this moment, the liquid surfaces inside the fermentation chamber and inside the hydraulic chamber are concurrently subjected to one atmospheric pressure, and therefore these two liquid surfaces are at the same level. Their differences both in atmospheric pressure and in liquid surface are zero. The present working condition of the hydraulic biogas digester is described as the "initial working order", the height of slurry surface at the time of the initial working order as 0-0 level, and the remaining space inside the fermentation chamber as V_o.

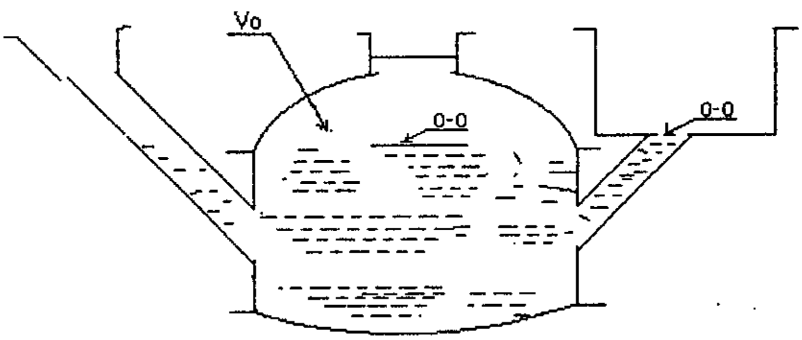

Fig.3.5 The initial working order of the biogas digester

After initiation, the slurry in the digester begins to ferment and produce gas. With the increasing gas yield, the gas storage volume in the upper gas tank of the fermentation chamber becomes getting greater and greater, and at the same time the gas produced presses the slurry in the fermentation chamber into the hydraulic chamber. The volume of the slurry displaced is equal to that of the gas produced. When the gas storage volume inside the fermentation chamber reaches the maximum, $V_{storage}$, the increased slurry inside the hydraulic chamber also rises to the maximum, $V_{storage}$. At this very moment, it can be seen that liquid surface in the fermentation chamber has dropped down to the lowest possible position, A-A level (Fig. 3.6), whereas the liquid surface in the hydraulic chamber has risen to the highest possible position, B-B level. The working order at B-B level is defined as the limit working order.

The dropping of liquid surface in the fermentation chamber and the rising of liquid surface in the hydraulic chamber bring about a difference in the height of these two liquid surfaces. The potential energy of high-level slurry gives the gas inside the fermentation chamber a definite pressure intensity, whose value is equal to the product to the height difference between the two liquid surfaces and the specific gravity of the slurry. Owing to the specific gravity of slurry being near 1, the height difference between the two liquid surfaces is generally considered to be the value of gas pressure in the digester. The height difference between the liquid surfaces at the time of the limit working order is the maximum, hence called the limit biogas pressure. From Fig 3.6 it can be seen that the value of the limit biogas pressure is equal to:

$$\Delta H = H_1 + H_2$$

In the formula,

H1: The maximum dropping value of liquid surface in the fermentation chamber;

H_2: The maximum rising value of liquid surface in the hydraulic chamber;

ΔH: The maximum difference between the liquid surfaces in the digester.

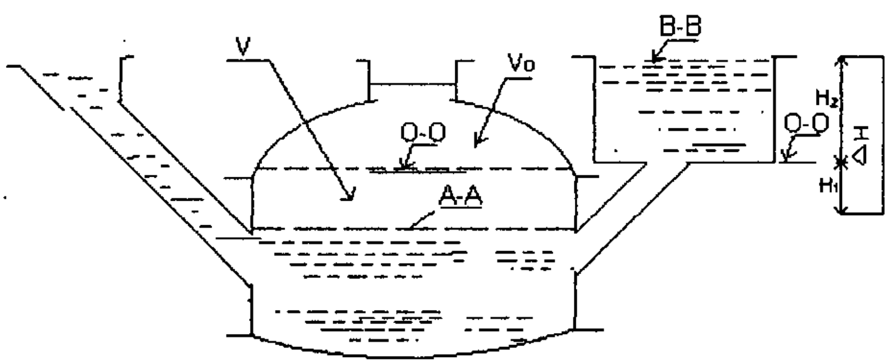

Fig: 3.6 Limiting working order of the biogas digester

A-A: the lowest position of liquid surface inside the fermentation chamber; B-B: the highest position of liquid surface inside the hydraulic chamber; 0-0:the initial position of liquid surface in the digester; V_0: the volume of the dead gas tank; $V_{storage}$: the maximum gas storage volume; H_1: the maximum drop of liquid surface in the fermentation chamber; H_2: the maximum rising elevation of liquid surface in the hydraulic chamber; Δ H: the maximum height difference between the liquid surfaces in the digester.

When users' burners such as biogas stoves, lamps, etc. work, the gas inside the digester is gradually delivered out under the pressure of high level liquid in the hydraulic chamber. With the diminishing gas reserves inside the fermentation chamber, the liquid surface in the hydraulic chamber drops while the liquid surface in the fermentation chamber begins to rise little by little. Now, the pressure of outgoing gas is also getting smaller and smaller along with the decrease of the height difference between the two liquid surfaces. When the slurry surfaces in the fermentation chamber and the hydraulic chamber are at the same level, namely, the digester returns to its initial working order once again, the gas in the digester will not be displaced any more because its pressure is zero.

As a result, the operating process in the biogas digester is exactly an unlimited circulation of continuously producing and consuming gas. And in the course of operation, the hydraulic biogas digester is always within the range of the initial and final limit working orders, and cannot be beyond this range.

3.5.5 Design Consideration

Considering the working principles as described above, the following bases can be considered for the design of the hydraulic biogas digester:

a. The highest position for charging the digester with material (including slurry) can only be the height of liquid surface, which the digester holds in its initial working order. At this very moment, the liquid surface is at 0-0 liquid level; and in the fermentation chamber there is still a part of the upper gas tank capable of storing gas. However, this part of gas cannot be utilized due to no ways to displace it, hence called "dead gas". The space occupied by the "dead gas" known as "idle gas tank", or "dead gas tank".

b. When the slurry surface in the hydraulic chamber is at 0-0 level, that is, at the initial working order, it is at the lowest position, unable to continue dropping. For this reason, if the hydraulic chamber has some slurry lower than 0-0 position, this portion of slurry has no potential energy of action of displacing the gas in the tank, hence being "dead slurry". This portion of hydraulic chamber occupied by the " dead slurry" is known as "idle hydraulic chamber".

As the idle gas tank and the idle hydraulic chamber are of no service to the operation of the digester, utmost restrictions should be imposed on their volumes. Under the principle of meeting the functional requirements, the smaller the volumes of both the idle gas tank and the idle hydraulic chamber, the higher the efficiency of the digester, and the lower the building cost.

c. When the hydraulic biogas digester is in the limit working condition, the liquid surface in its fermentation chamber is the lowest while that in its hydraulic chamber the highest. At the very moment, the pressure in the digester has come to the highest value and , it is called the highest designing pressure. In the course of operation, the pressure in the digester should not go beyond this value, or otherwise the digester will be destroyed because of its overload. In order to prevent the digester from overloading operation, the measure commonly adopted in design is to install the ends of the inlet and outlet pipes (or either pipe) on the intersecting line of the A-A liquid-level surface with the digester body. In this way, when the gas storage amount- exceeds the maximum capacity, namely when the liquid surface is lower than the A-A position, surplus gas will escape of itself from the inlet or outlet pipes, keeping the pressure inside the digester not greater than the highest designed pressure. At the same time, the lower end of overflow hole is designed at the B-B position. In this case, even if the liquid surface in the hydraulic chamber is possible to exceed the B-B position, the excess slurry will also flow out of the overflow hole thus making the level difference between the two liquid surfaces always within the range of the maximum liquid difference.

The three points mentioned above are main bases for the structural design of the hydraulic biogas digester.

3.5.6 Design parameters

Besides the above considerations, the design of the hydraulic biogas digester is also in need of some parameters concerning the technology of biogas fermentation. Its major parameters are described below:

Gas pressure: As biogas burners, including biogas lamps, stoves and kitchens, are capable of normal work only within the range of rated pressure, the gas pressure value should be taken into consideration. In accordance with the practical conditions of rural areas, the designed gas pressure of the hydraulic biogas digester had better be 7,840 Pa, namely, 80-cm water column[23] Too high gas pressure will easily do damage to the digester body so as to cause leakage whereas too low gas pressure is not convenient for the delivery and utilization of gas and will make the hydraulic chamber occupy a too large space. Normally, the gas leakage ratio within 24 hours should be less than 3% when the gas pressure within the digester is 7840 Pa.

Gas production rate of the digester volume: The gas production rate of the digester volume means the gas amount produced by each cubic meter of fermentation chamber per day. The gas production rate represents the productive capacity of the digester under certain conditions. There are many factors affecting the gas production rate such as the temperature inside the digester, slurry concentration, mixing, the kind of fermentation materials, material pretreatment, inoculum, management, type of the digester, etc. Under normal temperature and semi- continuous fermentation conditions, the gas production rate is often variable. As a design parameter, it is only an estimated data for the design. According to the practical situation 0.15 to 0.30 m^3/m^3.day are usually adopted as the gas production rate of the hydraulic biogas digester [23].

Gas storage capacity: The gas storage capacity of the hydraulic biogas digester refers to the maximum gas storage amount inside the gas tank. It depends on the gas generation in the digester and the gas consumption of users. After analysis and testing, it is comparatively suitable to take 12 hours of the gas production amount as the maximum gas storage capacity of the digester for rural cooking use. Since the gas storage capacity equals the slurry amount displaced, it is also equal to the effective volume of the hydraulic chamber.

Digester volume: The digester volume means the volume of the fermentation chamber. It hinges on the population of a family, the gas consuming standard and the gas production rate. According to the present living standard in rural areas and utility, the designed digester volume generally ranges from 100 to 1000 cft.

Input material ratio: The input material ratio refers to the percentage, which the utmost input slurry occupies in the fermentation chamber volume. The size of the input material ratio determines that of the idle gas tank. The higher the input material ratio, the smaller the idle gas tank, and therefore the more economical the digester. And the reverse is also true. However, attention should be paid to the fact that the input material ratio cannot be 100%. The reason is as follows: when the gas pipe is installed, it should stretch 3-5cm out of the downward surface of the movable cover in order to stop maggots from crawling in it so as to cause a blockage; and at the same time, for the purpose of keeping slurry or scum from entering the gas pipe, the liquid surface should be 15 to 20 cm lower than the gas pipe. Accordingly, it is advisable that the input material ratio should generally range from 85-95% [23].

3.5.7 Design of the fermentation chamber

The fermentation chamber can be designed according to the following procedure:
Volume determination: The size of the digester volume chiefly depends on the population of a family, the gas consumption standard and the estimated gas production rate. Their mutual relation is expressed as:

$$\text{Digester volume} = \frac{(\text{cft/person}) \times (\text{No. of persons})}{\text{Estimated gas production rate}}$$

The following points are to be noted:

a. To estimate the gas production rate of the digester volume, the gas production in spring or summer is generally adopted as the standard.

b. From the actual gas consumption condition it can be seen that, on the same living standard, the per capita average gas consumption of a family with more people is a little lower, whereas that of a family with fewer people is a little higher. Accordingly, when the digester volume to be built is determined for a family with more than 6 or less than 3 people, the calculated data should be slightly adjusted.

If the digester is selected from the compilation of standard designs or other publication of commonly used designs, the selected digester volume should be no less than the calculated value.

Determination of the gas storage capacity: The size of gas storage capacity varies with the gas production rate of digester volume and the gas consumption. For rural biogas digesters, hours of gas production, namely, a half of one day and night's gas production, is taken as the storage capacity of the digester, for the gas produced is mostly used for cooking. Its computating formulas are given below:

Gas storage capacity = 1/2 x daily gas production
But, daily gas production = gas production rate x volume
Accordingly, gas storage capacity = 1/2 x gas production rate x volume

Calculation of the fermentation chamber volume: The cylinder-shaped fermentation chamber is mostly used in Bangladesh. The cylinder- shaped fermentation chamber consists of three parts, namely, dome body and bottom. The dome is shaped like a spherical segment, the body like a cylinder and the bottom like an inverted spherical segment (Fig. 3.7). The volume-calculating formulas of the three parts are as follows:

$$V_1 = \pi/6\, f_1\, (3R^2+f_1^2)$$

$= \pi f_1^2 (r_1 - f_1/3);$

$V_2 = \pi/6\ f_2 (3R^2+f_2^2)$

$= \pi f_2^2 (r_2 - f_2/3)$;

$V_3 = \pi R^2 H.$

where,

V_1: Volume of the dome;

V_2: Volume of the bottom;

V_3: Volume of the body;

f_1: Vector rise of the dome;

f_1: Vector rise of the bottom;

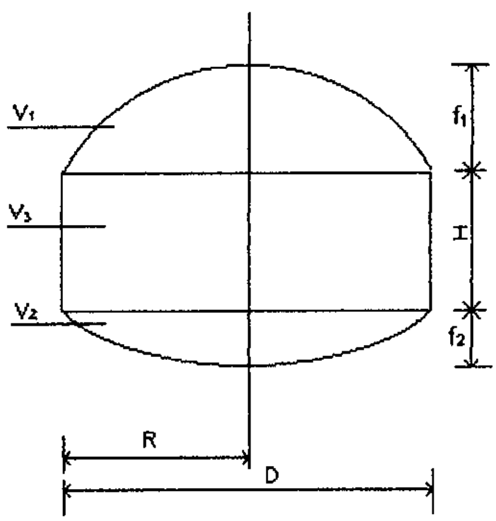

Fig. 3.7 Dimensions of the cylinder-shaped digester body

r_1: Curvature radius of the dome. Its relational expression with other dimensions is :

$r_1 = 1/2f_1 (R^2 + f_1^2)$;

r_2: Curvature radius of the bottom . Its relational expression with other dimensions is:

$r_2 = 1/2f_2 (R^2 + f_2^2)$;

R: Internal diameter of the body;

H: Height of the body.

In consideration of various factors, such as internal force structure, amount of materials used, techniques of construction, management and utilization, it is generally agreed that, when the ratio of vector rise to span (Fig. 3.8) for its dome $f_1/D = 1/5$, that for the bottom $f_2/D = 1/8$ and the height of its body $H = D/2.5$, the digester has a proportion of relatively rational dimensions.

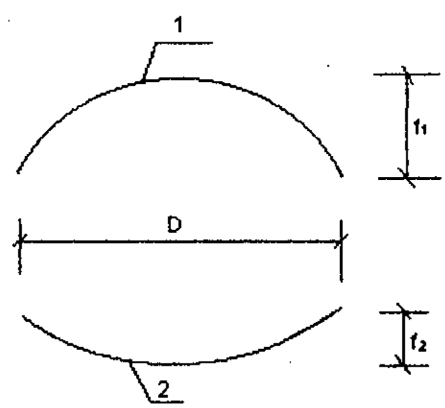

Fig.3.8 Diagram of ratio of vector rise to span

1: Dome 2 : Bottom D : Diameter of the body f_1 : Vector height for the dome

f_2 : Vector height for the bottom

As a result, once a certain size of the fermentation chamber is determined, the dimensions of other parts and the volume of various parts of the fermentation chamber can be calculated.

<u>Determination of the installation position of the inlet and outlet pipes</u>: It will have a great influence upon the fermentation and gas production of the biogas digester whether the installation of inlet and outlet pipes is suitable or not. Their unfit installation in the horizontal position will be unable to use the fermented material to full advantage, whereas

their wrong installation in the vertical position will give rise to gas escaping or too high pressure, etc.

a. Determination of the horizontal position: The horizontal positions of inlet and outlet pipes biogas digester are generally set at both ends of the fermentation chamber diameter. The symmetrical layout like this makes the distance between the inlet and the outlet the farthest, which is of great benefit to ensuring the retention period and flow evenness of the slurry in the digester, hence decreasing such appearances as the short circuit of slurry and occurrence of dead space in fermenting.

b. Determination of the vertical position: The vertical positions of the inlet and the outlet of the hydraulic biogas digester are determined by the two methods below:

<u>Pressure controlling method</u>: This method is to fix the positions of inlet and outlet pipes at the height of the lowest designed liquid surface of the fermentation chamber. As a result, when the gas storage amount in the digester comes to the maximum gas storage capacity designed (and at the same time the pressure in the digester also reaches the highest designed), the lower ends of inlet and outlet are beginning to appear out of the liquid surface. At this very moment, if gas continues producing, the gas produced will escape from the digester through the inlet and outlet pipes, keeping the pressure in the digester body constantly within the range of the designed. The advantage of this method is that it is capable of limiting the pressure automatically thus safeguarding the digester body. But its disadvantage is that the positions of the inlet and outlet are rather high, hence difficult to take out thicker slurry when fertilizer is needed.

<u>Middle-layer discharge installation method</u>: The installation of inlet and outlet pipes like that is convenient for middle layer discharge, benefiting sanitation. The upper layer of slurry has much scum, low digestibility and poor bactericidal effect; that bottom layer of slurry contains relatively more parasite egg because of

deposition; but that middle layer of slurry has few eggs and better digestibility. As a result, middle-layer discharge is very ideal for sanitation.
For middle-layer discharge biogas digesters, it is preferable to mount their inlet and outlet pipes in the middle but downward position of the cylinder-shaped digester body wall. This position is about 20 cm lower than that calculated by the pressure controlling method [23].

When the middle-layer discharge installation method is adopted, the pressure inside the digester is sometimes likely to be higher than the designed, which is unfavorable to the safety of the digester body. Consequently, consideration should be given to decompressing safeguards for the digester. The commonly-used measures are to enlarge the safety coefficient of digester body structure, or to adopt other forms of pressure reducing devices, for instance, a barometer capable of controlling its glass tube height. In this way, excessively great pressure will cause the water column to rush out of the barometer to obtain the result of reducing pressure to protect the digester body.

Each of the two methods described above has its own merits and demerits. In practice it is advisable to combine these two methods, namely, to decide the installation position of inlet pipe by the pressure controlling method, but to determine the position of outlet pipe by the middle-layer discharge method. That can ensure both the pressure from exceeding the designed and the middle-layer discharge, thus benefiting the prevention of diseases and elimination of pests and facilitating the fertilizer and utilization.

3.5.8 Design of the hydraulic chamber

The hydraulic chamber holds several functions simultaneously, such as exerting pressure on the gas in the digester, storing manure and facilitating discharge. It is required for designing a rational hydraulic chamber that its idle volume should be zero, and that the gas pressure in the gas tank is exactly equal to the designed when the hydraulic chamber is filled up with slurry. In order to accomplish these two points, it is necessary to decide the three dimensions in designing:

Elevation of the bottom surface of hydraulic chamber: When the bottom surface of hydraulic chamber is on a level with 0-0 position, the initial condition of the fermentation chamber, there is no idle volume in the hydraulic chamber. And therefore it is very ideal to decide the datum mark of the bottom surface of hydraulic chamber in this position.

Height of the hydraulic chamber: The designed pressure in the digester is decided by the sum of the dropping value of liquid surface in the fermentation chamber and the rising value of liquid surface in the hydraulic chamber. And it is also the pressure produced by this sum when the digester has the maximum gas storage amount. At this very moment, the liquid surface in the hydraulic chamber comes to the highest position, i. e., B-B liquid surface. As a result, it is both most economical and rational to adopt this position as the top surface of the hydraulic chamber.

Volume of the hydraulic chamber: As the amount of slurry displaced from the digester is equal to the gas storage amount in the digester the volume of the hydraulic chamber should equal the maximum gas storage amount. Effective volume of the hydraulic chamber is 50% of daily gas production.

3.5.9 Maintenance of Fixed Dome Biogas Plant

The maintenance of fixed dome biogas plant is very simple. Once the digester is carefully constructed, as per standard procedure, there is hardly any maintenance requirements except periodic replacement of gas valves, pipes, burner and hajack.

Chapter 4

Data Collection and Methodology

4.1 Introduction

Data on cost, performance characteristics of the technologies available for cooking and lighting houses and providing fertilizer on medium fertile land are analyzed and presented in this chapter. Biogas is not traded, and, therefore, has no market price. Hence it has to be valued according to the equivalents that are traded [17]. Several fuels can be considered as alternatives, especially for cooking where dung, firewood, charcoal, other gases, electricity and kerosene have all been used and for lighting houses where kerosene, electricity have all been used. Here the output of biogas plant is used for cooking which replaces the equivalent firewood requirement of a household, for lighting house that replaces the equivalent kerosene requirement of a household and as fertilizer, which replaces the equivalent Urea requirement of a household. The prices of key inputs were estimated and the output of the biogas plant was estimated by considering the market price of firewood, kerosene and fertilizer. For economic evaluation of the biogas plant the pay-back period and discounting cash flow analysis were used. Pay-back period of the biogas plant of different sizes was calculated by considering initial investment and average of net cash flows. In the discounted cash flow analysis, net present value, internal rate of return and benefit cost ratio of the biogas plant of different sizes were calculated. These calculations were then used to compare the economic viability of each plant size. The results are presented in the subsequent chapters. Methodology adapted for cost economic evaluation is also discussed in this chapter.

4.2 Reference cost

Biogas as a fuel is mainly used for cooking and lighting in daily life of rural Bangladesh. Many biogas plants are already in operation. These plants were built in co-operation with BCSIR. Therefore, the data on cost of different components of biogas plant (for different plant size) supplied by the BCSIR were considered as reference cost. Costs of different components of the biogas plant (plant size 100 cft.) are given in Table 4.2.1 of Appendix-A. Similarly cost for other plant size i.e. daily output are calculated and shown in Table 4.2.2 to Table 4.2.5 of Appendix-A.

Annual cost comprises of annual operation and maintenance cost. The operation cost consists of labour cost and price of cowdung, where as for expenses relating to the change of gas-valves, burners, hajacks, gas pipe etc. are considcred maintenance.

Labour cost: To keep the plant operative cow dung has to be charged everyday. Considering the part time job of the labour per month labour cost has been assumed to be Tk.300.00 for plant size upto 300 cft. For a plant size 500 cft. labour cost per month has been assumed to be Tk.450.00 and for a 1000cft plant size Tk.900.00 per month.

Cost of cowdung: The amount of cowdung required to be charged everyday for 100 cft, 200 cft, 300 cft, 500 cft and 1000 cft is 70 kg, 140 kg, 210 kg, 350 kg and 700 kg respectively [24]. Since cow dung is used for other purposes i.e. cooking and as manure, the price of cowdung is also considered. The price of cowdung is assumed as Tk.0.25 per kg [17].

Maintenance cost: As discussed with the owner and BCSIR Officials following items need to be replaced. These are mentioned below along with their time of replacement.

Gas valve: Gas valve has to be replaced every year due to leakage.

Gas pipe: Gas pipe is replaced every 10 (ten) years because of leakage.

Burner: Moisture present in the gas causes corrosion of the burner. For this reason burner is to be replaced every 10 (ten) years.

Hajack: Hajack is to be replaced in every 10 (ten) years because of corrosion.

Set up cost: For initial start up of the plant certain amount of cowdung has to be charged which increases with the sizes of the plant. The amount of cowdung required for 100 cft, 200 cft, 300 cft, 500 cft and 1000 cft is 2000 kg, 4000 kg, 6000 kg, 10000 kg and 20000 kg respectively [24].

4.3 Oven and hajack light

Normal householders in the rural areas of Bangladesh use wood as a fuel in the oven. Kerosene is used for lighting hajack. Biogas can be used for both the above-mentioned purposes.

4.3.1 Wood as a fuel

The wood is used as a fuel in cooking. A 100cft plant is capable to meet the fuel requirement for a family of 7 to 8 members [24]. The daily requirement of wood is about 10 kg and the market price of wood is Tk.2.00 per kg (1998 market price). The output of 100 cft biogas plant will replace this amount of wood. Similarly, the output of 200 cft, 300 cft, 500 cft and 1000 cft bio-gas plant are equivalent to 20 kg, 30 kg, 50 kg and 100 kg of wood with respect to cooking. The amount of wood requirement and the price of wood were collected from surveying few families and market at Tongi, Gazipur.

4.3.2 Kerosene as a fuel

Kerosene is used as fuel in lighting houses. The amount of kerosene required for a family of 7 to 8 members is about one litre. A 100 cft plant is capable to meet the fuel requirement for a family of 7 to 8 members [24]. So the output of 100 cft biogas plant would replace this amount of kerosene. Similarly, the output of 200 cft, 300 cft, 500 cft and 1000 cft bio-gas plant are equivalent to two litres, three litres, five litres and ten litres of kerosene with respect to lighting. The amount of kerosene requirement is collected from surveying few families at Tongi, Gazipur. The present market price of kerosene is Tk.14.00 per litre (as of 1998).

4.4 Fertilizer as an alternative to Urea

The cowdung residue obtained from biogas plant can be used as rich manure, which replaces the Urea requirement of cultivable land. The Urea meets Nitrogen requirements of land. Cowdung residue supplies Nitrogen [18]. Cowdung residue of 100 cft plant produces 75.6 kg of Nitrogen which is equivalent to 168 kg of Urea (Appendix-B). Similarly, cowdung residue of 200 cft, 300 cft, 500 cft and 1000 cft plant are equivalent to 336 kg, 504 kg, 840 kg and 1680 kg of Urea respectively. The present market price of Urea is Tk.6.00 per kg (as of 1998). Ranges of required different nutrient of rice crop production for medium fertile land and cost of equivalent Urea are presented in Appendix-B.

4.5 Methodology adopted in calculation

This section of the chapter describes the method adopted in making economic comparisons of the selected biogas plant of different sizes. Information, data and cost figures presented in the previous paragraphs have been used as input to the economic evaluation.

4.5.1 Discounting cash flow analysis

The method using discounting technique treats a new project as a business starting with no assets; but meets defined economic and financial criteria through out the plant life. Thus it takes into account the time value of money when comparing alternative cash flows. By using this method annual cash flow of the project have been calculated and then compared with the alternatives. Principal indicators, which are generally used in economic evaluation of any project, have been calculated. These are:

- Net present value (NPV)
- Internal rate of return (IRR)
- Benefit-cost ratio

4.5.1.1 Net present value

General form for expressing net present value [25] is

$$NPV = \sum_{t=0}^{N} [Y_t] / \sum_{j=0}^{t} (1 + i_j)$$

where NPV= the net present value

Y_t =the net cash flow at the end of period t

i_j = the interest (discount rate) for the period j.

N= the life of the project

j = points in time prior to t, j = 0,1,2, - - - - - t.

t = the point in time i.e. t = 0, 1, 2, - - - - - - N.

Thus, in general form, it is not for the interest rates, i_j to be equal, which permits one to assess the present value by using period-by-period evaluation in which the interest rate can take on different values. For the practical purposes of project evaluation, however, it is assumed that $i_1 = i_2 = \text{- - - - -} i_N = i$,

so that the above relationship reduces to

$$NPV = \sum_{t=0}^{N} Y_t / (1 + i)^t$$

Therefore, the net present value of a project can be defined as the value obtained by discounting, separately for each year, the difference of all cash flows accruing throughout the life of a project at a fixed, predetermined interest rate. This difference is discounted to the point at which the implementation of the project is supposed to start.

The NPVs obtained for the years of the life of the project are added to obtain the present NPV as follows:

$NPV = (NCF_1.a_1) + (NCF_2.a_2) + (NCF_3.a_3) + \ldots\ldots\ldots\ldots + (NCF_r.a_r) + \ldots\ldots + (NCF_n.a_n)$

Where NCF_r=The net cash flow of a project in years r,

a_r = The discount factor in years r

Where r = 1,2,3,.........i...., n appropriate to the discount rate applied.

For example, $a_n = 1/(1+I)^n$ is the discount factor for n years with discount rate of i.

4.5.1.2 Internal rate of return

The internal rate of return (IRR) is the discount rate at which the present value of cash in flows is equal to the present value of cash out flows. In other way it may be defined as the discount rate at which the present value of the receipts from the project is equal to the present value of the investment.

The calculation procedure begins with the preparation of cash flow table. Several test discount rates are then used to discount the net cash flow to the present value. If the NPV is positive, a higher discount rate is applied. If the NPV is negative at this higher rate, the IRR must be between these two rates. However, the discount rate must be increased until the NPV become negative.

A linear interpolation formula can be used to determine the IRR:

$$i_r = i_1 + \frac{PV(i_2 - i_1)}{PV + NV}$$

Where i_r is the IRR, PV is the NPV (positive) at low discount rate of i_1 and NV is the NPV (negative) at high discount rate of i_2. The value of PV and NV used in the above formula are positive. However, i_1 and i_2 should not differ by more than one or two percent. Otherwise, the results will not be realistic because the discount rate and the NPV are not related linearly.

4.5.1.3 Benefit-cost ratio

This is the ratio of benefits to costs. It should be calculated using the present values of each of them, discounted at an appropriate rate of interest. The ratio should be at least 1.0 for the project to be acceptable. Benefit-cost ratios are calculated in various ways, among which the following are mentioned below:

(i) Present value of all positive cash flows divided by present value of all negative cash flows (both on annual basis).

(ii) Present value of gross benefits from each year divided by present value of annual costs, including investment costs.

(iii) Present value of net annual operating benefits over present value of investment costs.

The above analyses will require a selling price of unit output to be assumed. Unfortunately, there is no such information available [17]. In such a situation it appears to be more useful to use the approach of calculating benefit cost ratio. Here in the cash flow table the cost of different components of bio-gas plant, and operational and maintenance cost to run the plant are assumed to be the cost; while that of the alternative i.e. wood, kerosene and fertilizer is considered as benefit. Thus in this approach the benefit is calculated internally for the purpose of comparison.

4.5.2 Pay-back Period

In order to recognize that recovery of the original investment is the important element in appraising a project, pay-back period method is used. Pay-back period (PBP) is the period required for the savings in costs or net cash flow after tax but before depreciation to recover the cost of investment. In other words, it represents the number of years in which the investment is expected to 'pay for itself'. Thus when net cash flow accrues at even rate:

$$\text{Pay-back period} = \frac{\text{Cost of the investment}}{\text{Net cash flow per year.}}$$

4.5.3 Effects of differential economic life

It may be noted that the calculations were carried out for an economic life of 20 years, which is the suggested operating life of the biogas plant. Operating lives of different components of biogas plant may differ from this assumed economic life. Therefore, for making the calculations compatible to an uniform set of economic ground rules, provisions have been made in the Computer Program to automatically replace any components upon receiving information on malfunctioning of components.

Results of various base cases and sensitivity calculations based on the above conditions and parameters are presented in the next chapter.

Chapter 5

Results and Analysis

5.1 Introduction

This chapter contains results of calculation of representative base case and also the calculation of cost of wood, kerosene and fertilizer as output of the biogas plant. In addition to this, sample calculation on comparison of biogas plant of different sizes with wood, kerosene and fertilizer as output of the plant to be used for cooking, lighting and cultivating land has also been performed along with some sensitivity analysis.

5.2 Estimation of cost and cash inflow

COST CALCULATION (CASH OUTFLOW) FOR 100 CFT PLANT

A. Capital cost **Tk.14000.00** (Table 5.2.1)

B. Set up cost

Cost of cowdung to start the plant 0.25Tk./kg*2000kg **Tk.500.00**

C. Annual operating cost

i. Labour cost (300.00Tk./month)		Tk.3600.00
ii. Price of cowdung (0.25Tk./kg)	0.25Tk./kg*70kg/day*30*12day	Tk.6300.00
Total annual operating cost		**Tk.9900.00**

D. Maintenance cost

Maintenance cost for 100 cft plant is shown in Table 5.2.1 of Appendix-A. Similarly for other plant sizes, maintenance cost is shown in Tables 5.2.2 to Table 5.2.5 of Appendix-A.

OUTPUT CALCULATION (CASH INFLOW) FOR 100CFT PLANT

A. Wood

Daily requirement	10kg	
Unit price	Tk.2.00	
Annual cost Tk2.00*10kg/day*30*12day		**Tk.7200.00**

B. Kerosene

Daily requirement	1 Liter	
Unit price	Tk14.00	
Annual cost Tk14.00*1 Liter/day*30*12day		**Tk.5040.00**

C. Fertilizer

Cost of equivalent Urea	Tk. 6/kg*168kg	**Tk.1008.00** (Appendix-B)

Total annual cash inflow (A+B+C)	**Tk.13248.00**

5.3 Calculation Procedure (A sample problem)

A sample calculation showing how the net present value is determined is given below. In the calculation the cash flows in the biogas plant have been considered and the discount rate of 10% has been assumed. The cash flows used here have been taken from the Table 5.3.1 in Appendix-A corresponding to a plant producing 100 cft gas per day.

5.3.1 Net present value

The following relationship has been used to calculate the net present value, NPV.

$NPV = (NCF_1.a_1) + (NCF_2.a_2) + (NCF_3.a_3) + \ldots\ldots\ldots\ldots + (NCF_r.a_r) + \ldots\ldots + (NCF_n.a_n)$

Where NCF_r=The net cash flow of a project in the r^{th} year,

a_r = The discount factor for r years appropriate to the discount rate applied,

r = 1,2,3,.........i...., n appropriate to the discount rate applied.

For example, $a_n=1/(1+I)^n$ is the discount factor for n years with discount rate of i. The discount factors for the 1^{st}, 2^{nd}, 3^{rd}, --------------- 20^{th} year are calculated using I=10%. With these net present value is calculated as follows:

NPV CALCULATION AT 100% CAPACITY FACTOR FOR 100 CFT PLANT

NPV =-14,500*1+3348*0.9090909+3,198*0.826446281+3,198*0.751314801
+3,198*0.683013455+3,198*0.620921323+3,198*0.56447393+3,198*0.513158118
+3,198*0.46650738+3,198*0.424097618+3,198*0.385543289+1,598*0.350493899
+3,198*0.318630818+3,198*0.28966438+3,198*0.263331254+3,198*0.239392049
+3,198*0.217629136+3,198*0.197844669+3,198*0.17985879+3,198*0.163507991
+3,198*0.148643628
= Tk.12302.00 (Table 5.3.1 in Appendix-A)

Similarly NPV for 100 cft plant at different discount rates are calculated and shown in Table 5.3.2 to Table 5.3.6 in Appendix-A.

NPV CALCULATION AT 90% CAPACITY FACTOR FOR 100 CFT PLANT

NPV at 90% capacity factor and different discount rates are calculated and shown in Table 5.3.7 to Table 5.3.9 in Appendix-A.

NPV CALCULATION AT 80% CAPACITY FACTOR FOR 100 CFT PLANT

NPV at 80% capacity factor and different discount rates are calculated and shown in Tables 5.3.10 to Table 5.3.14 in Appendix-A.

NPV for 100 cft, 200 cft, 300 cft, 500cft and 1000 cft plant at different capacity factors and different discount rates are summarized in Tables 5.3.15 to Table 5.3.19.

5.3.2 Internal rate of return

A linear interpolation formula is used to determine the internal rate of return, IRR:

$$i_r = i_1 + \frac{PV(i_2 - i_1)}{PV + NV}$$

Where i_r is the IRR, PV is the NPV (positive) at low discount rate of i_1 and NV is the NPV (negative) at high discount rate of i_2. The value of PV and NV used in the above formula are positive. However, i_1 and i_2 should not differ by more than one or two percent. Otherwise, the results will not be realistic because the discount rate and the NPV are not related linearly.

IRR Calculation at 100% capacity factor for 100 cft plant

Discount Factor	NPV
10%	12302
16%	4277
18%	2486
20%	983
21%	320
22%	-293

IRR = 21+{320*(22-21)} / (320+293)%

= 21.522%

≈ 21.50%

IRR Calculation at 90% capacity factor for 100 cft plant

NPV is shown below at different discount factor

Discount Factor	NPV
10%	1023
11%	44
12%	-834

IRR = [11+{44*(12-11)} / (44+834)]%

= 11.0501%

≈ 11%

IRR Calculation at 80% capacity factor for 100 cft plant

NPV is shown below at different discount factor

Discount Factor	NPV
10%	-10256
8%	-9663
6%	-8911
4%	-7942
1%	-5889

IRR can not be calculated, as the NPV at 1% discount rate is negative.

Similarly IRR for 100 cft, 200 cft, 300 cft, 500 cft and 1000 cft at different capacity factors are calculated and summarized in Table 5.3.20.

5.3.3 Benefit Cost Ratio

This is the ratio of benefits to costs. It should be calculated using the present values of each of them, discounted at an appropriate rate of interest The benefit cost ratio is calculated using the following formula at discount rates of 10 - 15% as these are the minimum rates for a project to be economically viable [8].

BENEFIT COST RATIO AT 100% CAPACITY FACTOR AND 10% DISCOUNT RATE (100 CFT)

Benefit Cost Ratio = NPV of Cash Inflows at 10% discount rate / NPV of cash outflows at 10% discount rate

= 112787.69/100486

= 1.122 (Table 5.3.21).

BENEFIT COST RATIO AT 90% CAPACITY FACTOR AND 10% DISCOUNT RATE (100 CFT)

Benefit Cost Ratio = NPV of Cash Inflows at 10% discount rate / NPV of cash outflows at 10% discount rate

= 101508.92/100486

= 1.010 (Table 5.3.22)

BENEFIT COST RATIO AT 80% CAPACITY FACTOR AND 10% DISCOUNT RATE (100 CFT)

Benefit Cost Ratio = NPV of Cash Inflows at 10% discount rate / NPV of cash outflows at 10% discount rate

= 90236.15/100486

= 0.897 (Table5.3.23)

Similarly, benefit cost ratio for 100 cft, 200 cft, 300 cft, 500 cft and 1000 cft at different discount rate and capacity factor is calculated and presented in the Table 5.3.24 to Table 5.3.29

5.3.4 Pay-back period

PAY-BACK PERIOD CALCULATION AT 100% CAPACITY FACTOR (100 CFT)

Pay-back period = Initial investment/Average of net cash flow of each year

=14500/3125.5 Year

=4.64 Year

≈5th Year (Table 5.3.30)

PAY-BACK PERIOD CALCULATION AT 90% CAPACITY FACTOR (100 CFT)

Pay-back period = Initial investment/Average of net cash flow of each year

= 145000/1800.70 YEAR

= 8.05 year

≈ 8th YEAR (Table 5.3.31)

PAY-BACK PERIOD CALCULATION AT 80% CAPACITY FACTOR (100 CFT)

Pay-back period = Initial investment/Average of net cash flow of each year

= 14500/475.9 YEAR

= 30.46 YEAR

≈ 31st YEAR (TABLE 5.3.32)

Similarly, pay back period for 100 cft, 200 cft, 300 cft, 500 cft and 1000 cft at different capacity factor is calculated and summarized in Table 5.3.33.

5.4 Sensitivity analysis

Sensitivity analysis has been carried out to determine the net present value (NPV), internal rate of return (IRR), benefit cost ratio (BCR) and pay-back period (PBP) of biogas plants of different sizes. The output of the biogas plant mainly depends upon the availability of its input i.e. cow-dung. Therefore the capacity of the plant will vary depending upon the amount of cow-dung available in the locality where the plant is installed. For this, cost estimation has been made for different capacity factor of the biogas plants of different sizes. Cost estimation is made upto 70% of the plant ideal capacity over the whole life of the plant.

The prices of different construction materials may increase over the period of time. As such sensitivity analysis has also been performed by considering an average of 10% increase in the price of raw materials. Then the effects of both the capacity factors i.e. plant output and 10% escalation in prices of different raw materials are evaluated together. These are presented in Table 5.3.38 to Table 5.3.46 and Fig. 5.14 to Fig. 5.21.

5.5 Summarized results

Results of the present work are summarized and presented in tabular form by calculating different economic indicators like NPV, IRR, BCR, PBP etc. At a 100% capacity factor of the plant IRR of 100 cft, 200 cft, 300 cft, 500 cft and 1000 cft is 21.5%, 45.2%, 56.6%, 58.7% and 73.3% respectively (Table 5.3.20). If the prices of raw materials are increased by 10%, IRR of 100 cft, 200 cft, 300 cft, 500 cft and 1000 cft plant at 100% capacity becomes 12.08%, 37.87%, 42.28%, 46.41% and 58.21% respectively and at 90% capacity IRR is 0.19%, 27.39%, 32.32%, 34.19% and 43.07% respectively (Table 5.3.39). At 80% capacity factor IRR of 200 cft, 300 cft, 500 cft and 1000 cft is 20.9%, 29.7%, 31.6% and 39.9% respectively and with 10% increase in prices of raw materials, IRR is 16.22%, 19.70%, 21.29% and 27.71% respectively (Table 5.3.20 and Table 5.3.39). Similarly at 70% capacity factor, IRR of 200 cft, 300 cft, 500 cft and 1000 cft is 6.7%, 15.7%, 17.6% and 22.8% respectively and with 10% price escalation IRR is 3.19%, 5.08%, 7.29% and 10.72% respectively (Table 5.3.20 and Table 5.3.39).

The benefit cost ratio (BCR) at 100% capacity factor and 10% discount rate for 100 cft, 200 cft, 300 cft, 500 cft and 1000 cft plant is 1.122, 1.387, 1.505, 1.533 and 1.579 respectively and 1.020, 1.335, 1.368, 1.394 and 1.435 respectively when the prices of raw materials are increased by 10%. BCR at 100% capacity factor and 11% discount rate for 100 cft, 200 cft, 300 cft, 500 cft and 1000 cft is 1.111, 1.374, 1.492, 1.519 and 1.567 respectively and 1.010, 1.321, 1.356, 1.381and 1.424 respectively when the prices of raw materials are increased by 10%. BCR at 100% capacity factor and 12% discount rate for 100 cft, 200 cft, 300 cft, 500 cft and 1000 cft is 1.100, 1.361, 1.478, 1.505 and 1.555 respectively and 1.000, 1.307, 1.344, 1.368 and 1.414 respectively when the prices of raw materials are increased by 10%. Similarly at 100% capacity factor and 13% discount rate, BCR of 100 cft, 200 cft, 300 cft, 500 cft and 1000 cft is 1.089, 1.348, 1.464, 1.491 and 1.543 respectively and 0.990, 1.294, 1.331, 1.356 and 1.403 respectively when the prices of raw materials are increased by 10%. BCR at 100% capacity factor and 14% discount rate for 100 cft, 200 cft, 300 cft, 500 cft and 1000 cft is 1.079, 1.335, 1.451, 1.477 and 1.531 respectively and 0.981, 1.280, 1.319, 1.343 and 1.392 respectively when the prices of raw materials are increased by 10%. BCR at 100% capacity factor and 15% discount rate for 100 cft, 200 cft, 300 cft, 500 cft and 1000 cft is 1.068, 1.323, 1.437, 1.463, and 1.519 respectively and 0.971, 1.266, 1.306, 1.330 and 1.381 respectively when the prices of raw materials are increased by 10%. Similarly, BCR for 100 cft, 200 cft, 300 cft, 500 cft and 1000 cft plant at different capacity factor and discount rates and 10% price escalation of raw materials is presented in the Table 5.3.24 to Table 5.3.29 and Table 5.3.40 to Table 5.3.45.

Pay-back period (PBP) at 100% capacitor factor for 100 cft, 200 cft, 300 cft, 500 cft and 1000 cft is 4.60, 2.25, 1.80, 1.73 and 1.40 years respectively and with 10% increase in prices of raw materials, PBP is 7.55, 2.56, 2.30, 2.19 and 1.75 years respectively. Pay-back period at 90% capacitor factor for 100 cft, 200 cft, 300 cft, 500 cft and 1000 cft is 8.05, 3.06, 2.36, 2.25 and 1.80 years respectively and with 10% increase in prices of raw materials, PBP is 20.23, 3.53, 3.16, 2.98 and 2.37 years respectively. PBP at 80% capacity factor for 100 cft, 200 cft, 300 cft, 500 cft, and 1000 cft is 30.46, 4.80, 3.40, 3.20 and 2.55 years respectively and with 10% increase in prices of raw materials, PBP is 29.74, 5.67, 5.06, 4.64 and 3.68 years respectively. PBP at 70% capacity factor for 200 cft, 300 cft, 500 cft and 1000 cft is 10.94, 6.15, 5.57 and 4.4 years respectively and with 10% increase in prices of raw materials, PBP is, PBP is 14.42, 12.53, 10.50 and 8.26 years respectively (Table 5.3.33 and Table 5.3.46).

Also shown in the tables are NPV, IRR, BCR and PBP at different capacity factors of different plant sizes and with 10% increase in prices of raw materials.

From the above results, it seems that for 100 cft plant at 100% capacity factor IRR is 21.5%; BCR at 15% discount rate is 1.068, at 14% discount rate 1.079, at 13% discount rate 1.089, at 12% discount rate 1.100, at 11% discount rate 1.111, at 10% discount rate 1.122; and PBP is 4.6 years. At 90% capacity factor IRR is 11%; BCR at 15% discount rate is 0.961, at 14% discount rate 0.971, at 13% discount rate 0.981, at 12% discount rate 0.990, at 11% discount rate 1.000 and at 10% discount rate 1.010; and PBP is 8.05 years. At 80% capacity factor IRR can not be calculated, as the NPV is negative at 1% discount rate. It clearly emphasizes that 100 cft plant is only economically viable if it runs with 90% capacity and if prices of raw materials escalate by 10%, it is not economically viable (IRR= 0.19% and BCR<1). (Fig. 5.1 and Fig. 5.6 to Fig. 5.21)

For 200 cft at 80% capacity factor IRR is 20.9%; BCR at 15% discount rate is 1.058, at 14% discount rate 1.068, at 13% discount rate 1.079, at 12% discount rate 1.089, at 11% discount rate 1.099 and at 10% discount rate 1.109; and PBP is 4.8 years. At 70% capacity factor IRR is 6.7%; BCR at 15% discount rate is 0.926 and 10% discount rate 0.971; and PBP is 10.94 years. Therefore 200 cft plant at 80% capacity factor is economically viable; but at 70% capacity factor, as per IRR (6.7%, and 3.19% with 10% price escalation of raw materials) and BCR (<1), it is not economically viable as World Bank recommended discount factor for a project to be economically viable is 8-10% [8]. (Fig. 5.2 and Fig. 5.6 to Fig. 5.21).

For 300 cft at 70% capacity factor IRR is 15.7%; BCR at 15% discount rate is 1.006 and at 10% discount rate 1.054; and PBP is 6.15 years. Therefore 300 cft plant is economically viable upto 70% capacity factor, and if the prices of raw materials are increased by 10%, it is not economically viable (IRR=5.08% and BCR<1). With 80% capacity and 10% increase in prices of raw materials, 300 cft plant is economically viable (Fig. 5.3 and Fig. 5.6 to Fig. 5.21).

For 500 cft at 70% capacity factor IRR is 17.6%; BCR at 15% discount rate is 1.024 and at 10% discount rate 1.073; and PBP is 5.57 years. Therefore 500 cft plant at 70% capacity factor is economically more viable than 300 cft plant at 70% capacity factor. If the prices of raw materials are increased by 10%, 500 cft plant with 70% capacity is not economically viable; it is only viable with 80% capacity (Fig.5.4 and Fig. 5.6 to Fig. 5.21).

For 1000 cft at 70% capacity factor IRR is 22.8%; BCR at 15% discount rate is 1.063 and at 10% discount rate 1.105; and PBP is 4.4 years. So 1000 cft plant at 70% capacity factor is economically more viable than 500 cft plant at 70% capacity factor. If the prices of raw materials are increased by 10%, 1000 cft plant with 70% capacity is economically viable with a lower discount rate and with a higher discount rate at 80% capacity (Fig.5.5 to Fig. 5.21).

From the above discussion we can conclude that economic viability is increasing with the plant size.

Table 5.3.15
NPV at different capacity factor (100 cft)

Discount Factor	NPV	Discount Factor	NPV
	100%		90%
0.1	12302	0.1	1023
0.16	4277	0.11	44
0.18	2486	0.12	-834
0.2	983		
0.21	320		
0.22	-293		

Table 5.3.16
NPV at different capacity factor (200 cft)

Discount Factor	NPV	Discount Factor	NPV	Discount Factor	NPV	Discount Factor	NPV
	100%		90%		80%		70%
0.1	62981	0.1	40423	0.1	17866	0.06	1289
0.16	37207	0.16	21497.8	0.16	5789	0.07	-484
0.2	26635	0.2	13732.3	0.2	830	0.08	-2054
0.25	17483	0.25	7006	0.22	-1090	0.1	-4692
0.3	11093	0.3	2307				
0.35	6419	0.34	-521				
0.4	2869						
0.44	594						
0.46	-398						

Table 5.3.17
NPV at different capacity factor (300 cft)

Discount Factor	NPV	Discount Factor	NPV	Discount Factor	NPV	Discount Factor	NPV
	100%		90%		80%		70%
20%	52287	20%	32933	20%	13580	10%	12151
30%	26056	30%	12877.3	26%	3817	14%	2861
40%	12185	40%	2260.76	30%	-301	16%	-554
50%	3728	50%	-4218				
60%	-1943						

Table 5.3.18
NPV at different capacity factor (500 cft)

Discount Factor	NPV	Discount Factor	NPV	Discount Factor	NPV	Discount Factor	NPV
	100%		90%		80%		70%
0.2	91326	0.2	59070	0.2	26814	0.1	27012
0.3	46513	0.3	24549	0.26	9772	0.14	10190
0.4	22822	0.4	6281.86	0.3	2585.2	0.16	4006
0.5	8382	0.5	-4862	0.32	-590.98	0.18	-1129
0.6	-1300						

Table 5.3.19
NPV at different capacity factor (1000 cft)

Discount Factor	NPV	Discount Factor	NPV	Discount Factor	NPV	Discount Factor	NPV
	100%		90%		80%		70%
30%	113436	30%	69508	30%	25580	15%	34817
40%	65924	40%	32843	35%	10913	20%	9788
50%	36969	50%	10481	40%	-237	22%	2399
60%	17559	60%	-4519			24%	-3931
70%	3661						
75%	-1904						

Table 5.3.20
IRR of different plant size at different capacity factor

Plant size	IRR at different capacity factor			
	100%	90%	80%	70%
100cft	21.50%	11%	-3.70%	
200cft	45.20%	33.30%	20.90%	6.70%
300cft	56.60%	43.50%	29.70%	15.70%
500cft	58.70%	45.60%	31.60%	17.60%
1000cft	73.30%	57%	39.90%	22.80%

Table 5.3.21

Benefit cost ratio of 100cft plant at 100% capacity factor and 10% discount rate

Year	Cash outflow	Cash inflow	Net cashflow	Discount factor	NPV of outflow	NPV of inflow
0	14,500	-	(14,500)	1	14,500	0
1	9,900	13,248	3,348	0.909090909	9,000	12043.63636
2	10,050	13,248	3,198	0.826446281	8,306	10948.76033
3	10,050	13,248	3,198	0.751314801	7,551	9953.418482
4	10,050	13,248	3,198	0.683013455	6,864	9048.562257
5	10,050	13,248	3,198	0.620921323	6,240	8225.965688
6	10,050	13,248	3,198	0.56447393	5,673	7478.150625
7	10,050	13,248	3,198	0.513158118	5,157	6798.31875
8	10,050	13,248	3,198	0.46650738	4,688	6180.289773
9	10,050	13,248	3,198	0.424097618	4,262	5618.445248
10	10,050	13,248	3,198	0.385543289	3,875	5107.677498
11	11,650	13,248	1,598	0.350493899	4,083	4643.34318
12	10,050	13,248	3,198	0.318630818	3,202	4221.221073
13	10,050	13,248	3,198	0.28966438	2,911	3837.473703
14	10,050	13,248	3,198	0.263331254	2,646	3488.612457
15	10,050	13,248	3,198	0.239392049	2,406	3171.46587
16	10,050	13,248	3,198	0.217629136	2,187	2883.150791
17	10,050	13,248	3,198	0.197844669	1,988	2621.046174
18	10,050	13,248	3,198	0.17985879	1,808	2382.769249
19	10,050	13,248	3,198	0.163507991	1,643	2166.153862
20	10,050	13,248	3,198	0.148643628	1,494	1969.230784
Total					**100,486**	**112787.6922**
Benefit cost ratio						**1.122424833**

Table 5.3.22

Benefit cost ratio of 100cft plant at 90% capacity factor and 10% discount rate

Year	Cash outflow	Cash inflow	Net cashflow	Discount factor	NPV of outflow	NPV of inflow
0	14,500	-	(14,500)	1	14,500	0
1	9,900	11,923	2,023	0.909090909	9,000	10839.27273
2	10,050	11,923	1,873	0.826446281	8,306	9853.884298
3	10,050	11,923	1,873	0.751314801	7,551	8958.076634
4	10,050	11,923	1,873	0.683013455	6,864	8143.706031
5	10,050	11,923	1,873	0.620921323	6,240	7403.369119
6	10,050	11,923	1,873	0.56447393	5,673	6730.335563
7	10,050	11,923	1,873	0.513158118	5,157	6118.486875
8	10,050	11,923	1,873	0.46650738	4,688	5562.260796
9	10,050	11,923	1,873	0.424097618	4,262	5056.600723
10	10,050	11,923	1,873	0.385543289	3,875	4596.909749
11	11,650	11,923	273	0.350493899	4,083	4179.008862
12	10,050	11,923	1,873	0.318630818	3,202	3799.098966
13	10,050	11,923	1,873	0.28966438	2,911	3453.726332
14	10,050	11,923	1,873	0.263331254	2,646	3139.751211
15	10,050	11,923	1,873	0.239392049	2,406	2854.319283
16	10,050	11,923	1,873	0.217629136	2,187	2594.835712
17	10,050	11,923	1,873	0.197844669	1,988	2358.941556
18	10,050	11,923	1,873	0.17985879	1,808	2144.492324
19	10,050	11,923	1,873	0.163507991	1,643	1949.538476
20	10,050	11,923	1,873	0.148643628	1,494	1772.307706
Total					**100,486**	**101508.9229**
Benefit cost ratio						**1.01018235**

Table 5.3.23
Benefit cost ratio of 100cft plant at 80% capacity factor and 10% discount rate

Year	Cash outflow	Cash inflow	Net cashflow	Discount factor	NPV of outflow	NPV of inflow
0	14,500	-	(14,500)	1	14,500	0
1	9,900	10,598	698	0.909090909	9,000	9634.909091
2	10,050	10,598	548	0.826446281	8,306	8759.008264
3	10,050	10,598	548	0.751314801	7,551	7962.734786
4	10,050	10,598	548	0.683013455	6,864	7238.849805
5	10,050	10,598	548	0.620921323	6,240	6580.77255
6	10,050	10,598	548	0.56447393	5,673	5982.5205
7	10,050	10,598	548	0.513158118	5,157	5438.655
8	10,050	10,598	548	0.46650738	4,688	4944.231818
9	10,050	10,598	548	0.424097618	4,262	4494.756199
10	10,050	10,598	548	0.385543289	3,875	4086.141999
11	11,650	10,598	(1,052)	0.350493899	4,083	3714.674544
12	10,050	10,598	548	0.318630818	3,202	3376.976858
13	10,050	10,598	548	0.28966438	2,911	3069.978962
14	10,050	10,598	548	0.263331254	2,646	2790.889966
15	10,050	10,598	548	0.239392049	2,406	2537.172696
16	10,050	10,598	548	0.217629136	2,187	2306.520633
17	10,050	10,598	548	0.197844669	1,988	2096.836939
18	10,050	10,598	548	0.17985879	1,808	1906.215399
19	10,050	10,598	548	0.163507991	1,643	1732.92309
20	10,050	10,598	548	0.148643628	1,494	1575.384627
Total					**100,486**	**90230.15373**
Benefit cost ratio						**0.897939866**

Table 5.3.24
BCR at 10% discount factor of different plant size at different capacity factor

Plant size	Benefit cost ratio at different capacity factor			
	100%	90%	80%	70%
100	1.122	1.010	0.897	
200	1.387	1.248	1.109	0.971
300	1.505	1.355	1.204	1.054
500	1.533	1.380	1.226	1.073
1000	1.579	1.421	1.263	1.105

Table 5.3.25
BCR at 11% discount factor of different plant size at different capacity factor

Plant size	Benefit cost ratio at different capacity factor			
	100%	90%	80%	70%
100	1.111	1.000	0.890	
200	1.374	1.237	1.099	0.962
300	1.492	1.342	1.193	1.044
500	1.519	1.367	1.215	1.063
1000	1.567	1.410	1.253	1.097

Table 5.3.26

BCR at 12% discount factor of different plant size at different capacity factor

Plant size	Benefit cost ratio at different capacity factor			
	100%	90%	80%	70%
100	1.100	0.990	0.880	
200	1.361	1.225	1.089	0.953
300	1.478	1.330	1.182	1.034
500	1.505	1.355	1.204	1.053
1000	1.555	1.404	1.244	1.088

Table 5.3.27

BCR at 13% discount factor of different plant size at different capacity factor

Plant size	Benefit cost ratio at different capacity factor			
	100%	90%	80%	70%
100	1.089	0.981	0.871	
200	1.348	1.213	1.079	0.944
300	1.464	1.318	1.171	1.025
500	1.491	1.342	1.193	1.044
1000	1.543	1.389	1.234	1.08

Table 5.3.28

BCR at 14% discount factor of different plant size at different capacity factor

Plant size	Benefit cost ratio at different capacity factor			
	100%	90%	80%	70%
100	1.079	0.971	0.863	
200	1.335	1.202	1.068	0.935
300	1.451	1.305	1.160	1.015
500	1.477	1.329	1.182	1.034
1000	1.531	1.378	1.225	1.072

Table 5.3.29

BCR at 15% discount factor of different plant size at different capacity factor

Plant size	Benefit cost ratio at different capacity factor			
	100%	90%	80%	70%
100	1.068	0.961	0.854	
200	1.323	1.190	1.058	0.926
300	1.437	1.293	1.149	1.006
500	1.463	1.317	1.170	1.024
1000	1.519	1.367	1.215	1.06

Table 5.3.30
Payback period at 100 capacity factor (100 cft)

Year	Cash outflow	Cash inflow	Net cashflow	Discount factor	NPV of outflow	NPV of inflow
0	14,500	-	(14,500)	1	14,500	0
1	9,900	13,248	3,348	0.909090909	9,000	12043.63636
2	10,050	13,248	3,198	0.826446281	8,306	10948.76033
3	10,050	13,248	3,198	0.751314801	7,551	9953.418482
4	10,050	13,248	3,198	0.683013455	6,864	9048.562257
5	10,050	13,248	3,198	0.620921323	6,240	8225.965688
6	10,050	13,248	3,198	0.56447393	5,673	7478.150625
7	10,050	13,248	3,198	0.513158118	5,157	6798.31875
8	10,050	13,248	3,198	0.46650738	4,688	6180.289773
9	10,050	13,248	3,198	0.424097618	4,262	5618.445248
10	10,050	13,248	3,198	0.385543289	3,875	5107.677498
11	11,650	13,248	1,598	0.350493899	4,083	4643.34318
12	10,050	13,248	3,198	0.318630818	3,202	4221.221073
13	10,050	13,248	3,198	0.28966438	2,911	3837.473703
14	10,050	13,248	3,198	0.263331254	2,646	3488.612457
15	10,050	13,248	3,198	0.239392049	2,406	3171.46587
16	10,050	13,248	3,198	0.217629136	2,187	2883.150791
17	10,050	13,248	3,198	0.197844669	1,988	2621.046174
18	10,050	13,248	3,198	0.17985879	1,808	2382.769249
19	10,050	13,248	3,198	0.163507991	1,643	2166.153862
20	10,050	13,248	3,198	0.148643628	1,494	1969.230784
Total			**62,510**			
Average			**3,125.50**			
Pay back period			**4.64**			

Table 5.3.31
Payback period at 90 capacity factor (100 cft)

Year	Cash outflow	Cash inflow	Net cashflow	Discount factor	NPV of outflow	NPV of inflow
0	14,500	-	(14,500)	1	14,500	0
1	9,900	11,923	2,023	0.909090909	9,000	10839.27273
2	10,050	11,923	1,873	0.826446281	8,306	9853.884298
3	10,050	11,923	1,873	0.751314801	7,551	8958.076634
4	10,050	11,923	1,873	0.683013455	6,864	8143.706031
5	10,050	11,923	1,873	0.620921323	6,240	7403.369119
6	10,050	11,923	1,873	0.56447393	5,673	6730.335563
7	10,050	11,923	1,873	0.513158118	5,157	6118.486875
8	10,050	11,923	1,873	0.46650738	4,688	5562.260796
9	10,050	11,923	1,873	0.424097618	4,262	5056.600723
10	10,050	11,923	1,873	0.385543289	3,875	4596.909749
11	11,650	11,923	273	0.350493899	4,083	4179.008862
12	10,050	11,923	1,873	0.318630818	3,202	3799.098966
13	10,050	11,923	1,873	0.28966438	2,911	3453.726332
14	10,050	11,923	1,873	0.263331254	2,646	3139.751211
15	10,050	11,923	1,873	0.239392049	2,406	2854.319283
16	10,050	11,923	1,873	0.217629136	2,187	2594.835712
17	10,050	11,923	1,873	0.197844669	1,988	2358.941556
18	10,050	11,923	1,873	0.17985879	1,808	2144.492324
19	10,050	11,923	1,873	0.163507991	1,643	1949.538476
20	10,050	11,923	1,873	0.148643628	1,494	1772.307706
Total			**36,014**			
Average			**1,800.70**			
Pay back period			**8.05**			

Table 5.3.32
Payback period at 80 capacity factor (100 cft)

Year	Cash outflow	Cash inflow	Net cashflow	Discount factor	NPV of outflow	NPV of inflow
0	14,500	-	(14,500)	1	14,500	0
1	9,900	10,598	698	0.909090909	9,000	9634.909091
2	10,050	10,598	548	0.826446281	8,306	8759.008264
3	10,050	10,598	548	0.751314801	7,551	7962.734786
4	10,050	10,598	548	0.683013455	6,864	7238.849805
5	10,050	10,598	548	0.620921323	6,240	6580.77255
6	10,050	10,598	548	0.56447393	5,673	5982.5205
7	10,050	10,598	548	0.513158118	5,157	5438.655
8	10,050	10,598	548	0.46650738	4,688	4944.231818
9	10,050	10,598	548	0.424097618	4,262	4494.756199
10	10,050	10,598	548	0.385543289	3,875	4086.141999
11	11,650	10,598	(1,052)	0.350493899	4,083	3714.674544
12	10,050	10,598	548	0.318630818	3,202	3376.976858
13	10,050	10,598	548	0.28966438	2,911	3069.978962
14	10,050	10,598	548	0.263331254	2,646	2790.889966
15	10,050	10,598	548	0.239392049	2,406	2537.172696
16	10,050	10,598	548	0.217629136	2,187	2306.520633
17	10,050	10,598	548	0.197844669	1,988	2096.836939
18	10,050	10,598	548	0.17985879	1,808	1906.215399
19	10,050	10,598	548	0.163507991	1,643	1732.92309
20	10,050	10,598	548	0.148643628	1,494	1575.384627
Total			**9,518**			
Average			**475.90**			
Pay back period			**30.47**			

Table 5.3.33
PBP of different plant size at different capacity factor

Plant size	Payback period at different capacity factor			
	100%	90%	80%	70%
100	4.60	8.05	30.47	
200	2.25	3.06	4.80	10.94
300	1.80	2.36	3.40	6.15
500	1.73	2.25	3.20	5.57
1000	1.40	1.80	2.55	4.4

Table 5.3.34

NPV at different capacity factor and 10% price escalation(PE) (100 cft)

Discount Factor	NPV	Discount Factor	NPV	Discount Factor	NPV
	100%		90%		80%
10%	2553	2%	-3007	0%	-26677
12%	72	8%	-8028	4%	-23140
14%	-1697			6%	-21959

Table 5.3.35

NPV at different capacity factor and 10% price escalation(PE) (200 cft)

Discount Factor	NPV	Discount Factor	NPV	Discount Factor	NPV	Discount Factor	NPV
	100%		90%		80%		70%
10%	56710	10%	34152	10%	11595	2%	2951
16%	31693	16%	15983	14%	3309	4%	-2006
20%	21456	20%	8553	16%	275	7%	-7319
25%	12612	25%	2136	18%	-2241	8%	-8683
30%	6451	30%	-2334				
35%	1956						
40%	-1449						

Table 5.3.36

NPV at different capacity factor and 10% price escalation(PE) (300 cft)

Discount Factor	NPV	Discount Factor	NPV	Discount Factor	NPV	Discount Factor	NPV
	100%		90%		80%		70%
20%	38162	20%	18808	15%	8642	4%	3027
30%	15483	30%	2304	16%		6%	-2557
40%	3479	35%	-2666	20%	-545	10%	-10319
45%	-582						

Table 5.3.37

NPV at different capacity factor and 10% price escalation(PE) (500 cft)

Discount Factor	NPV	Discount Factor	NPV	Discount Factor	NPV	Discount Factor	NPV
	100%		90%		80%		70%
20%	68202	20%	35946	20%	3690	6%	5480
30%	29200	30%	7236	22%	-2017	8%	-3040
40%	8564	35%	-1406			10%	-9762
45%	1584						
50%	-4024						

Table 5.3.38

NPV at different capacity factor and 10% price escalation(PE) (1000 cft)

Discount Factor	NPV	Discount Factor	NPV	Discount Factor	NPV	Discount Factor	NPV
	100%		90%		80%		70%
30%	80851	20%	36924	20%	30120	10%	3923
40%	39436	40%	6355	25%	8276	12%	-7037
50%	14178	45%	-3992	30%	-7004	15%	-19748
55%	4945						
60%	-2763						

Table 5.3.39

IRR of different plant size at different capacity factor (10% PE)

Plant size	IRR at different capacity factor			
	100%	90%	80%	70%
100	12.08%	0.19%		
200	37.87%	27.39%	16.22%	3.19%
300	42.28%	32.32%	19.70%	5.08%
500	46.41%	34.19%	21.29%	7.29%
1000	58.21%	43.07%	27.71%	10.72%

Table 5.3.40

BCR at 10% discount factor of different plant size at different capacity factor (10% PE)

Plant size	Benefit cost ratio at different capacity factor			
	100%	90%	80%	70%
100	1.020	0.918	0.816	
200	1.335	1.202	1.068	0.935
300	1.368	1.233	1.095	0.958
500	1.394	1.254	1.115	0.975
1000	1.435	1.292	1.148	1.004

Table 5.3.41

BCR at 11% discount factor of different plant size at different capacity factor (10% PE)

Plant size	Benefit cost ratio at different capacity factor			
	100%	90%	80%	70%
100	1.010	0.909	0.808	
200	1.321	1.189	1.057	0.925
300	1.356	1.220	1.085	0.949
500	1.381	1.243	1.105	0.967
1000	1.424	1.282	1.139	0.997

Table 5.3.42

BCR at 12% discount factor of different plant size at different capacity factor (10% PE)

Plant size	Benefit cost ratio at different capacity factor			
	100%	90%	80%	70%
100	1.000	0.900	0.800	
200	1.307	1.177	1.046	0.915
300	1.344	1.209	1.075	0.940
500	1.368	1.231	1.094	0.958
1000	1.414	1.272	1.131	0.989

Table 5.3.43

BCR at 13% discount factor of different plant size at different capacity factor (10% PE)

Plant size	Benefit cost ratio at different capacity factor			
	100%	90%	80%	70%
100	0.990	0.891	0.792	
200	1.294	1.164	1.035	0.905
300	1.331	1.198	1.065	0.932
500	1.356	1.220	1.084	0.949
1000	1.403	1.263	1.122	0.982

Table 5.3.44

BCR at 14% discount factor of different plant size at different capacity factor (10% PE)

Plant size	Benefit cost ratio at different capacity factor			
	100%	90%	80%	70%
100	0.981	0.882	0.784	
200	1.280	1.152	1.024	0.896
300	1.319	1.187	1.055	0.923
500	1.343	1.208	1.074	0.940
1000	1.392	1.253	1.113	0.974

Table 5.3.45

BCR at 15% discount factor of different plant size at different capacity factor (10% PE)

Plant size	Benefit cost ratio at different capacity factor			
	100%	90%	80%	70%
100	0.971	0.874	0.776	
200	1.266	1.139	1.013	0.886
300	1.306	1.176	1.045	0.914
500	1.330	1.197	1.064	0.931
1000	1.381	1.243	1.105	0.967

Table 5.3.46

PBP of different plant size at different capacity factor (10% PE)

Plant size	Payback period at different capacity factor			
	100%	90%	80%	70%
100	7.55	20.23	29.74	
200	2.56	3.53	5.67	14.42
300	2.30	3.16	5.04	12.53
500	2.19	2.98	4.64	10.50
1000	1.75	2.37	3.68	8.26

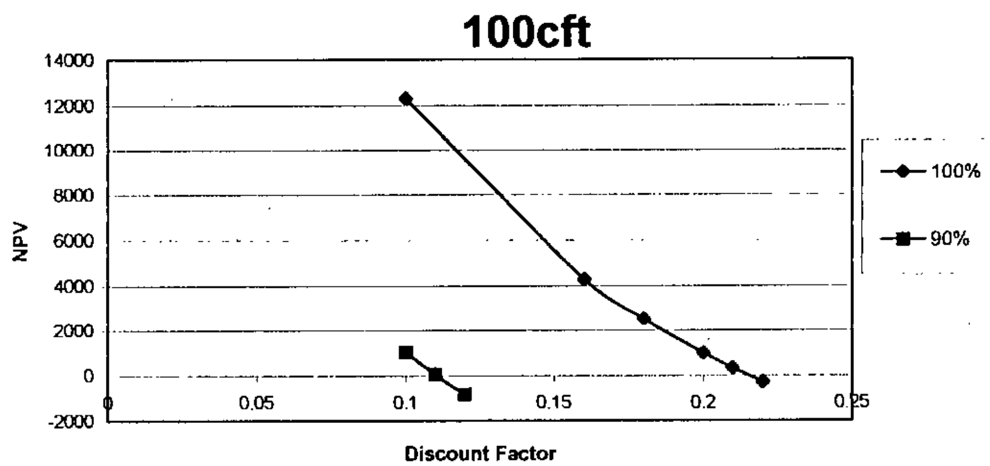

Figure 5.1 NPV Vs Discount Factor at different capacity factor

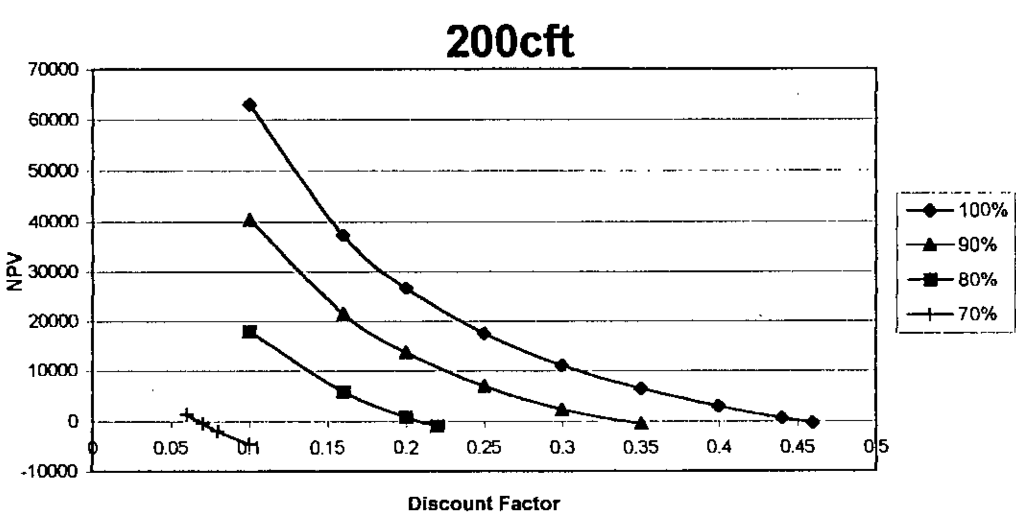

Figure 5.2 NPV Vs Discount Factor at different capacity factor

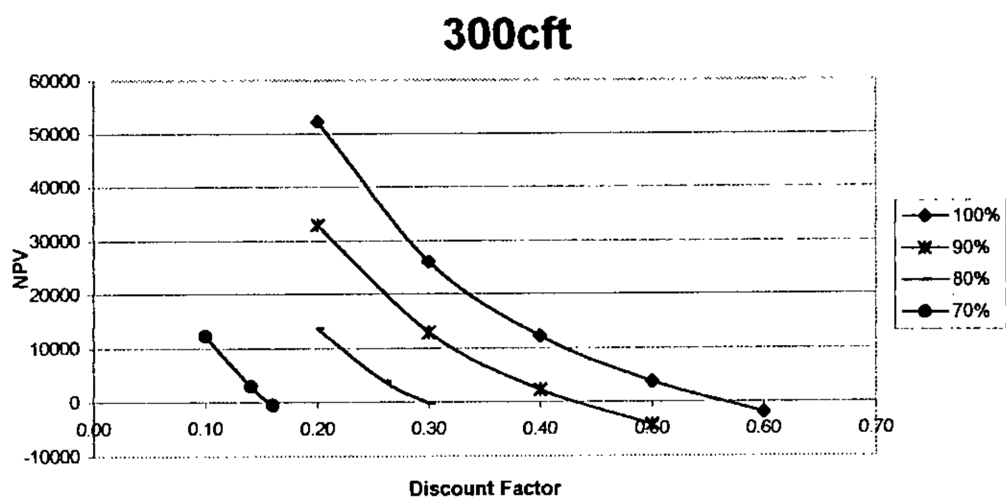

Figure 5.3 NPV Vs Discount Factor at different capacity factor

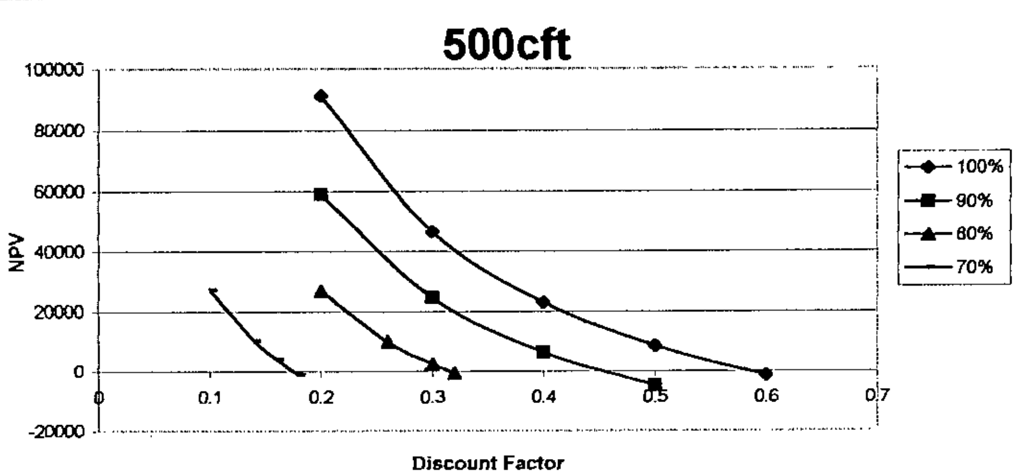

Figure 5.4 NPV Vs Discount Factor at different capacity factor

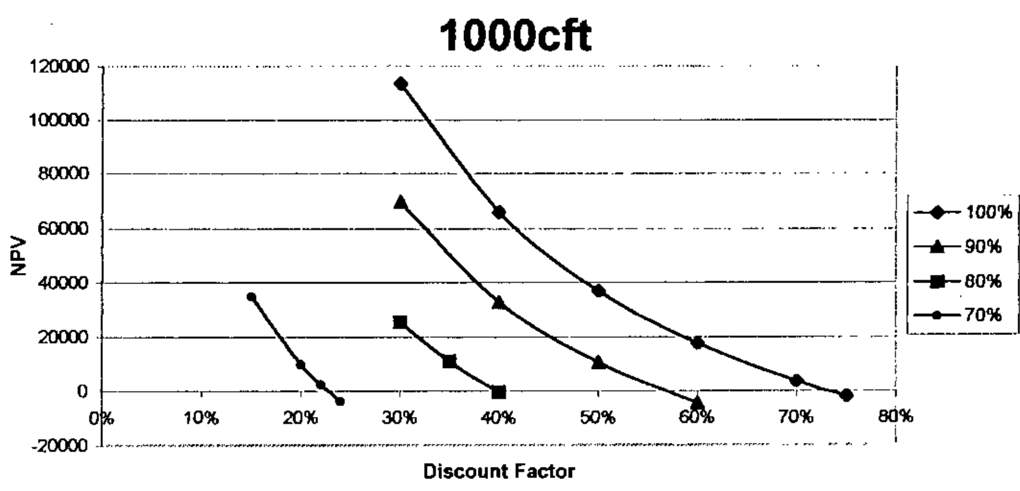

Figure 5.5 NPV Vs Discount Factor at different capacity factor

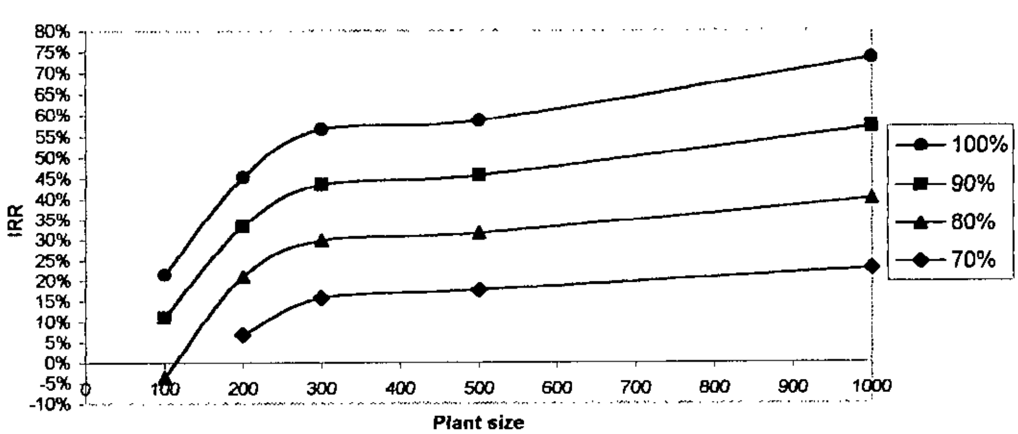

Figure 5.6 Plant size vs IRR at different capacity factor

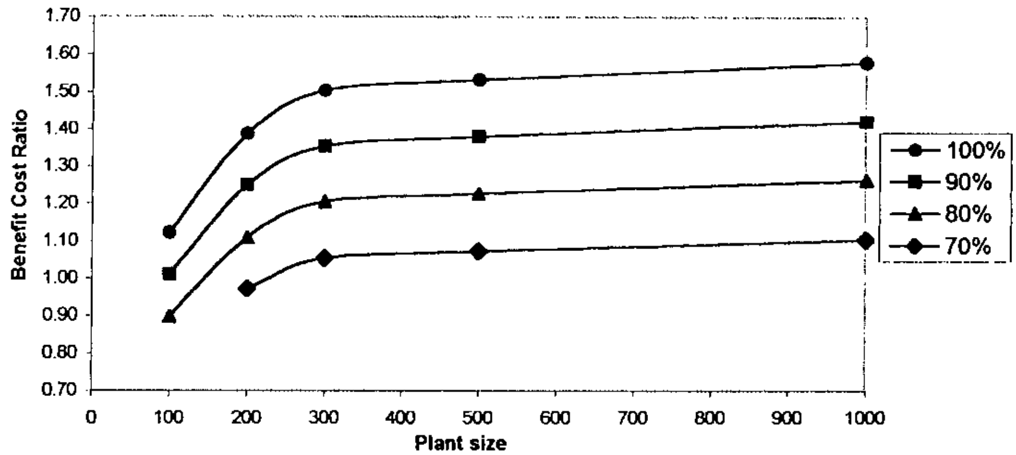

Figure 5.7 Benefit Cost Ratio at different capacity factor
(10% Discount Factor)

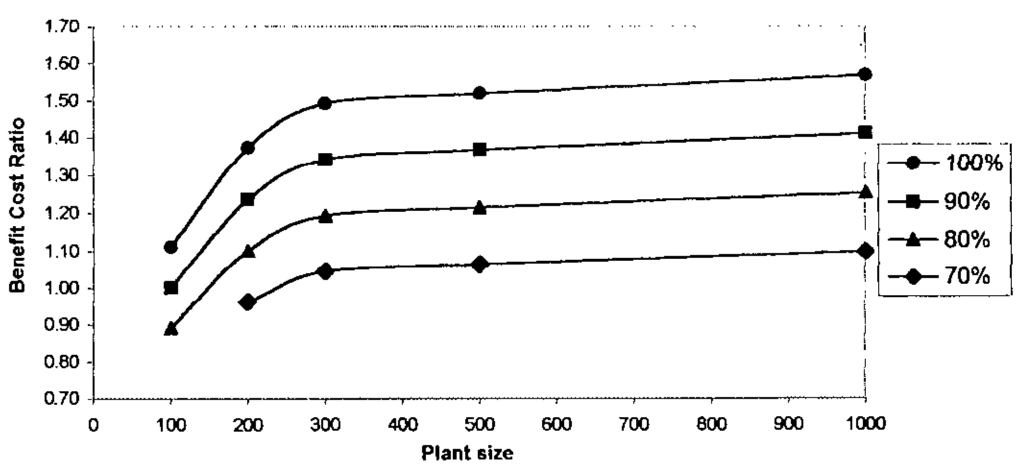

Figure 5.8 Benefit Cost Ratio at different capacity factor
(11% Discount Factor)

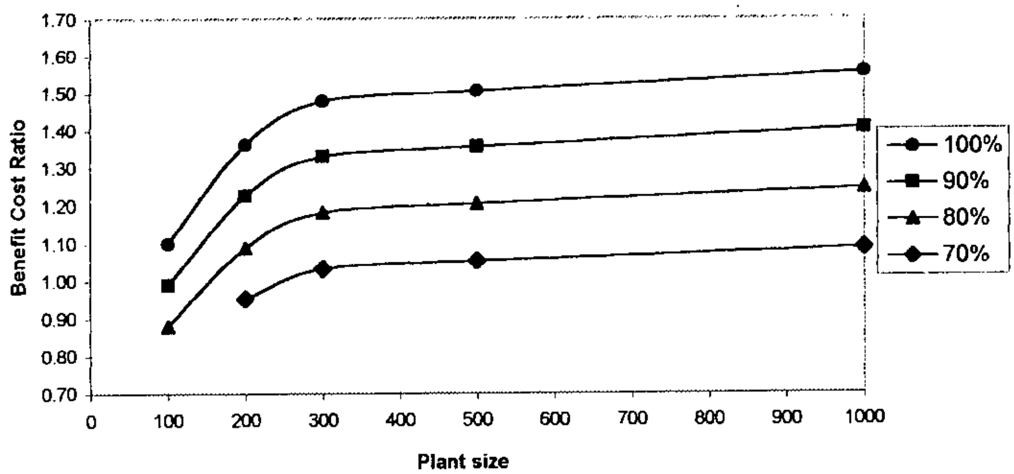

Figure 5.9 Benefit Cost Ratio at different capacity factor
(12% Discount Factor)

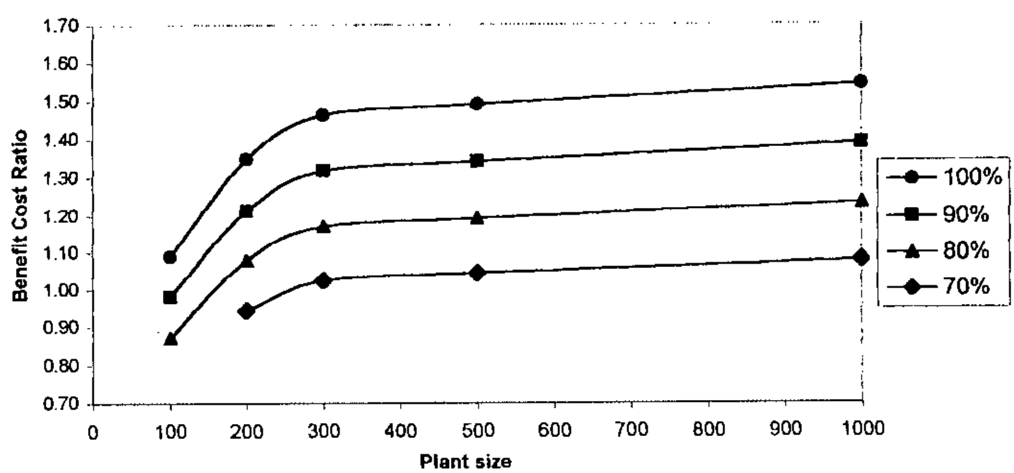

Figure 5.10 Benefit Cost Ratio at different capacity factor
(13% Discount Factor)

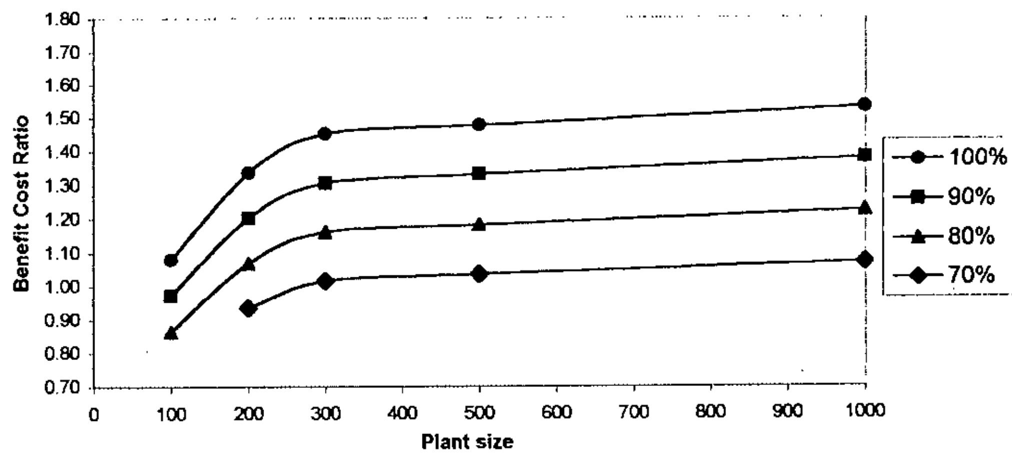

Figure 5.11 Benefit Cost Ratio at different capacity factor
(14% Discount Factor)

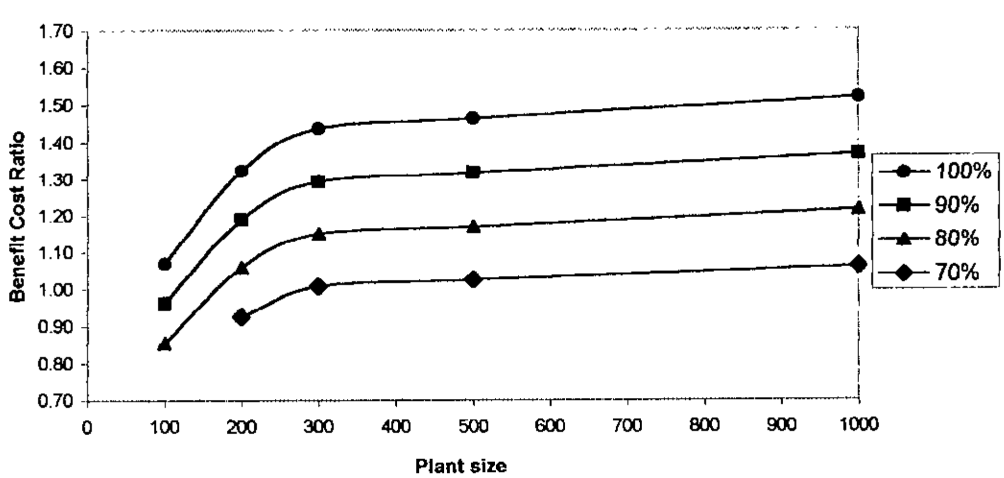

Figure 5.12 Benefit Cost Ratio at different capacity factor
(15% Discount Factor)

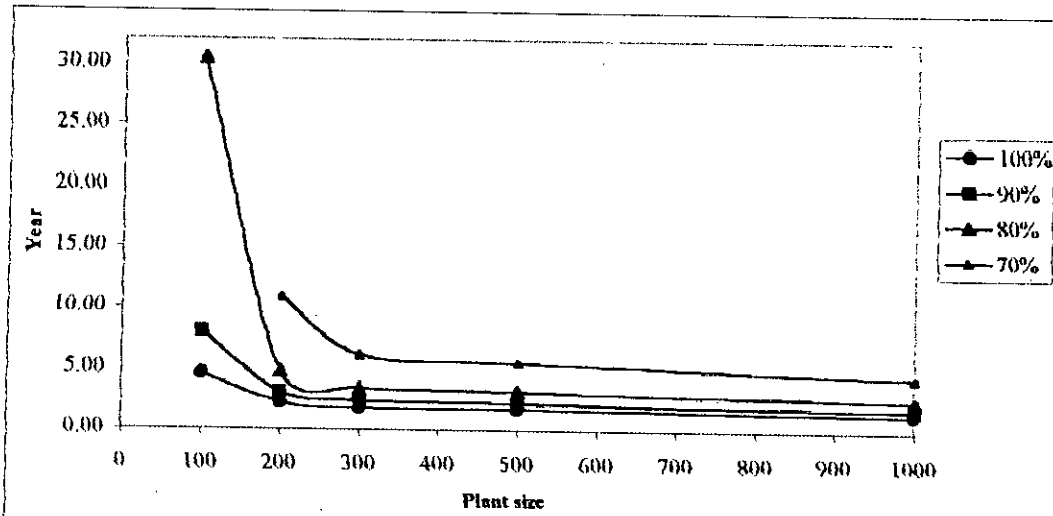

Figure 5.13 Payback period at different capacity factor

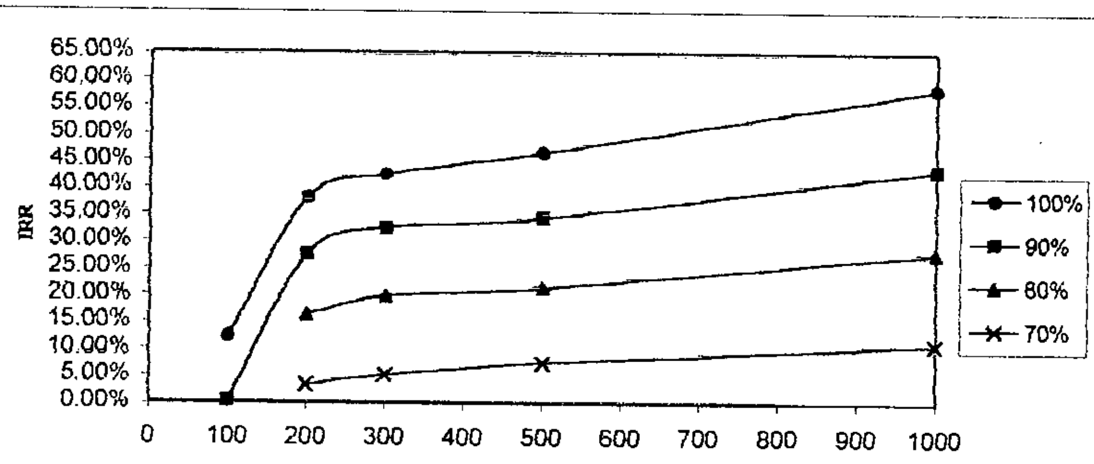

Figure 5.14 Plant size vs IRR at different capacity factor & 10% price escalation

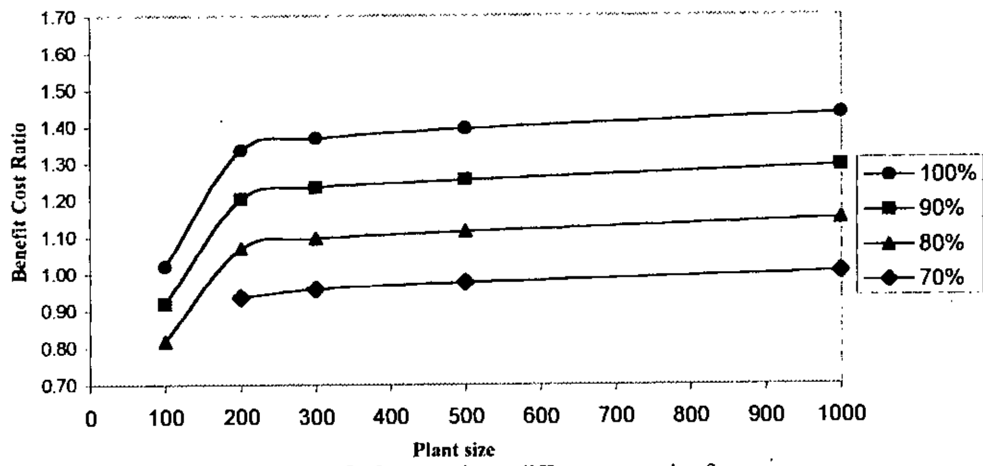

Figure 5.15 Benefit Cost Ratio at different capacity factor & 10% price escalation (10% Discount Factor)

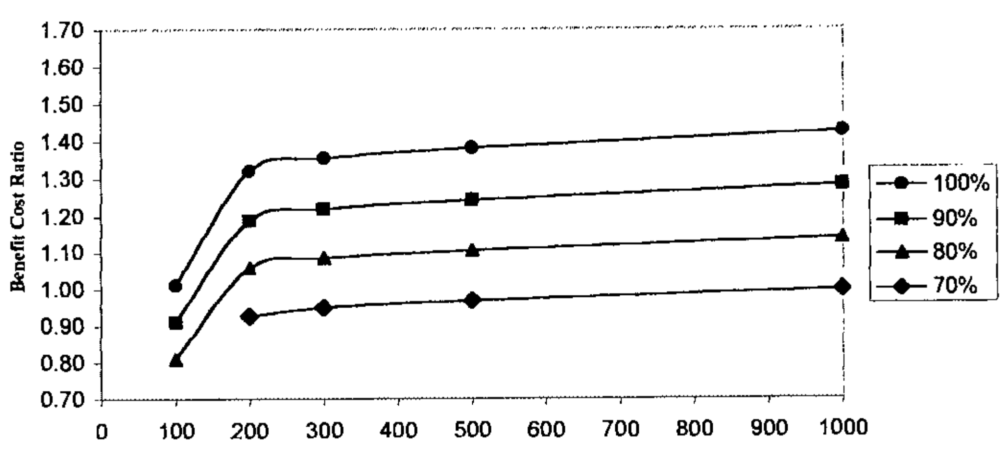

Figure 5.16 Benefit Cost Ratio at different capacity factor & 10% price escalation (11% Discount Factor)

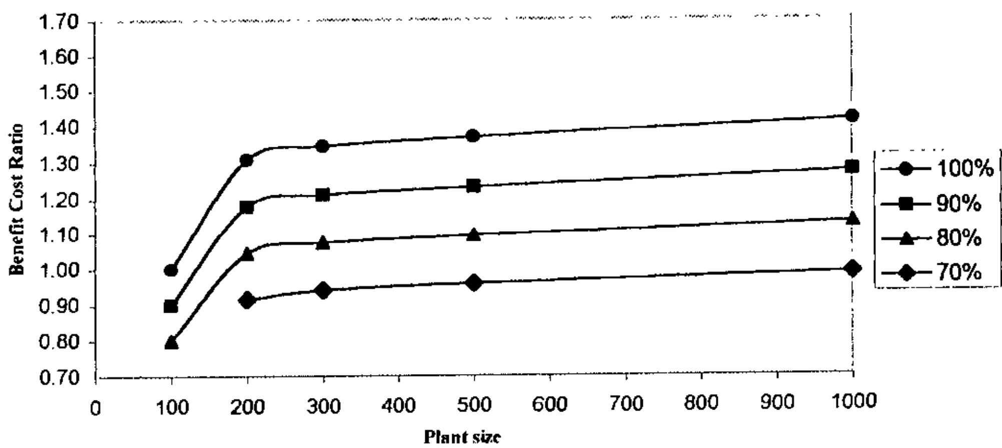

Figure 5.17 Benefit Cost Ratio at different capacity factor & 10 % price escalation (12% Discount Factor)

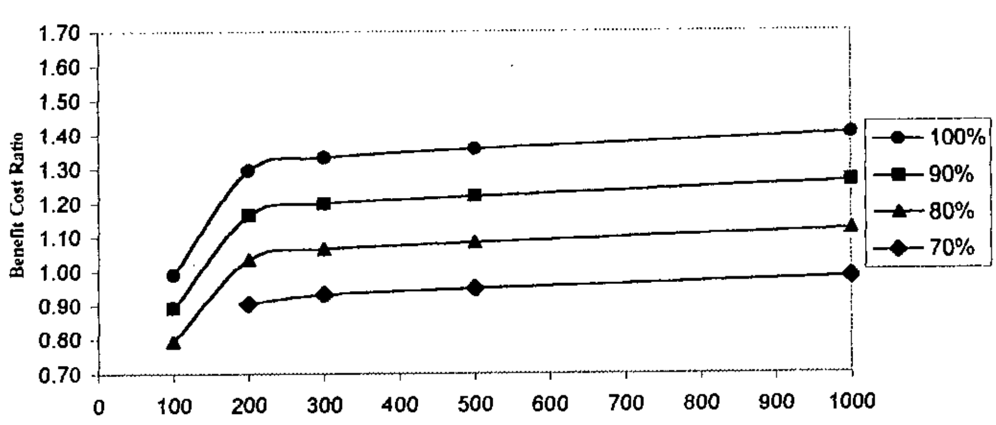

Figure 5.18 Benefit Cost Ratio at different capacity factor & 10 % price escalation (13% Discount Factor)

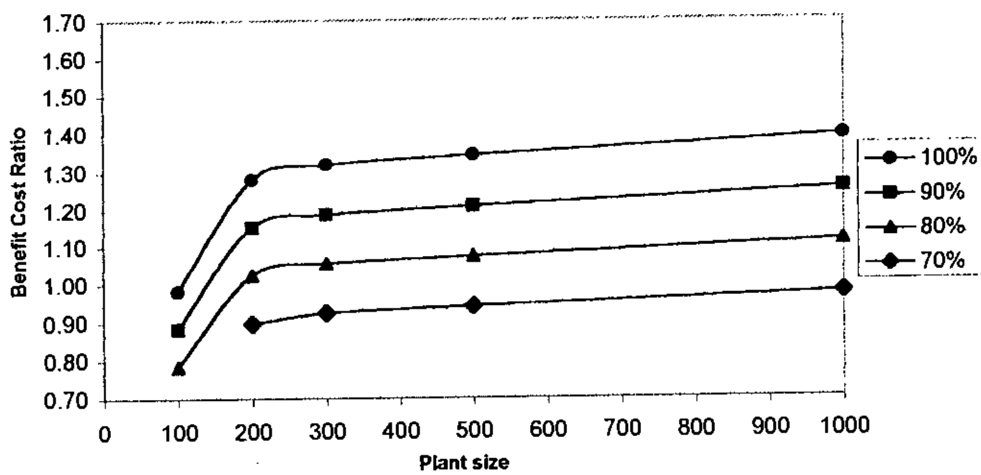

Figure 5.19 Benefit Cost Ratio at different capacity factor & 10 % price escalation (14% Discount Factor)

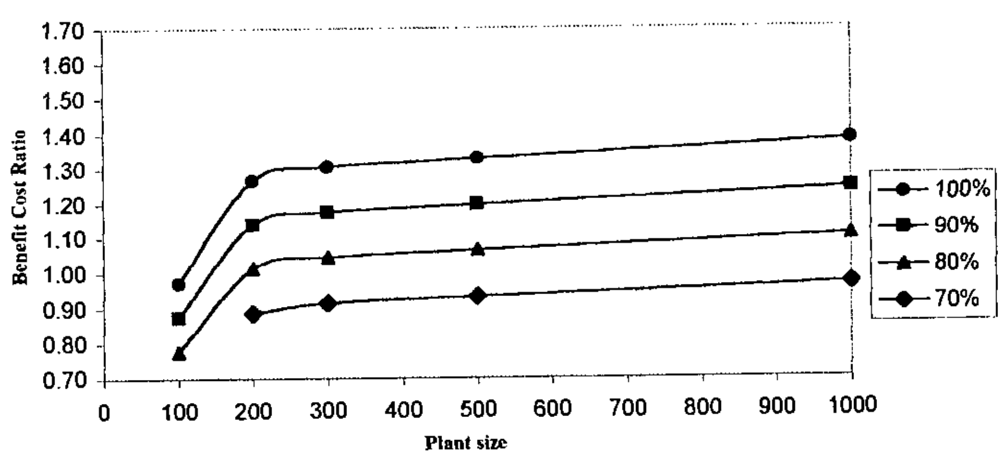

Figure 5.20 Benefit Cost Ratio at different capacity factor & 10 % price escalation (15% Discount Factor)

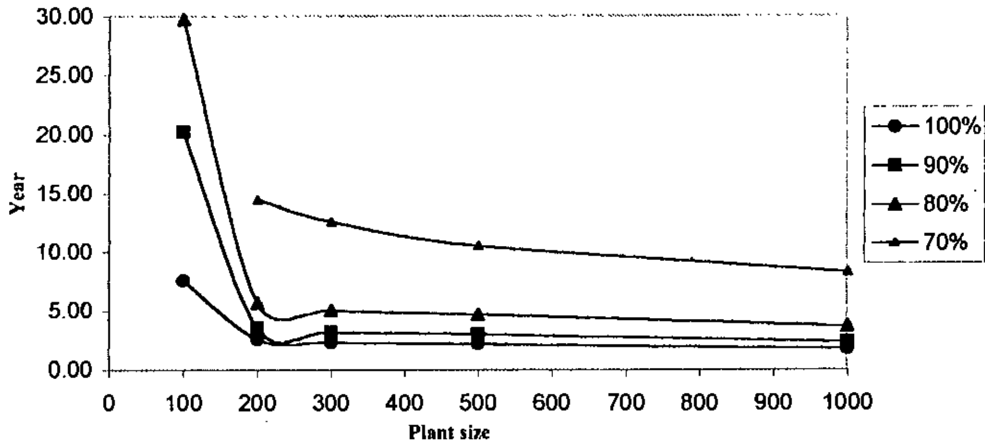

Figure 5.21 Payback period at different capacity factor & 10%price escalation.

Chapter 6

Conclusions and Recommendation

6.1 Conclusions

The conclusions and the relevant recommendations are based on the performance and the results of cost economics of biogas plants of different sizes, sensitivity analyses covering a range of capacity factor and escalation of prices of raw materials. Main objective of the study was to find the scope of biogas technology primarily in terms of choice of the technology i.e. type of biogas plant and economic viability under the prevailing conditions in Bangladesh. There are various end-uses of biogas and its by-products. However, in this project, cooking, lighting and fertilizing of land were considered for the analyses. Depending on the results and analysis, following conclusions can be made.

1. With the present conditions prevailing in Bangladesh biogas plants can be operated economically.

2. Through critical study of the available literature, it appears that fixed dome technology is suitable for the local conditions of Bangladesh.

3. A plant having a capacity of 100 cft is only economically viable if it runs with 90% capacity or above at an IRR of 11%. A 200 cft plant at 80% capacity exhibits an IRR of 20.90%. Similarly, 300 cft, 500 cft and 1000 cft at 70% capacity show the IRR of 15.70%, 17.60% and 22.80% respectively. Therefore, the higher the capacity the more attractive the plant is.

6.2 Recommendation

The work performed had various limitations due to the scope of testing the performance of the biogas plant. Economic analysis of cooking, lighting with hajack and fertilizing on land by biogas has been performed in this study where cowdung has been used as input. But biogas plant can also be run by other inputs i.e. human waste, waste of poultry farm etc. Therefore, analysis may be carried out for each of the individual cases to determine the economic viability.

It has been found that increase in capacity utilization results in increase of output of the biogas plant. By ensuring the proper amount of cowdung charged into the digester and proper maintenance of the plant can be optimized. A technical study can be carried out in this respect.

The output of the biogas plant has been used for cooking, lighting houses with hajack and fertilizing of land; but electricity can also be produced through generator by using biogas. However, electricity using biogas is not generated in Bangladesh. Therefore, a technical and economic analysis may be made to find out the techno-economic suitability for generating electricity with biogas.

Main reason for the limited success of the biogas technologies are high initial capital cost, unavailability of sufficient cowdung and lack of proper maintenance support. Therefore, a detailed technical performance study of the installed biogas plants may be made to find the possible solution.

Other factors like social benefit, environmental suitability that can not be easily quantified have not been considered in the study. Without these factors assessment of the technology can not be considered to be complete especially when biogas energy is much more environmentally benign as compared to other forms conventional energy. Further studies may be performed by incorporating such factors.

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Appendix-A

Table 4.2.1
Capital cost for 100cft plant

Raw Materials	Quantity	Unit Price (Tk)	Total Cost (Tk)
Digging Mud(cft)	700	0.9	630
Brick	1300	2.7	3510
Cement	14	250	3500
Sand(cft)	70	8	560
Khoa(cft)	35	25	875
RCC pipe(ft)	7.5	25	187.5
Rod(kg	32	18	576
Wax(kg)	2	50	100
Mason	10	120	1200
Labor	12	70	840
Valve	1	150	150
Burner(Double)	1	600	600
Hazak	1	500	500
Gas-pipe(ft)	100	5	500
			13728.5
			~14000.00

Table 4.2.2
Capital cost for 200cft plant

Raw Materials	Quantity	Unit Price (Tk)	Total Cost (Tk)
Digging Mud(cft)	1200	0.9	1080
Brick	2150	2.7	5805
Cement	20	250	5000
Sand(cft)	100	8	800
Khoa(cft)	55	25	1375
RCC pipe(ft)	9	25	225
Rod(kg	45	18	810
Wax(kg)	3	50	150
Mason	15	120	1800
Labor	18	70	1260
Valve	1	150	150
Burner(Double)	2	600	1200
Hazak	2	500	1000
Gas-pipe(ft)	150	5	750
			21405
			~21500.00

Table 4.2.3
Capital cost for 300cft plant

Raw Materials	Quantity	Unit Price (Tk)	Total Cost (Tk)
Digging Mud(cft)	1600	0.9	1440
Brick	2850	2.7	7695
Cement	27	250	6750
Sand(cft)	130	8	1040
Khoa(cft)	70	25	1750
RCC pipe(ft)	10	25	250
Rod(kg	85	18	1530
Wax(kg)	3	50	150
Mason	20	120	2400
Labor	24	70	1680
Valve	1	150	150
Burner(Double)	3	600	1800
Hazak	3	500	1500
Gas-pipe(ft)	200	5	1000
			29135
			~29000.00

Table 4.2.4
Capital cost for 500cft plant

Raw Materials	Quantity	Unit Price(Tk)	Total Cost(Tk)
Digging Mud(cft)	2400	0.9	2160
Brick	5700	2.7	15390
Cement	40	250	10000
Sand(cft)	200	8	1600
Khoa(cft)	110	25	2750
RCC pipe(ft)	13	25	325
Rod(kg	110	18	1980
Wax(kg)	4	50	200
Mason	28	120	3360
Labor	35	70	2450
Valve	1	150	150
Burner(Double)	5	600	3000
Hazak	5	500	2500
Gas-pipe(ft)	300	5	1500
			47365
			~47500.00

Table 4.2.5
Capital cost for 1000cft plant

Raw Materials	Quantity	Unit Price (Tk)	Total Cost (Tk)
Digging Mud(cft)	5000	0.9	4500
Brick	8500	2.7	22950
Cement	65	250	16250
Sand(cft)	350	8	2800
Khoa(cft)	160	25	4000
RCC pipe(ft)	16	25	400
Rod(kg	135	18	2430
Wax(kg)	6	50	300
Mason	36	120	4320
Labor	48	70	3360
Valve	1	150	150
Burner(Double)	10	600	6000
Hazak	10	500	5000
Gas-pipe(ft)	500	5	2500
			74960
			~75000.00

Table 5.2.1
Maintenance cost for 100cft plant

Year	Valve Replacement cost	Gaspipe Replacement cost	Burner Replacement cost	Hajack Replacement cost	Total Maintenance cost
0	0	0	0	0	0
1	0	0	0	0	0
2	150	0	0	0	150
3	150	0	0	0	150
4	150	0	0	0	150
5	150	0	0	0	150
6	150	0	0	0	150
7	150	0	0	0	150
8	150	0	0	0	150
9	150	0	0	0	150
10	150	0	0	0	150
11	150	500	600	500	1750
12	150	0	0	0	150
13	150	0	0	0	150
14	150	0	0	0	150
15	150	0	0	0	150
16	150	0	0	0	150
17	150	0	0	0	150
18	150	0	0	0	150
19	150	0	0	0	150
20	150	0	0	0	150

Table 4.2.5
Capital cost for 1000cft plant

Raw Materials	Quantity	Unit Price (Tk)	Total Cost (Tk)
Digging Mud(cft)	5000	0.9	4500
Brick	8500	2.7	22950
Cement	65	250	16250
Sand(cft)	350	8	2800
Khoa(cft)	160	25	4000
RCC pipe(ft)	16	25	400
Rod(kg	135	18	2430
Wax(kg)	6	50	300
Mason	36	120	4320
Labor	48	70	3360
Valve	1	150	150
Burner(Double)	10	600	6000
Hazak	10	500	5000
Gas-pipe(ft)	500	5	2500
			74960
			~75000.00

Table 5.2.1
Maintenance cost for 100cft plant

Year	Valve Replacement cost	Gaspipe Replacement cost	Burner Replacement cost	Hajack Replacement cost	Total Maintenance cost
0	0	0	0	0	0
1	0	0	0	0	0
2	150	0	0	0	150
3	150	0	0	0	150
4	150	0	0	0	150
5	150	0	0	0	150
6	150	0	0	0	150
7	150	0	0	0	150
8	150	0	0	0	150
9	150	0	0	0	150
10	150	0	0	0	150
11	150	500	600	500	1750
12	150	0	0	0	150
13	150	0	0	0	150
14	150	0	0	0	150
15	150	0	0	0	150
16	150	0	0	0	150
17	150	0	0	0	150
18	150	0	0	0	150
19	150	0	0	0	150
20	150	0	0	0	150

Table 5.2.2
Maintenace cost for 200cft plant

Year	Valve Replacement Cost	Gaspipe replacement cost	Burner Replacement cost	Hajack Replacement cost	Total maintenance cost
0	0	0	0	0	0
1	0	0	0	0	0
2	150	0	0	0	150
3	150	0	0	0	150
4	150	0	0	0	150
5	150	0	0	0	150
6	150	0	0	0	150
7	150	0	0	0	150
8	150	0	0	0	150
9	150	0	0	0	150
10	150	0	0	0	150
11	150	750	1200	1000	3100
12	150	0	0	0	150
13	150	0	0	0	150
14	150	0	0	0	150
15	150	0	0	0	150
16	150	0	0	0	150
17	150	0	0	0	150
18	150	0	0	0	150
19	150	0	0	0	150
20	150	0	0	0	150

Table 5.2.3
Maintenace cost for 300cft plant

Year	Valve Replacement cost	Gaspipe Replacement cost	Burner Replacement cost	Hajack Replacement cost	Total Maintenance cost
0	0	0	0	0	0
1	0	0	0	0	0
2	150	0	0	0	150
3	150	0	0	0	150
4	150	0	0	0	150
5	150	0	0	0	150
6	150	0	0	0	150
7	150	0	0	0	150
8	150	0	0	0	150
9	150	0	0	0	150
10	150	0	0	0	150
11	150	1000	1800	1500	4450
12	150	0	0	0	150
13	150	0	0	0	150
14	150	0	0	0	150
15	150	0	0	0	150
16	150	0	0	0	150
17	150	0	0	0	150
18	150	0	0	0	150
19	150	0	0	0	150
20	150	0	0	0	150

Table 5.2.4
Maintenace cost for 500cft plant

Year	Valve Replacement cost	Gaspipe Replacement cost	Burner Replacement cost	Hajack Replacement cost	Total Maintenance cost
0	0	0	0	0	0
1	0	0	0	0	0
2	150	0	0	0	150
3	150	0	0	0	150
4	150	0	0	0	150
5	150	0	0	0	150
6	150	0	0	0	150
7	150	0	0	0	150
8	150	0	0	0	150
9	150	0	0	0	150
10	150	0	0	0	150
11	150	1500	3000	2500	7150
12	150	0	0	0	150
13	150	0	0	0	150
14	150	0	0	0	150
15	150	0	0	0	150
16	150	0	0	0	150
17	150	0	0	0	150
18	150	0	0	0	150
19	150	0	0	0	150
20	150	0	0	0	150

Table 5.2.5
Maintenace cost for 1000cft plant

Year	Valve Replacement cost	Gaspipe Replacement cost	Burner Replacement cost	Hajack Replacement cost	Total Maintenance cost
0	0	0	0	0	0
1	0	0	0	0	0
2	150	0	0	0	150
3	150	0	0	0	150
4	150	0	0	0	150
5	150	0	0	0	150
6	150	0	0	0	150
7	150	0	0	0	150
8	150	0	0	0	150
9	150	0	0	0	150
10	150	0	0	0	150
11	150	2500	6000	5000	13650
12	150	0	0	0	150
13	150	0	0	0	150
14	150	0	0	0	150
15	150	0	0	0	150
16	150	0	0	0	150
17	150	0	0	0	150
18	150	0	0	0	150
19	150	0	0	0	150
20	150	0	0	0	150

Table 5.3.1

NPV at 10% Discount Factor (100cft plant at 100% capacity factor)

Year	Cash outflow	Cash inflow	Net cash flow	Discount factor	PV OF NCF
0	14,500	-	(14,500)	1	(14,500)
1	9,900	13,248	3348	0.909090909	3,044
2	10,050	13,248	3,198	0.826446281	2,643
3	10,050	13,248	3,198	0.751314801	2,403
4	10,050	13,248	3,198	0.683013455	2,184
5	10,050	13,248	3,198	0.620921323	1,986
6	10,050	13,248	3,198	0.56447393	1,805
7	10,050	13,248	3,198	0.513158118	1,641
8	10,050	13,248	3,198	0.46650738	1,492
9	10,050	13,248	3,198	0.424097618	1,356
10	10,050	13,248	3,198	0.385543289	1,233
11	11,650	13,248	1,598	0.350493899	560
12	10,050	13,248	3,198	0.318630818	1,019
13	10,050	13,248	3,198	0.28966438	926
14	10,050	13,248	3,198	0.263331254	842
15	10,050	13,248	3,198	0.239392049	766
16	10,050	13,248	3,198	0.217629136	696
17	10,050	13,248	3,198	0.197844669	633
18	10,050	13,248	3,198	0.17985879	575
19	10,050	13,248	3,198	0.163507991	523
20	10,050	13,248	3,198	0.148643628	475
	NPV				***12,302***

Table 5.3.2

NPV at 16% Discount Factor (100cft plant at 100% capacity factor)

Year	Cash outflow	Cash inflow	Net cash flow	Discount factor	PV OF NCF
0	14,500	-	(14,500)	1	(14,500)
1	9,900	13,248	3348	0.862068966	2,886
2	10,050	13,248	3,198	0.743162901	2,377
3	10,050	13,248	3,198	0.640657674	2,049
4	10,050	13,248	3,198	0.552291098	1,766
5	10,050	13,248	3,198	0.476113015	1,523
6	10,050	13,248	3,198	0.410442255	1,313
7	10,050	13,248	3,198	0.35382953	1,132
8	10,050	13,248	3,198	0.305025457	975
9	10,050	13,248	3,198	0.26295298	841
10	10,050	13,248	3,198	0.226683603	725
11	11,650	13,248	1,598	0.1954169	312
12	10,050	13,248	3,198	0.168462844	539
13	10,050	13,248	3,198	0.14522659	464
14	10,050	13,248	3,198	0.125195336	400
15	10,050	13,248	3,198	0.107927014	345
16	10,050	13,248	3,198	0.093040529	298
17	10,050	13,248	3,198	0.080207353	257
18	10,050	13,248	3,198	0.06914427	221
19	10,050	13,248	3,198	0.059607129	191
20	10,050	13,248	3,198	0.051385456	164
	NPV				***4,277***

Table 5.3.3
NPV at 18% Discount Factor (100cft plant at 100% capacity factor)

Year	Cash outflow	Cash inflow	Net cash flow	Discount factor	PV OF NCF
0	14,500	-	(14,500)	1	(14,500)
1	9,900	13,248	3348	0.847457627	2,837
2	10,050	13,248	3,198	0.71818443	2,297
3	10,050	13,248	3,198	0.608630873	1,946
4	10,050	13,248	3,198	0.515788875	1,649
5	10,050	13,248	3,198	0.437109216	1,398
6	10,050	13,248	3,198	0.370431539	1,185
7	10,050	13,248	3,198	0.313925033	1,004
8	10,050	13,248	3,198	0.266038164	851
9	10,050	13,248	3,198	0.225456071	721
10	10,050	13,248	3,198	0.191064467	611
11	11,650	13,248	1,598	0.16191904	259
12	10,050	13,248	3,198	0.137219525	439
13	10,050	13,248	3,198	0.116287733	372
14	10,050	13,248	3,198	0.098548926	315
15	10,050	13,248	3,198	0.083516039	267
16	10,050	13,248	3,198	0.070776305	226
17	10,050	13,248	3,198	0.059979919	192
18	10,050	13,248	3,198	0.05083044	163
19	10,050	13,248	3,198	0.043076644	138
20	10,050	13,248	3,198	0.036505631	117
		NPV			***2,486***

Table 5.3.4
NPV at 20% Discount Factor (100cft plant at 100% capacity factor)

Year	Cash outflow	Cash inflow	Net cash flow	Discount factor	PV OF NCF
0	14,500	-	(14,500)	1	(14,500)
1	9,900	13,248	3348	0.833333333	2,790
2	10,050	13,248	3,198	0.694444444	2,221
3	10,050	13,248	3,198	0.578703704	1,851
4	10,050	13,248	3,198	0.482253086	1,542
5	10,050	13,248	3,198	0.401877572	1,285
6	10,050	13,248	3,198	0.334897977	1,071
7	10,050	13,248	3,198	0.279081647	893
8	10,050	13,248	3,198	0.232568039	744
9	10,050	13,248	3,198	0.193806699	620
10	10,050	13,248	3,198	0.161505583	516
11	11,650	13,248	1,598	0.134587986	215
12	10,050	13,248	3,198	0.112156655	359
13	10,050	13,248	3,198	0.093463879	299
14	10,050	13,248	3,198	0.077886566	249
15	10,050	13,248	3,198	0.064905472	208
16	10,050	13,248	3,198	0.054087893	173
17	10,050	13,248	3,198	0.045073244	144
18	10,050	13,248	3,198	0.037561037	120
19	10,050	13,248	3,198	0.031300864	100
20	10,050	13,248	3,198	0.026084053	83
		NPV			***983***

Table 5.3.5

NPV at 21% Discount Factor (100cft plant at 100% capacity factor)

Year	Cash outflow	Cash inflow	Net cash flow	Discount factor	PV OF NCF
0	14,500	-	(14,500)	1	(14,500)
1	9,900	13,248	3348	0.826446281	2,767
2	10,050	13,248	3,198	0.683013455	2,184
3	10,050	13,248	3,198	0.56447393	1,805
4	10,050	13,248	3,198	0.46650738	1,492
5	10,050	13,248	3,198	0.385543289	1,233
6	10,050	13,248	3,198	0.318630818	1,019
7	10,050	13,248	3,198	0.263331254	842
8	10,050	13,248	3,198	0.217629136	696
9	10,050	13,248	3,198	0.17985879	575
10	10,050	13,248	3,198	0.148643628	475
11	11,650	13,248	1,598	0.122845974	196
12	10,050	13,248	3,198	0.101525598	325
13	10,050	13,248	3,198	0.083905453	268
14	10,050	13,248	3,198	0.069343349	222
15	10,050	13,248	3,198	0.057308553	183
16	10,050	13,248	3,198	0.047362441	151
17	10,050	13,248	3,198	0.039142513	125
18	10,050	13,248	3,198	0.032349184	103
19	10,050	13,248	3,198	0.026734863	85
20	10,050	13,248	3,198	0.022094928	71
		NPV			***320***

Table 5.3.6

NPV at 22% Discount Factor (100cft plant at 100% capacity factor)

Year	Cash outflow	Cash inflow	Net cash flow	Discount factor	PV OF NCF
0	14,500	-	(14,500)	1	(14,500)
1	9,900	13,248	3348	0.819672131	2,744
2	10,050	13,248	3,198	0.671862403	2,149
3	10,050	13,248	3,198	0.550706887	1,761
4	10,050	13,248	3,198	0.451399088	1,444
5	10,050	13,248	3,198	0.369999252	1,183
6	10,050	13,248	3,198	0.303278076	970
7	10,050	13,248	3,198	0.248588587	795
8	10,050	13,248	3,198	0.203761137	652
9	10,050	13,248	3,198	0.167017325	534
10	10,050	13,248	3,198	0.136899447	438
11	11,650	13,248	1,598	0.112212661	179
12	10,050	13,248	3,198	0.091977591	294
13	10,050	13,248	3,198	0.075391468	241
14	10,050	13,248	3,198	0.061796285	198
15	10,050	13,248	3,198	0.050652693	162
16	10,050	13,248	3,198	0.041518601	133
17	10,050	13,248	3,198	0.03403164	109
18	10,050	13,248	3,198	0.027894787	89
19	10,050	13,248	3,198	0.022864579	73
20	10,050	13,248	3,198	0.018741459	60
		NPV			***(293)***

Table 5.3.7

NPV at 10% Discount Factor (100cft plant at 90% capacity factor)

Year	Cash outflow	Cash inflow	Net cash flow	Discount factor	PV OF NCF
0	14,500	-	(14,500)	1	(14,500)
1	9,900	11,923.20	2023.2	0.909090909	1,839
2	10,050	11,923.20	1,873	0.826446281	1,548
3	10,050	11,923.20	1,873	0.751314801	1,407
4	10,050	11,923.20	1,873	0.683013455	1,279
5	10,050	11,923.20	1,873	0.620921323	1,163
6	10,050	11,923.20	1,873	0.56447393	1,057
7	10,050	11,923.20	1,873	0.513158118	961
8	10,050	11,923.20	1,873	0.46650738	874
9	10,050	11,923.20	1,873	0.424097618	794
10	10,050	11,923.20	1,873	0.385543289	722
11	11,650	11,923.20	273	0.350493899	96
12	10,050	11,923.20	1,873	0.318630818	597
13	10,050	11,923.20	1,873	0.28966438	543
14	10,050	11,923.20	1,873	0.263331254	493
15	10,050	11,923.20	1,873	0.239392049	448
16	10,050	11,923.20	1,873	0.217629136	408
17	10,050	11,923.20	1,873	0.197844669	371
18	10,050	11,923.20	1,873	0.17985879	337
19	10,050	11,923.20	1,873	0.163507991	306
20	10,050	11,923.20	1,873	0.148643628	278
		NPV			***1,023***

Table 5.3.8

NPV at 12% Discount Factor (100cft plant at 90% capacity factor)

Year	Cash outflow	Cash inflow	Net cash flow	Discount factor	PV OF NCF
0	14,500	-	(14,500)	1	(14,500)
1	9,900	11,923.20	2023.2	0.892857143	1,806
2	10,050	11,923.20	1,873	0.797193878	1,493
3	10,050	11,923.20	1,873	0.711780248	1,333
4	10,050	11,923.20	1,873	0.635518078	1,190
5	10,050	11,923.20	1,873	0.567426856	1,063
6	10,050	11,923.20	1,873	0.506631121	949
7	10,050	11,923.20	1,873	0.452349215	847
8	10,050	11,923.20	1,873	0.403883228	757
9	10,050	11,923.20	1,873	0.360610025	675
10	10,050	11,923.20	1,873	0.321973237	603
11	11,650	11,923.20	273	0.287476104	79
12	10,050	11,923.20	1,873	0.256675093	481
13	10,050	11,923.20	1,873	0.22917419	429
14	10,050	11,923.20	1,873	0.204619813	383
15	10,050	11,923.20	1,873	0.182696261	342
16	10,050	11,923.20	1,873	0.163121662	306
17	10,050	11,923.20	1,873	0.145644341	273
18	10,050	11,923.20	1,873	0.13003959	244
19	10,050	11,923.20	1,873	0.116106777	217
20	10,050	11,923.20	1,873	0.103666765	194
		NPV			***(834)***

Table 5.3.9

NPV at 11% Discount Factor (100cft plant at 90% capacity factor)

Year	Cash outflow	Cash inflow	Net cash flow	Discount factor	PV OF NCF
0	14,500	-	(14,500)	1	(14,500)
1	9,900	11,923.20	2023.2	0.900900901	1,823
2	10,050	11,923.20	1,873	0.811622433	1,520
3	10,050	11,923.20	1,873	0.731191381	1,370
4	10,050	11,923.20	1,873	0.658730974	1,234
5	10,050	11,923.20	1,873	0.593451328	1,112
6	10,050	11,923.20	1,873	0.534640836	1,001
7	10,050	11,923.20	1,873	0.481658411	902
8	10,050	11,923.20	1,873	0.433926496	813
9	10,050	11,923.20	1,873	0.390924771	732
10	10,050	11,923.20	1,873	0.352184479	660
11	11,650	11,923.20	273	0.317283314	87
12	10,050	11,923.20	1,873	0.285840824	535
13	10,050	11,923.20	1,873	0.257514256	482
14	10,050	11,923.20	1,873	0.231994825	435
15	10,050	11,923.20	1,873	0.209004347	392
16	10,050	11,923.20	1,873	0.188292204	353
17	10,050	11,923.20	1,873	0.169632616	318
18	10,050	11,923.20	1,873	0.152822177	286
19	10,050	11,923.20	1,873	0.137677637	258
20	10,050	11,923.20	1,873	0.124033907	232
		NPV			***44***

Table 5.3.10

NPV at 10% Discount Factor (100cft plant at 80% capacity factor)

Year	Cash outflow	Cash inflow	Net cash flow	Discount factor	PV OF NCF
0	14,500	-	(14,500)	1	(14,500)
1	9,900	10,598.40	698.4	0.909090909	635
2	10,050	10,598.40	548	0.826446281	453
3	10,050	10,598.40	548	0.751314801	412
4	10,050	10,598.40	548	0.683013455	375
5	10,050	10,598.40	548	0.620921323	341
6	10,050	10,598.40	548	0.56447393	310
7	10,050	10,598.40	548	0.513158118	281
8	10,050	10,598.40	548	0.46650738	256
9	10,050	10,598.40	548	0.424097618	233
10	10,050	10,598.40	548	0.385543289	211
11	11,650	10,598.40	(1,052)	0.350493899	(369)
12	10,050	10,598.40	548	0.318630818	175
13	10,050	10,598.40	548	0.28966438	159
14	10,050	10,598.40	548	0.263331254	144
15	10,050	10,598.40	548	0.239392049	131
16	10,050	10,598.40	548	0.217629136	119
17	10,050	10,598.40	548	0.197844669	108
18	10,050	10,598.40	548	0.17985879	99
19	10,050	10,598.40	548	0.163507991	90
20	10,050	10,598.40	548	0.148643628	82
		NPV			***(10,256)***

Table 5.3.11

NPV at 8% Discount Factor (100cft plant at 80% capacity factor)

Year	Cash outflow	Cash inflow	Net cash flow	Discount factor	PV OF NCF
0	14,500	-	(14,500)	1	(14,500)
1	9,900	10,598.40	698.4	0.925925926	647
2	10,050	10,598.40	548	0.85733882	470
3	10,050	10,598.40	548	0.793832241	435
4	10,050	10,598.40	548	0.735029853	403
5	10,050	10,598.40	548	0.680583197	373
6	10,050	10,598.40	548	0.630169627	346
7	10,050	10,598.40	548	0.583490395	320
8	10,050	10,598.40	548	0.540268885	296
9	10,050	10,598.40	548	0.500248967	274
10	10,050	10,598.40	548	0.463193488	254
11	11,650	10,598.40	(1,052)	0.428882859	(451)
12	10,050	10,598.40	548	0.397113759	218
13	10,050	10,598.40	548	0.367697925	202
14	10,050	10,598.40	548	0.340461041	187
15	10,050	10,598.40	548	0.315241705	173
16	10,050	10,598.40	548	0.291890468	160
17	10,050	10,598.40	548	0.270268951	148
18	10,050	10,598.40	548	0.250249029	137
19	10,050	10,598.40	548	0.231712064	127
20	10,050	10,598.40	548	0.214548207	118
		NPV			***(9,663)***

Table 5.3.12

NPV at 6% Discount Factor (100cft plant at 80% capacity factor)

Year	Cash outflow	Cash inflow	Net cash flow	Discount factor	PV OF NCF
0	14,500	-	(14,500)	1	(14,500)
1	9,900	10,598.40	698.4	0.943396226	659
2	10,050	10,598.40	548	0.88999644	488
3	10,050	10,598.40	548	0.839619283	460
4	10,050	10,598.40	548	0.792093663	434
5	10,050	10,598.40	548	0.747258173	410
6	10,050	10,598.40	548	0.70496054	387
7	10,050	10,598.40	548	0.665057114	365
8	10,050	10,598.40	548	0.627412371	344
9	10,050	10,598.40	548	0.591898464	325
10	10,050	10,598.40	548	0.558394777	306
11	11,650	10,598.40	(1,052)	0.526787525	(554)
12	10,050	10,598.40	548	0.496969364	273
13	10,050	10,598.40	548	0.468839022	257
14	10,050	10,598.40	548	0.442300964	243
15	10,050	10,598.40	548	0.417265061	229
16	10,050	10,598.40	548	0.393646284	216
17	10,050	10,598.40	548	0.371364419	204
18	10,050	10,598.40	548	0.350343791	192
19	10,050	10,598.40	548	0.33051301	181
20	10,050	10,598.40	548	0.311804727	171
		NPV			***(8,911)***

Table 5.3.13

NPV at 4% Discount Factor (100cft plant at 80% capacity factor)

Year	Cash outflow	Cash inflow	Net cash flow	Discount factor	PV OF NCF
0	14,500	-	(14,500)	1	(14,500)
1	9,900	10,598.40	698.4	0.961538462	672
2	10,050	10,598.40	548	0.924556213	507
3	10,050	10,598.40	548	0.888996359	488
4	10,050	10,598.40	548	0.854804191	469
5	10,050	10,598.40	548	0.821927107	451
6	10,050	10,598.40	548	0.790314526	433
7	10,050	10,598.40	548	0.759917813	417
8	10,050	10,598.40	548	0.730690205	401
9	10,050	10,598.40	548	0.702586736	385
10	10,050	10,598.40	548	0.675564169	370
11	11,650	10,598.40	(1,052)	0.649580932	(683)
12	10,050	10,598.40	548	0.62459705	343
13	10,050	10,598.40	548	0.600574086	329
14	10,050	10,598.40	548	0.577475083	317
15	10,050	10,598.40	548	0.555264503	305
16	10,050	10,598.40	548	0.533908176	293
17	10,050	10,598.40	548	0.513373246	282
18	10,050	10,598.40	548	0.493628121	271
19	10,050	10,598.40	548	0.474642424	260
20	10,050	10,598.40	548	0.456386946	250
		NPV			***(7,942)***

Table 5.3.14

NPV at1% Discount Factor (100cft plant at 80% capacity factor)

Year	Cash outflow	Cash inflow	Net cash flow	Discount factor	PV OF NCF
0	14,500	-	(14,500)	1	(14,500)
1	9,900	10,598.40	698.4	0.99009901	691
2	10,050	10,598.40	548	0.980296049	538
3	10,050	10,598.40	548	0.970590148	532
4	10,050	10,598.40	548	0.960980344	527
5	10,050	10,598.40	548	0.951465688	522
6	10,050	10,598.40	548	0.942045235	517
7	10,050	10,598.40	548	0.932718055	512
8	10,050	10,598.40	548	0.923483222	506
9	10,050	10,598.40	548	0.914339824	501
10	10,050	10,598.40	548	0.905286955	496
11	11,650	10,598.40	(1,052)	0.896323718	(943)
12	10,050	10,598.40	548	0.887449225	487
13	10,050	10,598.40	548	0.878662599	482
14	10,050	10,598.40	548	0.86996297	477
15	10,050	10,598.40	548	0.861349475	472
16	10,050	10,598.40	548	0.852821262	468
17	10,050	10,598.40	548	0.844377487	463
18	10,050	10,598.40	548	0.836017314	458
19	10,050	10,598.40	548	0.827739915	454
20	10,050	10,598.40	548	0.81954447	449
		NPV			***(5,889)***

Appendix-B

Fertilizer

The cowdung supplied to the digester is recollected as cow-dung residue after anaerobic conversion in the digester. As a result of the conversion, the amount of cowdung is decreased by a factor of 25% [24].

Ranges of different nutrient required for rice crop production in a medium fertile land are

Nitrogen (Kg/ha)	Potasium (Kg/ha)	Phosphorus (Kg/ha)	Sulpher (Kg/ha)	Zinc (Kg/ha)
33-64	8-14	21-40	6-10	0-1.0

Ranges of different nutrient available in cowdung are

Nitrogen	Phosphorus	Potasium
0.5-1.5%	0.4-0.8%	0.5-1.9%

Cowdung residue of 5-10ton/ha supplies 20-40 kg of N per hactre. Forty-five kg of Nitrogen is equivalent to 100kg of Urea [26]. The anaerobic digestion results in no loss of N content in the cowdung residue [27].

Calculation of cost of equivalent Urea

Daily cow-dung supplied		70kg
Daily cowdung residue produced	70kg*0.75	52.5kg
Yearly cow-dung residue produced	52.5kg*30*12	18900kg
Equivalent Nitrogen produced		75.6kg
Equivalent Urea		168kg
Cost of equivalent Urea	Tk6/kg*168kg	Tk 1008.00

Figure A1: A 100 cft biogas plant at Dour, Uttara, Dhaka

Figure A2: A 450 cft biogas plant at Kamarpara, Uttara, Dhaka