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Performance Analysis and Modification of Portable Biogas Plant

by

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A THESIS

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ABSTRACT

Biogas technology has come a long way in Nepal since its introduction in 1955. The government started the biogas program in 1975 while the Biogas Support Program (BSP) established in 1992 contributed, to the popularization of use of biogas. Biogas is highly efficient, low carbon emitting renewable energy fuel and it can substitute both traditional biomass and liquid petroleum gas (LPG) for cooking and heating purposes. However, replication of the technology is still relatively low. Only 17% of all potential households make use of it. While the usage of LPG is steadily rising, a sizable portion of the population still relies on the use of solid biomass. In the development of the biogas market, Nepal has been introduced with different types of biogas plants. The most popular of it is the GGC model while a recent type of plant made of Fiber Reinforced Plastic has been introduced. The plant is basically a comparatively portable kind of tank especially designed for urban domestic use. This study tries to investigate the performance of the Portable FRP Biogas plant and compare it with existing GGC-2047 model. The test was performed with three conditions of feeding normal, with physical pretreatment and with greenhouse. With feedstocks mostly being food waste from households, the results show that biogas production is still possible. The plant when fed exclusively with organic waste produced maximum of 0.257 m^3 of biogas which had a maximum of 43% of methane content. The pH level dropped while feeding only organic waste for a month. The TS reduction in feedstock to digestate was upto 85% and VS reduction was upto 90%. The plant has a potential to displace 3.67kg of LPG per month

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LIST OF ACRONYMS AND ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
AD	Anaerobic Digestion
AEPC	Alternative Energy Promotion Center
APHA	American Public Health Association
cc	Cubic centimeter
C:N	Carbon:Nitrogen
CBS	Central Bureau of Statistics
CES	Centre for Energy Studies
CH_4	Methane
CO_2	Carbon Dioxide
DFRS	Department of Forest Research and Survey
FAN	Free Ammonia Nitrogen
FAO	Food and Agriculture Organization of the United Nations
FRP	Fiber Reinforced Plastic
FY	Fiscal Year
GGC	Gobar Gas Company
GJ	Gigajoules
GoN	Government of Nepal
IEA	International Energy Agency
IRR	Internal Rate of Return
KVIC	Khadi and Village Industries Commission
kWh	Kilowatt hour
LPG	Liquid Petroleum Gas
mm	millimeter
MOF	Ministry of Finance
MW	Mega Watt
NEA	Nepal Electricity Authority
NEF	Nepal Economic Forum
nm	Nano meter
NOC	Nepal Oil Corporation
NPC	National Planning Commision

NPK	Nitrogen Phosphorus Potassium
NPV	Net Present Value
OFMSW	Organic Fraction of Municipal Solid Waste
PBP	Portable Biogas Plant
ppm	Parts per million
RE	Renewable Energy
RRR	Required Rate of Return
SNV	Netherlands Development Organization
TAN	Total Ammonia Nitrogen
TS	Total Solids
VFA	Volatile Fatty Acids
VS	Volatile Solids
WECS	Water and Energy Commisions Secratariat

CHAPTER ONE : INTRODUCTION

1.1 Background

Biogas is a clean, renewable energy source which is generated from the decomposition of organic waste such as animal manure, food waste, and agricultural waste. It is a mixture of methane (CH_4) and carbon dioxide (CO_2) and can be used as a fuel for heating, cooking, and electricity generation. The production of biogas offers several benefits, including reducing greenhouse gas emissions, improving waste management, and providing a sustainable source of energy.

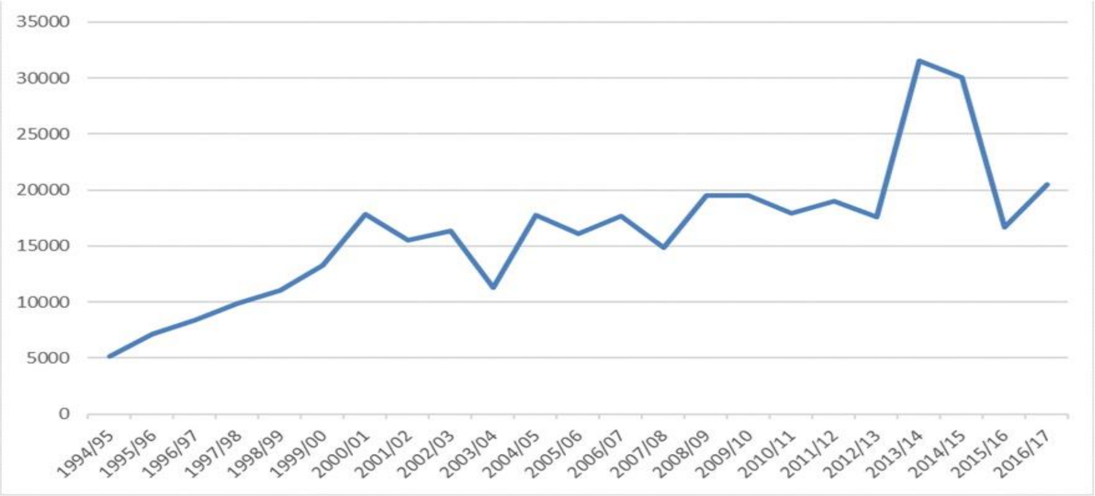
Biogas has a number of advantages over traditional fossil fuels. Firstly, it is a renewable energy source, which means that it will never run out. Secondly, it is a clean energy source, producing fewer emissions than traditional fossil fuels. Additionally, producing biogas from organic waste helps to reduce waste and improve waste management. An ideal technique for possible renewable energy recovery with nutrient-rich fertilizer and sustainable waste management has been considered anaerobic digestion, which produces biogas (Li, et al., 2011) (McCarty, 2001). Compared to other waste-treatment methods like incineration (Oliveira & Rosa, 2003), composting (Walker, et al., 20009), and landfilling (Lou & Nair, 2009), it emits fewer greenhouse gases.

Since Nepal lacks its own petroleum resources, all of these items are imported, making up 1/10th of the nation's gross primary energy consumption. (Malla, 2013; NPC, 2013). Nepal imported petroleum fuel worth Rupees 383 billion, which is 20% of total imports and around twice of it exports. Nepal imported a total of 536,028 metric tons of LPG in FY 2021-22 AD, which is a rise of more than 250% compared to the FY 2012/13 AD. 93% of the population across the country has access to electricity and the government has brought a policy to quit LPG and use electricity instead. The primary energy source in Nepal's ultimate energy consumption is conventional solid biomass. Currently, fuelwood makes up around 62% of the nation's total final energy consumption (MOF, 2020b), which is significantly more than the majority of developing nations worldwide 2 (IEA, 2020). The demand for fuelwood is still increasing in absolute terms even if its share of overall final energy consumption has declined between fiscal years (FY) 2008/9 and 2018/19 by 16 percentage points. For instance, the consumption of fuelwood grew by 19% from 7.3 MTOE in 2008/9 to 8.7 MTOE in 2017/18 (MOF, 2020b).

For the economic growth of every country an adequate and reliable energy supply is necessary. The energy source should be sustainable, affordable and easily accessible to all the population. However, the conventional and most affordable energy sources are often the least sustainable. The GoN has been actively pushing renewable energy technologies (RET), primarily micro-hydro, solar PV, and biogas, across the country with the goals of ensuring energy security, slowing the rate of deforestation, and reducing reliance on imported petroleum fuels. But less than 1% of all energy demand is supplied by RETs.

Being introduced for the first time in 1955 in Nepal, the Nepali Government officially launched the biogas programme in 1975. Following the launch of the Biogas Support Programme (BSP) with help from the Dutch government in 1992, this program gained additional traction in the nation. The Alternative Energy Promotion Center (AEPC) was founded in 1996 with the primary goal of informing the public and promoting the use of renewable energy technologies (RET) in order to raise rural residents' standards of living, provide them with clean, sustainable energy, and stop environmental deterioration. With the assistance of the GoN, the German Development Bank (KfW), and the World Bank (WB), AEPC is implementing BSP.

In Nepal, there is a significant amount of manure, sewage sludge, organic industrial waste, and organic solid waste. The environment must be protected by properly managing this garbage. The only environmentally beneficial option is landfilling. The recovery of biogas (approximately 60% methane) and digestate sludge as a byproduct of these wastes' anaerobic digestion is an environmentally advantageous and energy-efficient waste-management strategy. The latter is utilized as an organic fertilizer. This can assist Nepal in replacing chemical fertilizer, and biogas can be applied in industrial, industrial, and domestic settings. This technology is a good alternative as a clean energy solution in terms of accessibility to scattered settlements and displacing the use of traditional biomass as well as reducing the import expenditure of our country. Although biogas promotion is one of the government's priorities, replication of the technology is not as anticipated. As of now, Nepal has more than 450 000 household-level biogas plants (AEPC, 2021). However, due to technological issues, around 10% of the biogas digesters are inoperable (Paudel, et al., 2020).



(AEPC,2023)

Figure 1.1 Installation of biogas plants

In spite of being a mature technology, the biogas potential optimum use of has not been realized. Since the biogas produced cannot satisfy a household's energy needs, low yield of biogas in cold climates is seen as a major obstacle to widespread adoption of the technology (K.C., et al., 2011; SNV, 2010). Going by the moniker it is touted as, "Gobar gas," which literally translates to "gas from cattle dung," almost all household biogas systems in Nepal are operated on cattle dung. Research indicates that the amount of cattle dung may not be sufficient to produce biogas year-round (Jingura & Matengaifa, 2009; Lungkhimba, et al., 2011) due to its low gas output (Moller, et al., 2004). Income and quantity of landholdings are the main socioeconomic factors influencing the use of biogas in Nepal. Households in the country's hilly region find it challenging to employ biogas technology, highlighting the difficulties in installing and running biogas in mountainous and hilly regions. The quantity of biogas installation and maintenance service providers and the lack of banking facilities are the main barriers to biogas adoption in Nepal.

Previous studies have been conducted on wide variety of biogas plants like the widely popular in Nepal, the GGC model (Khanal & Jha, 2014) and other fixed dome plants, homebiogas which is a bag type digester of 2m^3 (Gautam & Jha, 2020), and FRP plant of 6m^3 capacity (Khanal & Jha, 2014). Meanwhile FRP biogas plant introduced by Alternative Bio is a fairly new model of plant in Nepal, which is an urban centric portable biogas plant promoted by the company for ease of installation, user friendly operation, possibility of use with wide variety of feedstock.

1.2 Problem statement

Many technologies of biogas plant have been developed of which FRP portable biogas plant was introduced in Nepal in 2017. The company has been struggling to get statutory certification for subsidies provided by the government through AEPC for lack of authentic performance analysis in Nepal. Studies have not been made regarding its suitability hence these warrants for relevant research on the plant.

1.3 Objectives

The main objective of this study is to evaluate the Fibre Reinforced Plastic Biogas plant for its performance during its utility with respect to the volume and quality of gas produced, amount of feedstock provided.

The following are the specific objectives of this study:

- To measure the quantity and quality of gas produced by the plant
- To measure the quantity and quality of the feedstock provided to the plant
- To compare the quantity and quality of gas under various temperature condition.
- To compare the quantity and quality of gas produced with and without pre-treatment.
- To compare Portable Biogas Plant with GGC 2047 model.

1.4 Research approach

The study is carried out in four phases: Literature review, Field survey, Data analysis and comparison of data.

Literature review

Literature review is briefly described in chapter two of this report. This discusses about the following topics –

- Biogas production process
- Uses of biogas
- Factors affecting biogas production (Temperature, Retention parameter, substrate characteristics)
- Benefits and disbenefits of biogas
- Biogas development in Nepal
- Types and design of domestic biogas plants

1.5 Structure of thesis

The six chapters that make up this thesis. The thesis is organized as follows.

Chapter One: The brief description of the background, statement of the problem, rationale of the study, objectives of the study, research approach, scope and limitation of the study and outline of the thesis.

Chapter Two: This chapter discusses about the energy structure in Nepal, its geography, economy, demography, energy demand and fuels commonly used.

Chapter Three: A comprehensive literature review of biogas technology and its development in Nepal.

Chapter Four: The methodology for assessing the quantity and quality of gas produced is described in this chapter.

Chapter Five: Analysis of the collected data and correlation of factors and discussion.

Chapter Six: Summary of the key conclusion of the research with the limitation and the recommendation for the future research

Chapter Seven: References of the study

Chapter Eight: Annex

CHAPTER TWO : LITERATURE REVIEW

2.1 Overview of Nepal

Nepal is a landlocked country situated in South Asia between India in the East, West and South and Tibet Autonomous Region of China in the North. Nepal occupies 0.03% and 0.3% of total land area of world and Asia respectively. The country stretched from east to west with mean length of 885kms and widens from north to south with mean breadth of 193 kilometers. It is located at 26˚04' North to 30˚27' North latitude and 80˚04' East to 88˚12' East longitude. It has a total area of 147181 sq.km.

Nepal can be divided into three different ecological regions namely, the Mountain, Hill and Terai, due to wide variation in altitude in relatively short distance (Winrock Nepal, 2004; WECS, 2010) (Figure 2.1-1). The mountainous area covers about 35% of the total land and is situated in the north above 4800m (CBS, 2012b; WECS, 2010). The hilly region spreads in the middle extending from 700m to 4800m and occupies about 42% of the total areas, while Terai covers 23% and lies on the south below 700m (CBS, 2012a).

(Jytte Agergaard, 2022)

Figure 2.1 Division of Administrative and Ecologial regions in Nepal Climate

The climate of Nepal is highly influenced by elevation as well as by its latitude, ranging from subtropical monsoon conditions in the Terai to Arctic condition in high Himalayas in the north. The nation is catergorized into five climatic zones (Practical Action, 2009b). The tropical zone lies below 1000m covering 18% of the nation's land area. The summer here is hot and rainy while winter is mild. The subtropical climate zone ranges from 1000 to 2000 meters occupying 22% of Nepal's land area with mean annual temperature of 15-21˚C. Majority of Nepal's population reside in the tropical and subtropical climate zones. From 2000 to 3000 meters temperate climate zone prevails which occupies 12% of Nepal's land area. The range of average temperature is between 8 and 15 C, with moderate and dry winters and mild but rainy summers. The subalpine zone from 3000 to 4000 meters covers 9% of Nepal's land area. The mean annual temperature is below 8˚C. above 4200m elevation, tundra type of climate dominates the region above 5000m with frost throughout the year and cold desert like conditions and alpine like climate is found below 5000m. It covers 8% of the country's land area.

2.2 Demography

The population of the country has reached 29,192,480, according to the Census report 2021, marking a growth of 2,697,976 compared to the count of 26,494,504 a decade ago. This translates to a population increase of 10.18% since 2011. In contrast to information from the Census Report of 2001–2011, which showed a growth rate of 1.35%, the average yearly growth rate has decreased, currently standing at 0.93%. The average family size has also decreased slightly to 4.33 compared to 4.88 from the last report.

In terms of urbanization, the urban population has risen to 66.8% from the 63.2% recorded in 2011. Conversely, the rural population has decreased to 33.9% in 2021, down from 36.8% in 2011. The Census report further indicates that the population distribution across regions is as follows: 53.66% in the Terai, 40.25% in the hilly region, and 6.09% in the mountainous area.

Notably, the Terai region's population density is experiencing rapid growth, reaching 461 people per square kilometer, a substantial increase from the mere 34 people per square kilometer noted in the mountainous regions.

2.3 Economy

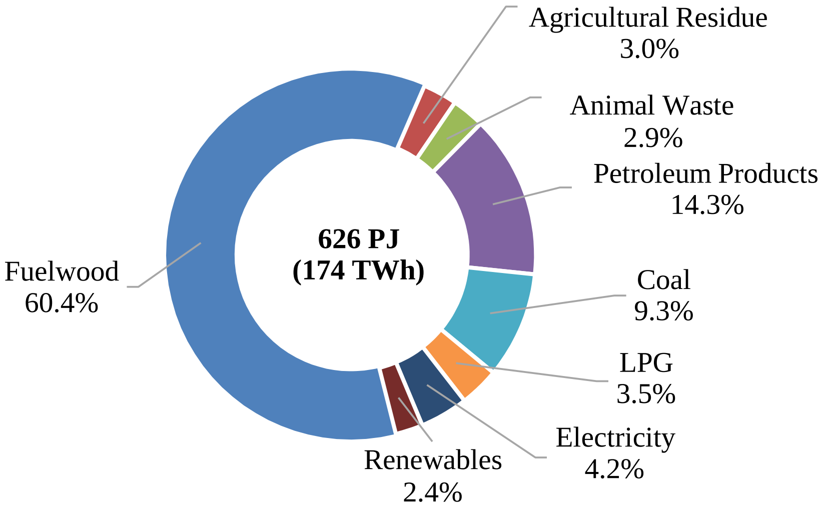
The GDP per capita in current prices was projected to rise by 7.5% to US$ 1191 (Rs. 140,819) in the fiscal year 2020/21. (Nepal Economic Survey 2020-21). In 2022, the agriculture sector’s contributed 23.95% to GDP, whereas the manufacturing sector's contribution was 14.3% to GDP. In the year 2000, the total population in Nepal that relied on the agricultural sector for their livelihood was approximately 75%, which by 2022 has decreased to 66%. (NEF, 2022). In the year 2021, Nepal achieved eligibility for moving out of the 'Least Developed Country' classification. This advancement was accomplished by meeting the prescribed thresholds on the Human Asset Index and the Economic Vulnerability Index. These indices evaluate the nation's well-being in terms of health, education, and economic stability, particularly its susceptibility to natural shocks like droughts, natural disasters, and fluctuations in agricultural production.

During the preceding year, 2020, the poverty rate had dwindled to 17 percent. Subsequently, in 2022, Nepal witnessed an improvement in its hunger situation as gauged by the Global Hunger Index, with the severity of hunger shifting from the severe category to a moderate level. Additionally, notable enhancements have been made to the country's infrastructure and road networks, thereby enhancing connectivity in rural areas.

2.4 Energy Supply in Nepal

Different type of fuel resources are used to derive energy in Nepal. Various forms of energy can be categorized into two main groups: renewable and non-renewable sources. The renewable category can be further broken down into two subgroups: traditional resources, which comprise biomass such as fuelwood and animal and agricultural waste as well as other trash, and modern renewables, which include energy produced from hydro, solar, and wind sources. On the other hand, non-renewable sources consist of coal and petroleum products.

The need for commercial energy, such as coal, petroleum products, and electricity, has increased even if traditional sources like fuelwood, agricultural waste, and animal waste still make up a sizeable share of these energy supplies. Simultaneously, the utilization of renewable resources is also on the rise, and there is an observable increase in electricity consumption.(WECS, 2022)



(Energy Sector Synopsis Report 2021/2022)

Figure 2.2 Energy consumption in 2021 by energy type

2.4.1 Traditional Resources

The forestry industry in Nepal is one of the country's main sources of energy. According to research findings, forests cover approximately 40.36% of Nepal's total land area. The sustainable fuelwood potential within the country was reported to be around 12.15 million tons in 2014, according to the DFRS.

A significant traditional biomass used as a source of energy is agricultural waste. Given that over 60% of the population is directly engaged in agriculture, the residues produced from cereal crops play a significant role in serving as a major energy source, rural areas in particular. Based on the agricultural yield, the implicit agricultural residue was expected to be between 4 and 26 million tons in 2021, up from an initial projection of about 23 million tons for 2019. In 2019, 2020, and 2021 separately, the inferred energy potential harvested from agricultural residue was estimated to be 406 million GJ, 416 million GJ, and 442 million GJ.

Another type of traditional biomass that is frequently used as an energy source in rural areas is dry dung. In 2019, it was estimated that the output of manure from animals would be around 6.8 million tons. This capacity exhibited a modest increase of just 0.35% in the subsequent year of 2020, resulting in a production of 6.84 million tons. The COVID-19 pandemic's effects are to blame for the muted growth. It is anticipated to reach 6.9 million tons in 2021, representing an overall growth rate of 1.12%, despite the pandemic's influence beginning to wane in that year.

The potential of energy derived from dry dung calculated was to be approximately 101.6 million GJ in 2019. This potential expanded to 102 million GJ in 2020 and further in 2021 to 103 mil GJ.

2.4.2 Modern Renewables

As per the findings of the Solar and Wind Energy Resource Assessment carried out by the AEPC, the estimated economically viable potential of the on-grid solar PV system in Nepal stands at 2,100MW. Currently, there have been over 961 thousand residential solar power systems installed, with a majority situated in the hilly regions of the Lumbini and Karnali provinces. Alongside smaller isolated systems, there's also a significant installation of large utility-scale solar plants. Among these, the Nepal Electricity Authority (NEA) manages approximately 1.35 MW of plants, while Independent Power Producers (IPPs) oversee around 21 MW of solar installations.

Moreover, micro-hydropower plants (MHPs) that have been installed contribute a cumulative power of up to 38 MW, as of the year 2018. More than 1,800 of these MHPs have been supplying electricity to nearly 344 thousand households located in remote areas across Nepal. In places with limited access to grid electricity, these MHPs are essential for providing a dependable supply of service.The biogas is another renewable resource with a significant potential for energy production. Approximately 1.9 million families, or a staggering 42% of all households in Nepal, are thought to have the capacity to establish a residential biogas system. Due to the availability of a significant quantity of feedstock and a hospitable temperature condition, the Terai region predominates the installation, followed by the Hilly belts.

In relation to energy by wind, Nepal possesses an estimated potential supply of about 3000MW. However, the actual utilization has been quite limited, with a mere 113.6 kW being harnessed thus far, and approximately 5MW capacity is currently in the process of construction across different regions of Nepal. The total installed capacity of Nepal's solar wind hybrid mini-grid systems as of 2022 is 1500kW.

Modern renewables can also be derived from domestic organic municipal waste. Research indicates that Kathmandu Metropolitan City holds the capability to generate electricity by waste is approximately 1745 MWh, while Lalitpur Sub Metropolitan City, an adjacent area, has a potential of about 278 MWh. Similarly, Pokhara, another major city in Nepal, has the capacity to produce 244 MWh of electricity from municipal waste. The average amount of organic garbage produced by each town in 2020, according to the CBS's garbage Management baseline research, was about 1,200 tons. A recent study also shows that 130,294 m3 of biogas can be produced in Kathmandu by using 100% of the organic fraction of municipal solid waste (OFMSW).

2.4.3 Commercial Resources of Energy

The NEA is the exclusive entity responsible for managing and distributing the electricity supply throughout the nation. According to NEA's 2021 reports, their collective installed capacity reached 582 MW. This capacity encompasses hydropower plants, including the small-scale facilities endorsed by NEA, which collectively generated a total of 2,810.74 GWh of electricity during the fiscal year 2020/21. This indicates a marginal decline of 6.96% compared to the 3,021.04 GWh generated in FY 2019/20.

The total installed capacity of hydropower plants in Nepal as of February 2022 was 2,023 MW. Along with this, 49.76 MW of grid-connected solar PV power plants and an additional 53.4 MW of energy are integrated from thermal power plants. By February 2022, this added up to a total installed capacity of 2,205 MW. Notably, during June 2022, the peak demand for electricity reached 1,864 MW, while the national demand was at 1,564 MW. The excess energy is subsequently exported to the southern neighboring country, India. About 10.9 thousand tons of coal are produced in Nepal each year, while 2 million tons of coal are imported to meet domestic demand. The majority of industries that manufacture bricks use coal..

The NOC is solely responsible for the importation and distribution of petroleum products across Nepal. With the exception of LPG, NOC has currently developed storage facilities with a total capacity of 68,000 KL to house all essential petroleum fuels. The COVID-19 pandemic's effects were noticeable in the import of petroleum products in 2020, which showed a fall of over 10% in the import of gasoline, diesel, and kerosene and a dramatic decrease of 31% in the import of aviation turbine fuel (ATF) in comparison to the numbers from 2019. Conversely, there was a 5% increase in LPG consumption, primarily due to the prevalent use of LPG for household purposes.

2.5 Biogas production and status of biogas development in Nepal

2.5.1 Introduction to Biogas

Biogas is a flammable gas abundant in methane, generated through the anaerobic fermentation of organic materials by the activity of methanogenic bacteria (Karki, et al., 2015). It consists of a gas mixture primarily composed of methane, along with CO2 and other gases (refer to Table 2.6.1). Biogas is colorless and odorless, burning with a distinct blue flame. Notably, it lacks smoke and possesses non-toxic qualities. Its ignition temperature falls between 650 and 750˚C, carrying calorific value of 23.4MJ per m3, which surpasses the energy content of conventional fuels such as kerosene, firewood, charcoal, cow-dung cakes, and other conventional sources of biomass fuels. (Karki, et al., 2015)

Biogas technology converts organic waste into energy that can be consumed as a clean and sustainable cooking and lighting fuel and the slurry can be used as a bio-fertilizer (FAO/CMS, 1996). It has two-fold advantages: economic gains for the consumer and environmental cost savings against biodegradable waste management, as such waste is withheld from getting dumped in landfill (Subedi, 2015; FAO/CMS, 1996).

Table 2.1 Biogas Composition

Substance	Symbol	Composition (Percentage)
Methane	CH_4	50-70
Carbon dioxide	CO_2	30-40
Hydrogen	H_2	5-10
Nitrogen	N_2	1-2
Water vapour	H_2O	0.3
Hydrogen Sulphide	H_2S	Traces

(Karki et. al.,2015)

2.5.2 Anaerobic Digestion Process

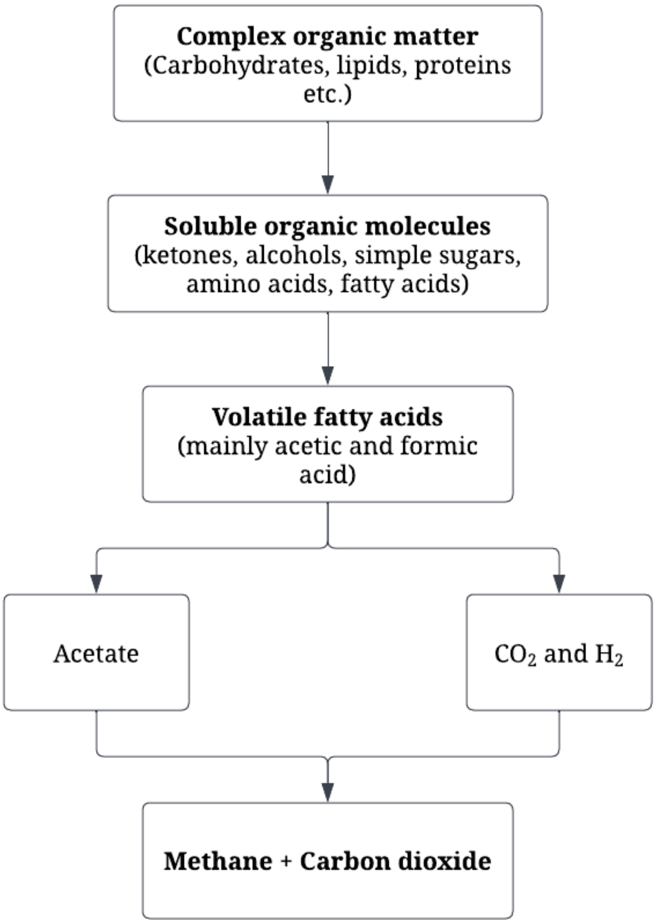
The organic substances derived from plants and animals primarily comprise lipids, proteins, carbohydrates and trace quantities of metabolites, the majority of which cannot dissolve in water. Groups of different micro-organisms convert complex organic substance in a series of four stages in an anaerobic digester. The first stage is solubilization or hydrolysis, second stage is acidogenesis, thirdly acetogenesis takes place then finally methanogenesis occurs (Figure 2.6.2) (Karki, et al., 2015; Balasubramaniyam, et al., 2008).

During hydrolysis, feedstock is dissolved into simpler, smaller components by the help of extracellular enzymes which the fermentative bacteria releases. The polymer breakdown stage is another name for this phase. During acidogenesis, the simple organic materials are converted by facultative anaerobic and hydrogen producing acidogenic bacteria into volatile fatty acids, ethanol, CO_2 and H_2. These fermented products are converted into acetic acid, CO_2 and H_2 in the acetogenesis phase. In the final stage of methanogenesis, methanogenic bacteria produce methane and CO_2 by using acetate and hydrogen produced in the previous stage.

$$\underset{\text{(Acetic acid)}}{CH_3COOH} \rightarrow \underset{\text{(Methane)}}{CH_4} + \underset{\text{(Carbon dioxide)}}{CO_2}$$

$$\underset{\text{(Ethanol)}}{2CH_3CH_2OH} + \underset{\text{(Carbon dioxide)}}{CO_2} \rightarrow \underset{\text{(Methane)}}{CH_4} + \underset{\text{(Acetic acid)}}{2CH_3COOH}$$

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



(Balasubramaniyam et al., 2008, Subedi, 2015)

Figure 2.3 Process of Single Stage Anaerobic Digestion

2.5.3 Factors Affecting Biogas Production

2.5.3.1 Seeding or Population of Bacteria

Acetogenic (acid-forming) and methanogenic bacteria are present in cow manure naturally. However, the population of these microorganisms is rather low. While methanogenic bacteria grow very slowly, acid-forming bacteria can multiply more quickly. For the initial activation, small amount of seed or inoculum has to be added which can be sludge from another digester. This sludge has the potential to improve the anaerobic digestion process of organic materials, as it contains elevated concentrations of acetogenic and methanogenic bacteria. Studies have shown that 30 to 50 percent of the input slurry can be the seeding materials. Nonetheless, if the amount of inoculum is further augmented, the volume of gas generated diminishes as a result of the reduced input feedstock supplied to the digester.

2.5.3.2 pH Stability

Another important and principal parameter of the process of anaerobic digestion is pH. It's variation influences microbial growth which has direct relation with hydrogen concentration. To achieve optimal methane production, it's crucial to maintain the pH level of the digester within the range of 6.8 to 7.6, as indicated by Li et al. (2011). If the pH falls below 6.1 or exceeds 8.3, it can lead to poor performance or even cause the digester to fail, as noted by Lay et al. (1997). An acidic environment hampers methane generation. Between 5.5 and 6.5 is the optimal pH range for processes like acidogenesis and hydrolysis (Hagos, et al., 2016).

2.5.3.3 Temperature

Temperature plays a pivotal role in initiating methane generation. Once metabolic processes are underway, exothermic reactions occur, aiding in the production of methane. The production of biogas follows a linear increase from 0°C to 20°C, as outlined by Sutter and Wellinger (1985), and becomes most favorable under mesophilic conditions. In mesophilic digestion, it's essential to maintain the temperature within the range of 30 to 40°C. Conversely, for thermophilic digestion, the temperature should be upheld between 45 and 60°C. In regions with cold climates, the digester's temperature should be kept at 35°C. The majority of reactors are typically operated at mesophilic or thermophilic temperatures, with optimal conditions at 35°C and 55°C, respectively (Bhattacharya and Mishra, 2003; Chynoweth et al., 2000; Liu et al., 2006). This is because at lower temperatures, the capacities of biomass activities and anaerobic treatment capacities are significantly reduced. Anaerobic digestion can still occur at psychrophilic temperatures below 20°C. Biochemical reactions occur at an exceptionally sluggish rate in psychrophilic environments when compared to the pace observed in mesophilic and thermophilic conditions (Chynoweth et al. 1999). Low temperature has negative impact on anaerobic digestion because of bacterial population needs longer replication time and significantly low biochemical activity, which results in the decrease of biogas yield and subsequently failure of digester. (Singh et. al., 1999). The biodegradability and methane yield were found to be higher at 55°C than 35°C (Jha et al., 2010a). Elevating the temperature within a specific range can speed up hydrolysis and expedite the process of digestion, but because more heat is required, the stability of the fermentation system may be jeopardized. Additionally, thermophilic bacteria are particularly sensitive to even minor fluctuations in temperature, thus making it preferable to operate digesters at mesophilic temperatures. According to Brummeler et al. (1992), during the startup phase, if the reactor temperature begins at 20°C and is gradually raised to 35°C, it leads to an extended digestion period. Conversely, if the startup temperature begins at 43°C and is gradually lowered to 30°C, it results in an equivalent digestion period compared to the startup at 35°C (Jha et al., 2011).

2.5.3.4 Concentration of Nitrogen

Methane is the byproduct of Carbon metabolism. High concentrations of nitrogen inside the reactor negatively affect process stability and efficiency because of ammonia formation. Total ammonia nitrogen (TAN), defined as the sum of free ammonia nitrogen (FAN, NH_3-N) and ammonium nitrogen (NH_4+-N), is formed during the hydrolysis of proteins, urea and nucleic acids during the AD(Korres, 2013) (Carlos et. al., 2007). Ammonia can freely pass through the cell membranes of methanogens and cause an imbalance in proton (Poirier, 2017), (Kayhanian, 1999). Free ammonia changes the intracellular pH of methanogenic bacteria and inhibits specific enzymatic reactions (Krakat, 2017), (Morozova, 2020). Disruption of methanogenesis can be caused by high concentrations of ammonia in anaerobic reactors and may induce complete failure of AD (Rajagopal, 2013). Chen et al. has reported that the temperature change has a direct effect on both growth rates of microbes and concentration of free ammonia. Increase in process temperature affects the metabolic rate of the microorganisms in a positive manner, however, it also results in increments of ammonia levels.

2.5.3.5 Carbon-Nitrogen Ratio

The Carbon-Nitrogen (C:N) ratio is a crucial factor within the digester that influences methane production. Nitrogen is an essential component required by all living organisms for protein synthesis. When nitrogen is insufficient, bacteria are unable to effectively utilize the available carbon, leading to reduced process efficiency (Karki, et al., 2015). An optimal metabolic state is achieved when the C:N ratio stands at 30:1. This specific ratio is attainable not only by using cow or other animal dung but also by incorporating various other substrates in the mix. Generally a narrow carbon-to-nitrogen (C/N) ratio of the feedstock results high nitrogen concentrations in the digestate (Kayhanian, 1994). Optimum C/N ratio is 30 and it should never be more than 35. When the C/N ratio is excessively high, there is a swift depletion of nitrogen leading to a decrease in the reaction rate. Conversely, when the C/N ratio is excessively low, nitrogen is released and accumulates as ammonia, which can prove toxic for methane production in specific circumstances. In order to decrease the concentrations of TAN and FAN in the digestate and in turn maximize the yield of biogas and methane, Shanmugam and Horan (Shanmugam, 2009) recommended keeping the C/N ratio of the feedstock in the range of 15 to 20, while according to Kayhanian, this ratio should be between 27 and 32.

2.5.3.6 Anaerobic Condition

Due to the anaerobic nature of methanogenic bacteria, the majority of these organisms become metabolically dormant in aerobic environments. Therefore, it is imperative to ensure that the digesters are completely airtight in order to uphold strict anaerobic conditions. A prevalent method to achieve this is by burying the digester underground, thereby maintaining the necessary anaerobic environment.

2.5.3.7 Succulent Plant or Algae Addition

To achieve efficient and optimal biogas production from animal dung and cow dung, the addition of various succulent plants or algae can be employed. A few examples of such plants suitable for the digester include green algae, lemon grass, and water hyacinth grass. Notably, a study revealed that the biogas yield from algae was double (344 ml/g dry algae) that of cow dung alone (179 ml/g dry cow dung). Furthermore, the duration of gas generation increased proportionally with the augmentation of slurry concentration. The gas obtained had a calorific value of 4800 Kcal/m3 and a methane content of 56.4%.

2.5.3.8 Rate of Loading

The loading rate refers to the quantity of raw material introduced into the digester per day in relation to the unit volume of the digester's capacity. The digester efficiency can be measured by the digester load (DL), measured in kg. The digester load depends primarily upon four major factors: substrate, temperature, volumetric burden and type of plant. It can determine the capability of the microorganisms to stabilize the substrate in a given time per unit reactor volume (kg volatile solids [VS]/m^3-day) (Khanal et. al., 2019). The upper limit of the organic loading rate is determined by factors such as the retained biomass in the bioreactor, the nature of the substrate (including concentration and biodegradability), environmental circumstances (like temperature and pH), and the configuration of the reactor, among others. Some indicators of overloading in the reactor include a decline in methane content and biogas generation rate, pH reduction, and a sudden increase in VFAs and the VFA/alkalinity ratio (Braun, 2007).

To attain an optimal loading rate, it's essential to maintain a neutral pH range, keep the total VFAs between 1500 and 4500 mg as acetic acid equivalent (HAc)/L, and ensure that ammonium nitrogen concentration remains below 4500 mg/L (Braun, 2007).

The ideal organic loading rate for high solid wastes such as organic fraction of municipal solid waste (OFMSW), vegetable waste, and fruit waste, typically ranges from 0.3 to 2.5 kg VS/m3/day (Khanal et al., 2019). The maximum daily loading rate for a normal agricultural biogas plant with a straightforward design is around 1.5 kg VS/m3. (1989; Werner, Stohr, and Hees).

2.5.3.9 Hydraulic Retention Time

Retention time, which is even called as detention time, denotes the average duration during which feedstock stays within the bio-digester. In the context of a plant utilizing cow dung as feed, the calculation of retention time involves dividing the total digester volume by the quantity of slurry introduced daily. Typically, for a cow-dung based system, the detention time fluctuates between 40 to 60 days, contingent upon the prevailing temperature conditions. As a result, the fermenting pit should be 40 to 60 times larger than the daily slurry input.

To successfully neutralize the pathogens included in human feces, however, a night-soil digester requires a extended retention duration of 70 to 90 days.

2.5.3.10 Dilution and Consistency of Inputs

Before introducing feedstock such as fresh cattle dung and kitchen waste into the digester, thorough mixing with water is essential. To achieve proper amalgamation of organic materials, a ratio of 1:1 between solids and water should be maintained on a unit volume basis. This implies an equal volume of water for a given volume of solid, especially when dealing with domestic wastes.

However, if the dung is intended to be used in a dry state, it must be pulverized before being introduced into the digester. In such cases, the quantity of water needs to be increased proportionally to attain the required consistency of the feedstock. This ratio can range from 1:1.25 to 1:2 depending on the situation.

2.6 Types and design of domestic biogas plants

Throughout the world, there have been numerous experimentations on biogas plant design by various engineers, scientists and academicians (Karki et al., 2015). Digesters having horizontal, rectangular and spherical shapes have been produced some of which were laid underground while some over ground. Materials of construction like mild steel as reinforcement, masonry work (bricks, cement, concrete) and plastic (sheets, pipes and pipe fittings) have been extensively used (Karki et al., 2015).

Fundamentally, a biogas plant, often referred to as a bioreactor, bio-digester, or anaerobic reactor, comprises primarily three indispensable components, which are as outlined below:

Digestion chamber: This chamber is an airtight area where organic matter is gathered and methanogenic bacteria use an anaerobic reaction to digest the organic material.

Inlet: Organic matter is fed into the digestion chamber using this structure called inlet.

Outlet: An outlet is the structure from where the digestate, i.e. the effluent is discarded from inside the digester.

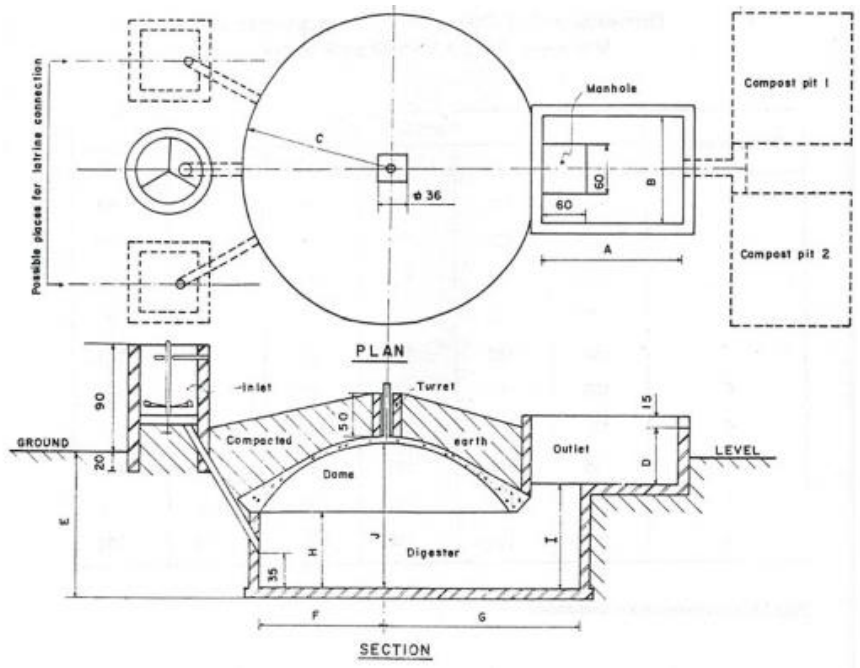
Two models among the different types of biogas plants developed have been found to be the most common (Subedi S.K., 2015; K.J. Singh & Sooch, 2004), which are discussed briefly in this section.

2.6.1 Fixed Dome Digester

The most well-known wet-fermentation biogas generators in the world are Fixed Dome digesters. These are typically underground generators which were first experimented in China circa 1936 (Derek I, 2012-2023). The typical configuration encompasses an inlet trough and a cylindrical fermentation reservoir, which is capped with a stationary concrete dome designed for both gas collection and storage. These components are integrated into a unified structure. Various types of fixed dome digesters exist, but Chinese design made of gas sealed brick and mortar or cement is the most popular. The design of a fixed-dome digester is simple and because of lack of moving parts, if constructed well, the structure will last for 20-50 years (Karki et. al. 2015).

Several nations have adjusted and customized the principles of the static-dome Chinese model to align with their specific local circumstances (Karki et al., 2015). For example

Deenbandhu model in India, CAMARTEC model of Tanzania and GGC 2047 of Nepal are some of the adaptations of fixed dome biogas plant.



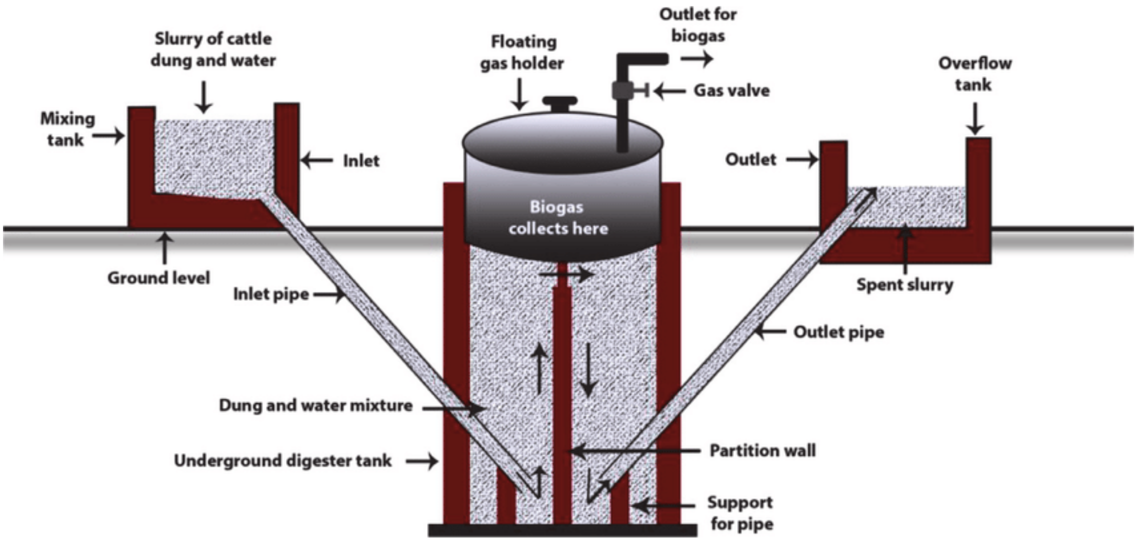
(AEPC, 2023)

Figure 2.4 Schematic diagram of Fixed dome biogas plant (GGC 2047 model plant).

The GGC 2047 model with the capacity of 4, 6, 8 and 10 cu.m. have been widely adopted in Nepal. The models haven been working fine up to 2100m altitude.

2.6.2 Floating Drum Digester

The first floating drum type biogas plant was designed by Jashu Bhai J Patel from India popularly called the Gobar gas plant in 1956. This type of plant is widely popular in India as a KVIC model. The setup includes an underground digestion tank, which can be either cylindrical or dome-shaped, constructed using brick masonry or cement mortar. Additionally, there is a floating gas-holder situated atop the digester chamber. This gas-holder is fashioned from mild steel drum material and remains buoyant on the slurry to store the generated gas. The gas holder may be kept to float directly over the fermentation slurry or in its own water jacket. The gas drum moves up or down, reflecting to the amount of gas produced and stored.



(Godwin et.al., 2021)

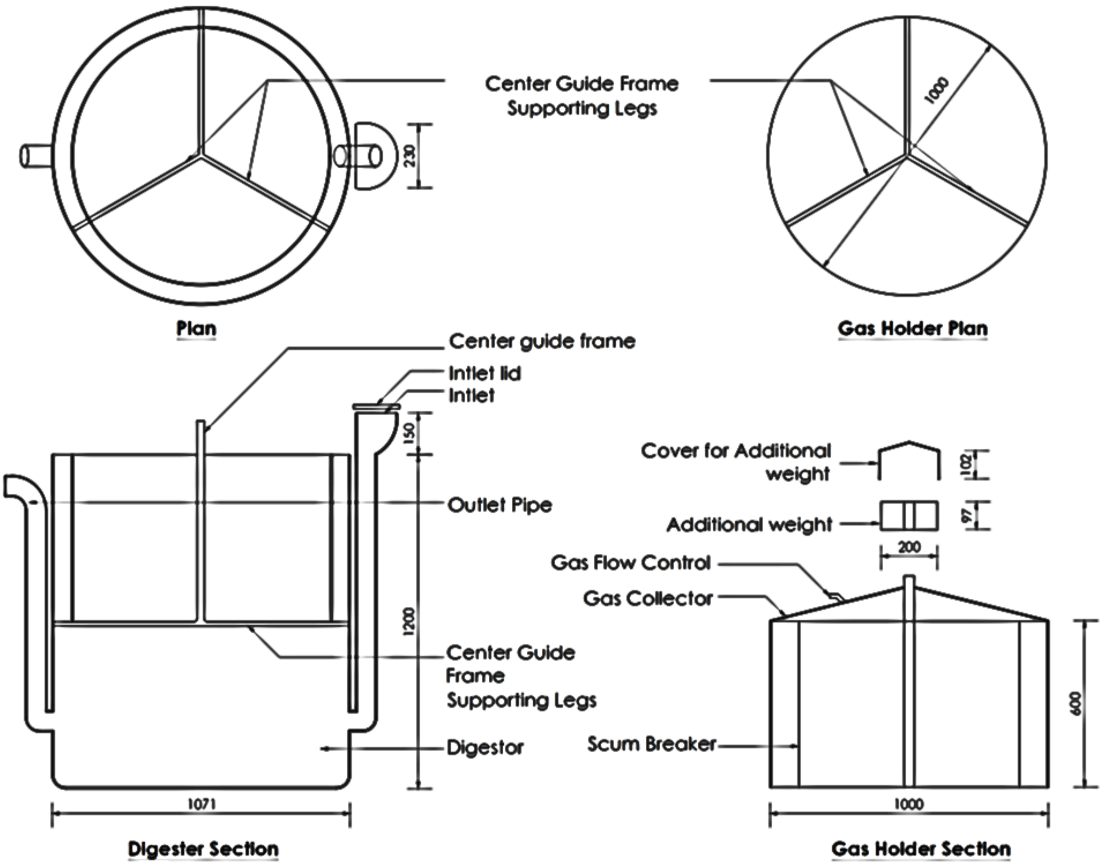
Figure 2.5 Schematic diagram of Floating drum biogas plant.

The use of a stainless steel floating drum has elevated the cost and necessitates regular maintenance and oversight. Also due to corrosion it may need to be completely replaced within a duration of 5-10 years (Karki et. al.,). Cheap Chinese models of Fixed dome plant got introduced after which Indian KVIC plants were displaced.

2.6.3 Portable biogas plant

The focus of this thesis is the portable biogas plant, which is a type of biogas plant relevantly new in the market, made up of fiber reinforced plastic. It is a type of floating drum biogas plant with intermittent feeding mechanism. It was designed in India by Biotech Renewable Energy. It is being marketed by Alternative Bio Energy P. Ltd., Pokhara, Nepal and Biotech Renewable Energy P. Ltd., India. It was first introduced in Nepal in July 2016. The plant is being promoted for urban domestic use as an alternative cooking fuel. The company so far has sold more than 400 such plants.

The plant consists of the digester tank of around 1000L which is the main part of the tank. Feedstock is inserted into the tank from the waste inlet pipe which also has a lid. Excess residue is removed from the outlet pipe. When biogas is generated in the tank, it gets collected in the collector tank which rise and fall according to gas production and use. The collector tank has a capacity of around 500L. The tank is independent of the digestor with its bottom edge submerged in the slurry. The top of the gas tank is provided with a cement weight to maintain pressure of the gas.



(Alternative Bio Energy, 2017)

Figure 2.6 Schematic Diagram of FRP Portable Biogas Plant made by Alternative Bio Energy P. Ltd

2.7 Installation of PBP

- The plant can be installed on ground, terrace or balconies, wherever possible. But the spot should preferably be sunny all day long
- The plant should be installed over levelled ground made by a layer of PCC over stone or brick soling. Incase if the base of the tank is tilted to one side, the gas production may be affected.
- It should be close to the kitchen so that gas pressure is good enough. Else the flame shall burn slow.
- When the plant is first installed it should be fed with a mixture of 3kg of jaggery and 10l of water. Then Chamber 1 and 2 is supplied with 1l E.M. each and clean water is filled up to level 2.
- After the E.M. is supplied, the plant is fed with about 325kgs of 8 to 10 days old cow or buffalo dung and mixed properly. The dung should be free from hay as much as possible. The mix should be filled upto level 3.

- The plant should then be filled with clean water covering all of the water jacket. Then the gas valve should be turned off and Additional cement block and cap should be placed tightly. The gas collector is then rotated a few times.
- After all the processes above is completed, every day the gas collector is filled and it raises by upto 2ft. One should try to burn the collected gas by turning on the gas valve and lighting up a matchstick. Initially CO2 gas is formed which doesn't burn. This should be evacuated daily. In an average after evacuating the gas formed about 5 to 6 times, methane gas starts to get formed.
- Methane production gradually increases. Domestic biodegradable waste can be added to the plant once the methane production is such that it is enough to burn for atleast half an hour.
- Domestic waste should be fed to the plant in small pieces so that the inlet pipe doesn't get blocked. About 1 to 3 kg can be fed to the tank daily with equal amount water. The gas collector should be rotated 8 to 10 times after every time the waste is added.

2.8 Biogas production in cold climate

Temperature has a significant impact on the anaerobic digestion process mediated by methanogenic bacteria, presenting one of the most notable constraints in biogas technology. The most favorable temperature for biogas production is 30-35˚C. When the temperature drops below 15 ˚C, it is seen that some digestors stop gas production while some have up to 75% drop (Karki et. al., 2015). In response to this challenge, researchers worldwide have devised numerous approaches aimed at maximizing biogas output during colder seasons, employing various methods encompassing physical, chemical, and biological techniques. The proposed processes to increase digester temperature are as follows :-

i. Apply external heat to the digester and/or feedstock utilizing solar thermal heating apparatus or utilizing a portion of the generated gas.,
ii. providing insulation around the digester
iii. fabricating a greenhouse covering the digester
iv. Construction of digester below building (heat transfer from barn to digester (Lettinger et. al., 2001; Sutter and Wellinger, 1985; Zeeman et. al., 1988).

However, despite the effectiveness of the aforementioned techniques in temperature elevation, these methods often encountered technological and economic obstacles

(Kashyap et al., 2003). The increased energy requirement for heating the process contributes to elevated costs, rendering it economically unfeasible in temperate climates.

CHAPTER THREE : RESEARCH METHODOLOGY

3.1 Introduction

Methodology is the description the procedures that are followed for carrying out a research. The research methodology gives an overarching plan for the research design. It can be defined as a “conceptual approach” on which the research method can be drawn (Grix, 2004). This section contains information about the study strategy, research design, population and sample size, research location, data collecting, validity, reliability, and data processing method and analysis. Quantitative research and qualitative research the two types of research strategies (Anon., 2018).

3.2 Conceptual Framework

Conceptual framework refers to the theoretical structure within which the research is conducted. A well-defined framework provides an easy gateway to achieving the set of objectives of research.

The study is carried out mainly in three phases: desk work, field work and Data analysis. Literature review is done as a part of the desk work which is briefly described in chapter two of this report. In the literature review different national and international case studies relating to the research topic are done. The important factors from the case studies are then listed and are incorporated in the study.

The basic framework of this study assumes that a portable biogas plant can be a cost-effective and reliable technology that can deliver affordable energy with low environmental impact. Co-digestion of mixed feedstocks has been found to improve biogas production efficiency (Subedi, 2015). The study shall examine the quantity of biogas production that can be increased by maintaining proper temperature condition. Different methods have been considered for increased biogas production, namely grinding of feedstock, mixing heated water with feedstock and installing greenhouse to cover the plant. The research also analyzes the economic cost of using such methods.

3.3 Research Process

This research encompasses 4 primary stages: i) Research Design; ii) Collection of Data; iii) Analysis of Data; and iv) Results and Discussion (Flick, 2015; Kumar, 2011; Subedi, 2015). Several processes are included in the research design phase, including problem identification, the development of research goals and objectives, the creation of a conceptual framework, the creation of a workable research plan, and the choice of a suitable research technique to address the research queries (Subedi, 2015; Glesne, 2016; Flick, 2015). The sampling design must be carefully formulated, and data collection procedures need to be thoroughly elucidated within the research design process (Glesne, 2016; Subedi, 2015).

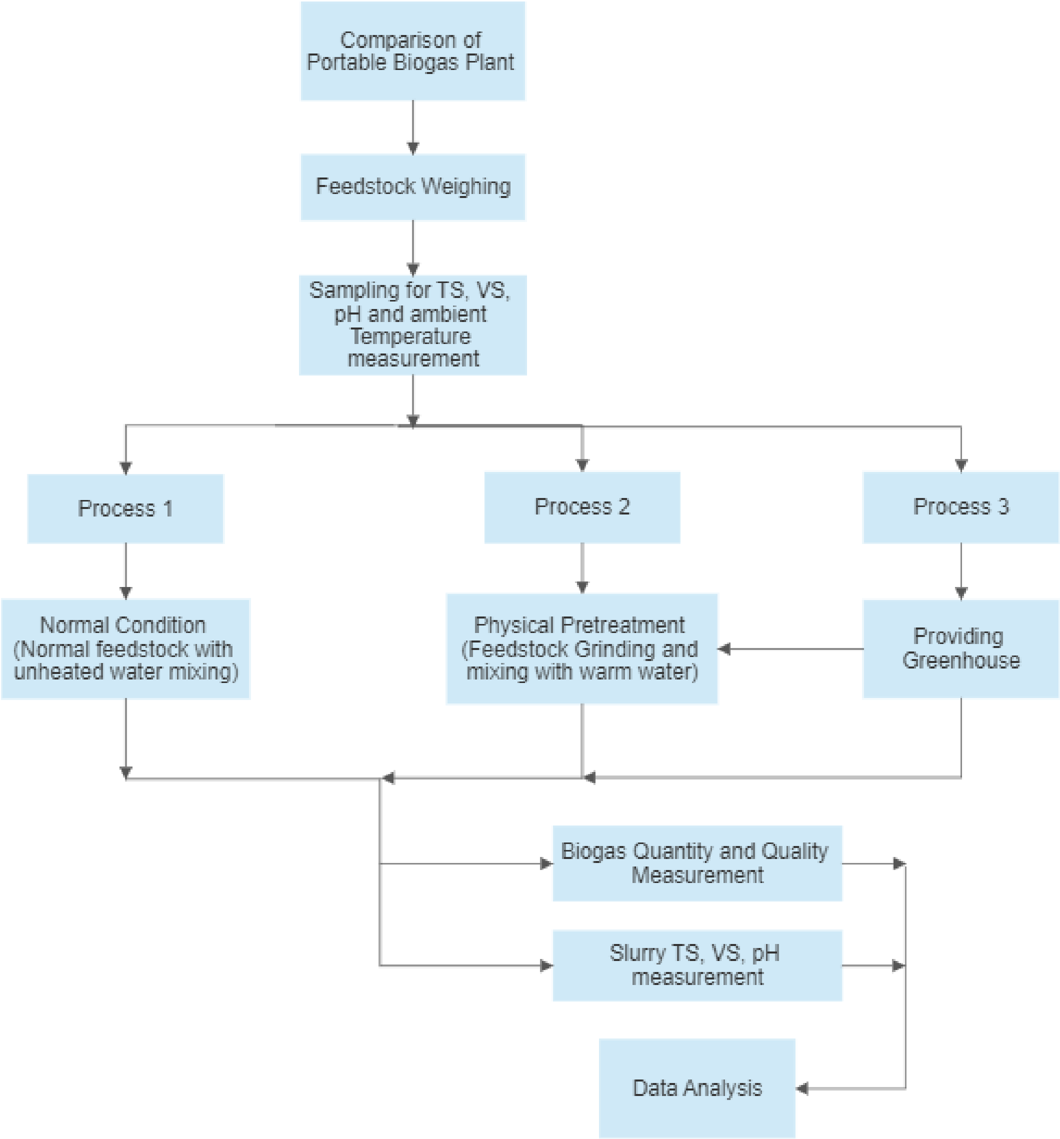


Figure 3.1 Methodology for the thesis

3.4 Selection and Description of Study Area

Field study was undertaken in Basnettar, Tarakeshor Municipality of Kathmandu district in Nepal (27°45'43.3"N 85°17'35.7"E). The researcher chose this place because a portable biogas was already in operational condition and gas was being produced satisfactorily. Another reasons for selecting the site were because the feedstock was purely domestic organic household waste and the site is easily accessible from the researcher's residence. The site is located in the hills towards the northwest direction of Kathmandu and the climatic conditions resembles close to the urban center of the Kathmandu valley. Surveying more sites would have had better value but the resources available to do this research did not allow for this. However, since the research was started in the onset of spring season and used greenhouse shelter to simulate higher temperature, the overall findings can be generalized to the wider country context.

3.5 Research Methods

3.5.1 Quantitative method

The data that are obtained in a numeric or physical form is referred as quantitative data. All the data and information obtained during the desk and the field investigation are processed and analyzed. The graphic presentation comprising various graphs, charts, diagrams, maps are then used to give a clear picture of the relations and differences of variables (Shakya, 2020). Computer programs, relevant models or software for statistical data analysis with plans about how to manage data, identifying variables; the role and function of descriptive statistics; appropriate use of statistical tests; and effective data presentation skill and capacity (O'Leary, 2013). Quantitative data includes primary and secondary data. Primary data in this research is taken from experimental setup while secondary data is taken from researches previous done.

3.5.2 Qualitative method

Qualitative research is inductive (Edmonds & Kennedy, 2013; Subedi, 2015), exploratory and investigative (S.B Merriam, 2002) in nature. It is expressed in words. It is used to understand concepts, thoughts or experiences. This type of researches enables one to gather in-depth insights on topics that are not well understood. Common qualitative methods include interviews with open-ended questions, observations described in words, and literature reviews that explore concepts and theories. (Streefkerk, 2019). The researcher is the primary instrument for data collection and data analysis. The researcher can process information immediately, clarify and summarize material, check with respondents for accuracy of interpretation, and explore unanticipated responses. (S.B Merriam, 2002).

3.6 Selection of research method

In this research, quantitative data analysis principles are mostly applied and involves the collection and analysis quantitative data. The collection of data was on domestic biogas production and utilization in city area. The data collection procedure was guided by the conceptual framework.

3.7 Experimental setup and procedure

Primary data is collected by field observation and laboratory sample testing. The field observation provides opportunities for the researchers to understand the context through their own experience and evidence. Multiple sources of data from various sites can be used in purposively selected samples to maximize the variations and variables to confirm findings with validity and reliability (S.B. Merriam, 2002; Subedi, 2015).

For the research, experiments were carried out in portable biogas plant of fiber reinforced plastic of $2m^3$ at site. The plant was fed with household kitchen waste. The plant's gas tank is slowly rotated few times to mix the slurry inside after feedstock is added to create a homogeneous substrate and to prevent stratification and distributing microorganism throughout the digester. The primary data collected at site are weight of the feedstock, ambient temperature, pH of feedstock and output slurry, volume of gas produced and quality of gas produced (concentration of CH_4, CO_2 and other gases). The weight of the samples was measured using digital weighing machine, temperature by digital thermometer of model 53IIB of Fluke brand; the pH measured using digital pH meter. The gas was measured using gas flow meter of Chint company and gas analyzer was from Cubic Ruiyi- Gasboard 3200 Plus. The samples are tested for Total Solids (TS), Volatile Solids (VS), Nitrogen (N_2), Phosphorus (P), Potassium (K) content and C:N (Carbon: Nitrogen) ratio at a laboratory. Laboratory tests are performed with standard procedures as mentioned in Chapter 2 under literature review.

The data was observed for 7 days without any pretreatment then consecutive 7 days with grinding of feedstock and mixing with warm water of 35˚C. Finally, the plant was covered with tarpaulin sheet with bamboo frame to make a greenhouse. Then data was taken for another 10 days.

3.8 Laboratory procedures

Table 3.1 Different methods followed for Laboratory test

Parameters	Test methods
Nitrogen (%)	Modified kzeldahl, FAO, Fertilizer and Plants Nutrition Bulletin No.19
Total Phosphorous as P_2O_5 (%)	Venadomolybdophosphric acid, FAO, Fertilizer and Plants Nutrition Bulletin No.19
Total potassium as K_2O (%)	Flame absorption, AAS, FAO, Fertilizer and Plants Nutrition Bulletin No.19
Total solids (mg/g)	Oven drying, Gravimetric, 2540 C, APHA
Volatile solids (mg/g)	Ignition and Gravimetric, 2540 C, APHA

3.8.1 Procedure for measurement of TS, VS

Determination of Total Solid in Water

Apparatus Required

1. Beakers
2. Desiccator
3. Oven
4. Heating mantle
5. Analytical balance
6. Tongs

Method

A. Total Solid (TS)

- A cleaned dish was heated for an hour at 103 to 105°C. The dish was then stored and cooled in desiccators until it gets cool. The dish was then weighed immediately before use (B g).
- 50 ml well-mixed sample was transferred to pre-weighed dish.
- The dry evaporated sample was then cooled and weighed on the analytical balance (Ag)

$$Total\ Solids\ (TS)(\frac{mg}{L}) = \frac{(A-B)\times 10^6}{mL\ Sample}$$

B. Total Dissolved Solids (TDS), Volatile Dissolved Solids (VDS), Fixed Dissolved Solid (FDS)for sample W

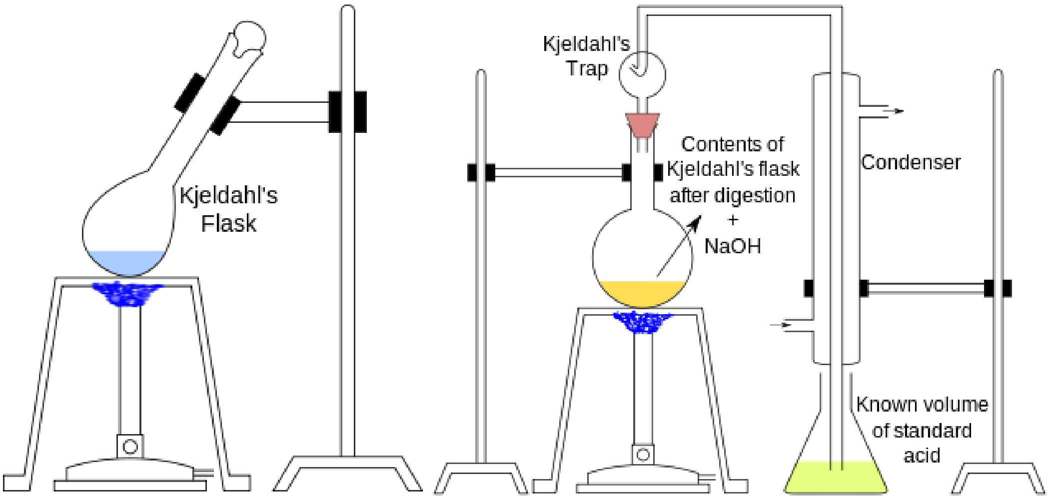
- Preparation of evaporating dish, if volatile solids are to be measured ignite cleaned evaporating dish at 500±50°C for 1 h in a muffle furnace. If only total dissolved solids are to be measured, heat-clean dish to 105±2°c for 1h. Store and cool dish in desiccators until cool. Weigh immediately before use (B g)
- 50 ml well-mixed sample was filtered through GF/C paper and washed with distilled water.
- Filtrate was transferred to the weighed dish and evaporated.
- Dried for at least 1 h at 108±2oC, then cool and weighed dish on the analytical balance (J\ mg)
- The sample ignite at 500±50oC for 15-20 min. in a muffle furnace, cool and weigh on the analytical balance (C g)

$$Total\ Solids\ (TDS)(\frac{mg}{L}) = \frac{(A-B)\times 10^6}{mL\ Sample}$$

$$Volatile\ Dissolved\ Solids\ (VDS)(\frac{mg}{L}) = \frac{(A-C)\times 10^6}{mL\ Sample}$$

$$Fixed\ Dissolved\ Solids\ (FDS)(\frac{mg}{L}) = \frac{(C-B)\times 10^6}{mL\ Sample}$$

3.8.2 Modified Kzeldahl method for Nitrogen



(Wikipedia, 2023)

Figure 3.2 Apparatus setup for Kzeldahl mehod

The Kjeldahl method is divided into three main steps namely: digestion, distillation and titration.

1. Digestion: This procedure involves heating the sample while sulphuric acid is present. Through oxidation, the acid degrades the organic material, releasing reduced nitrogen in the form of ammonium sulphate. To increase the medium's boiling point, potassium sulphate is typically added. The digestive process also makes use of catalysts like mercury, selenium, copper, or mercury or copper ions. When we receive a clear, colorless solution, the sample has completely broken down.
2. $\text{Organic compound} + H_2SO_4 \longrightarrow \text{[digest]}Cu^{2} + (NH_4)_2SO_4$
3. Distillation: To turn the ammonium salt into ammonia, the solution is then distilled after which a little amount of sodium hydroxide is added. The hydrochloric acid and water solution traps the distilled vapors.
   $(NH_4)_2SO_4 + 2NaOH \xrightarrow{\triangle} Na_2SO_4 + 2H_2O + 2NH_3$
4. Titration: The last step is to use back titration to calculate the sample's ammonia or nitrogen content. Some HCL is neutralized as the ammonia dissolves in the acid trapping solution. With a standard solution of a base, such as NaOH or other bases, the remaining acid can be re-titrated.
   $B(OH)_2 + H_2O + Na_2CO_3 \longrightarrow NaHCO_3 + CO_2 + H_2O$

$NH_3 + HCL \longrightarrow NH_4Cl$

The percentage of nitrogen can be determined using the given formula:

Percentage of nitrogen in the sample = $\frac{1.4\ V\ X\ N}{W}$

Where,

- V = acid used in titration (ml)
- N = normality of standard acid
- W = weight of sample (g)

3.8.3 Total Phosphorus as P_2O_5 (%)

Two methods that are frequently used to determine the current phosphorus concentration (P) in soils are Bray's approach for acidic soils and Olsen's method for neutral and alkaline soils.

In these techniques, by introducing suitable reagents into the solution, compounds with distinct colors are generated. The degree of coloring is directly related to the amount of the element being measured. A spectrophotometer measures the intensity of color. In spectrophotometric analysis, the ultraviolet portion of the spectrum is stretched to a specific wavelength of light source (say, not exceeding 0.1-1.0 nanometer in bandwidth). The spectrophotometer's photoelectric cells measure the light that the solution transmits. Table 2.10-2 tabulates the approximate range of wavelength of complementary hues. White light is seen to cover the entire visible spectrum between 400 and 760 nanometer.

Bray’s Method No. 1

The necessary equipment to perform Bray's Method No. 1 on acidic soils includes (Bray and Kurtz, 1945):

- A spectrophotometer
- 2, 5, 10, and 20 ml capacity pipettes
- 25, 50, 100, and 500 ml capacity beakers or flasks

The following reagents area needed:

- Bray’s Extractant No. 1 which is 0.03M ammonium fluoride in 0.025M hydrochloric acid: First 2.22 g of NH_4F should be dissolved in distilled water of 200 ml, then it should be filtered, and added to the filtrate of 1800 cc of water containing 4 cc of conc. hydrochloric acid, to make the volume up to 2 litres with distilled water.

- Molybdate reagent: $(NH_4)_2MoO_4$ of 1.50 g should be dissolved in distilled water of 300 cc. Gradually add this solution to 350 cc of 10M hydrochloric acid stirring continuously. Then the mixture is diluted to using distilled water to a 1000cc.
- Solution of Stannous chloride (stock solution): $SnCl_2 2H_2O$ of 10 g should be dissolved in 25 ml of conc hydrochloric acid. A pure piece of metallic tin is added, then the mix is stored inside a stoppered glass bottle.
- Solution of stannous chloride for working: 1cc of stock solution of $SnCl_2$ is diluted into 66 cc using distilled H_2O right before it is used. Fresh diluted solution should be prepared every working day.

Table 3.2 Wavelength and corresponding color ranges

Wavelength (nm)	Hue (transmitted)*	Complementary hue of the solution
<400	Ultraviolet	
400 to 435	Violet	Yellow green
435 to 480	Blue	Yellow
480 to 490	Greenish blue	Orange
490 to 500	Bluish green	Red
500 to 560	Green	Purple
560 to 580	Yellowish green	Violet
580 to 595	Yellow	Blue
595 to 610	Orange	Greenish blue
610 to 750	Red	Bluish green

The procedure involves the following steps:

i. Standard curve preparation:

To make a solution of 50 g P/ml, 0.2195 gram of pure dry potassium dihydrogen phosphate (KH_2PO_4) should be mixed thoroughly in a liter of distilled water. This should be kept on hand as the standard phosphate solution. To create a solution with 1μg of P per milliliter, dilute 10 ml of this solution with distilled water to make it equal to 0.5 liters. Add 0, 1, 2, 4, 6, & 10 cc of this diluted mixture to individual 25-ml flasks. 5 ml of the extractant solution and 5 ml of the molybdate reagent should be added to each flask before being diluted with distilled water to a final volume of around 20 ml. Add a milliliter of the diluted SnCl2 solution to each flask, shake the flask, and then re-dilute the solution until it has a final volume of 25 ml. Use a spectrophotometer set to 660 nm to measure the blue color's absorbance after the solution has been sitting for 10 minutes. Plot the absorbance values versus "µg P," then connect the dots you've drawn to form the standard curve.

ii. Extraction: 50 ml of the Bray’s Extractant No. 1 should be added to a 100-ml conical flask containing 5 g of soil sample. The content should be shaken for 5 minutes and filtered.

iii. Development of colour: 5 ml of the filtered soil extract should be taken with a bulb pipette in a 25-ml measuring flask; 5 ml of the molybdate reagent delivered with an automatic pipette, and diluted to make 20 ml with distilled water, shaken and 1 ml of the dilute $SnCl_2$ solution should be added with a bulb pipette. Filled to the 25-ml mark and shaken. The blue colour shoule be read after 10 minutes on the spectrophotometer at 660 nm after setting the instrument to zero with the blank prepared similarly but without the soil.

The calculation is:

$$\text{P (kg/ha)} = \frac{A}{1000000}\ x\ \frac{50}{5} x\ \frac{2000000}{5} = 4A$$

where:

- amount of the sample is 5 g;
- extract volume is 50 cc;
- extract's volume utilized to estimation is 5 cc;
- P observed in specimen with respect to standard curve is A (microgram);
- weight of 1 hectare of soil down to a thickness of 22cm is taken as 2 $x10^6$ kg.

A standard curve created for the Bray's Method No. 1 available P estimation during the establishment of a soil testing laboratory is shown in Figure 2.10-3.

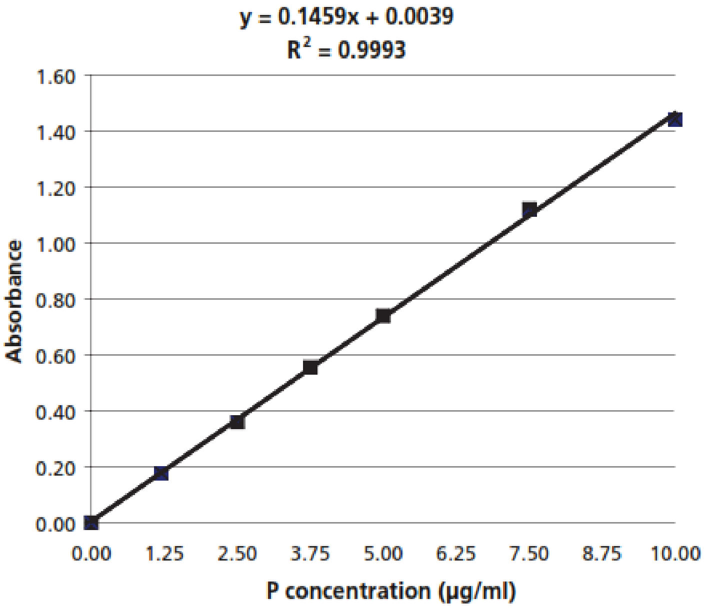


Figure 3.3 Standard curve for Phosphorus (P) on spectrophotometer

Olsen's method

The necessary equipment for Olsen's process (Olsen et al., 1954) on alkaline soils resembles the procedure mentioned above in Bray's Method No. 1. Required reagents are as follows:

- To make a bicarbonate extract, combine 0.042 kg of $NaHCO_3$ with 1 liter of distilled water, and then dilute NaOH or HCl to bring the pH to 8.5. If necessary, filter.

- Activated carbon free of P.

- Similar to the molybdate reagent used in Bray's Method No. 1.

- Similar to the Stannous Chloride Solution employed in Bray's Method No. 1.

The steps are described below:

1. Create the standard curve using the same procedures as described in Bray's Method No. 1.

2. Extraction: To a 100-ml conical flask holding 0.0025 kg of the feedstock specimen, add 50 ml of bicarbonate extractant. 1 g of activated carbon should be added. After shaking the flask on a mechanical shaker for 30 minutes, the mixture should be filtered.

3. Create color: The same color development steps as those outlined for Bray's Method No. 1 should be used.

All calculations remain analogous to those mentioned in Bray's Method No. 1

Nevertheless, despite all safety measures, each batch of molybdate reagent may have a minor variation in the strength of the blue color. Using two to three dilutions of the standard phosphate solution, it should be checked daily against the standard curve. Using new molybdate reagent, a new alignment with the standard curve should be established if there are any deviations.

Available potassium

The potassium content of the feedstock, which is referred to as plant-available K in both feedstock and soils, is extracted using a 1 molar solution of neutral ammonium acetate. A flame photometer is used to perform this estimation (Toth and Prince, 1949).

An automatic pipette or a 25cc multiple dispenser, few 100ml flasks & beakers, one flame photometer, and other items are required.

The requisite reagents comprise:

i. A solution of molar neutral ammonium acetate 1 liter of water should contain 77 g of ammonium acetate ($NH_4C_2H_3O_2$). Use a pH meter or bromothymol blue to check the solution's pH. To achieve neutrality, raise the pH upto 7.0 by adding NaOH or CH_3COOH as necessary.

ii. Standard for potassium solutions: One liter of purified water is dissolved with 1.908 g of pure KCl. 1 mg K/ml should be present in this solution. 100 cc of this solution should be taken, then dilute it with $NH_4C_2H_3O_2$ mixture to make 1000 ml. This stock solution ought to yield 0.1 mg K/ml.

iii. Working potassium standard solutions: Each volume of 0, 5, 10, 15 and 20 ml of the stock solution should be taken and diluted individually to 100 ml with the molar $NH_4C_2H_3O_2$ solution. Each of these solutions must have a potassium content of 0, 5, 10, 15 or 20 µg K/ml, respectively

The method is:

- Preparation of standard curve: 1. Setting up the flame photometer should involve alternately atomizing 0 and 20 g K/ml solutions to obtain readings of 0 and 100. Additionally, intermediate working standard solutions ought to be atomized, and readings ought to be kept. These values should be plotted against the corresponding potassium amounts to form a standard curve, and then a straight line should be drawn to connect the points.

- Extraction: 25 milliliter of the $NH_4CH_3CO_2$ extractant should be added in conical flask resting on a rack of wood that contains five grams of feedstock sample, stir 300 seconds, then filter.
- The content of potash of the filtrate is then determined using a flame photometer.

The following equation is used to calculate:

$$K\left(\frac{kg}{ha}\right) = \frac{A}{1000000}\ x\ 25\ x\ \frac{2000000}{5}$$

where:

- A = K (µg) content in specimen, as determined by the standard curve;
- quantity of extract is 25 cc;
- quantity of feedstock took is 5 gram;
- Weight of 1 hectare of soil is taken to be $2x10^6$ kg when dug to a depth of 22cm.

Figure 3.4 Depicts a standard curve for determining K using the flame photometer approach.

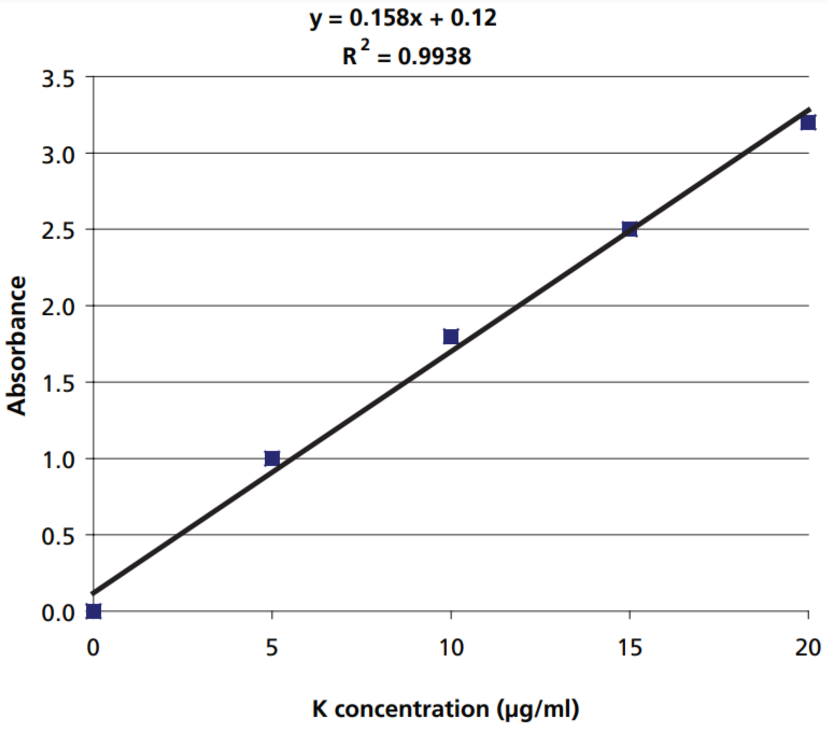


Figure 3.4 Potassium (K) standard curve on a flame photometer

CHAPTER FOUR : RESULTS AND DISCUSSION

4.1 Gas output and Feedstock

The gas output was observed from 11th March 2023 to 4th April 2023. The gas production varied from 0.015 m^3 to 0.257 m^3. The average gas output per day was 0.142 m^3 (142 L). The average energy produced per day was 0.917 kWh. The cumulative gas output from the system follows nearly increasing linear relationship with time. The average daily loading rate is 1.697 kg of organic waste. The readings for gas collection is represented in Figure 4.1

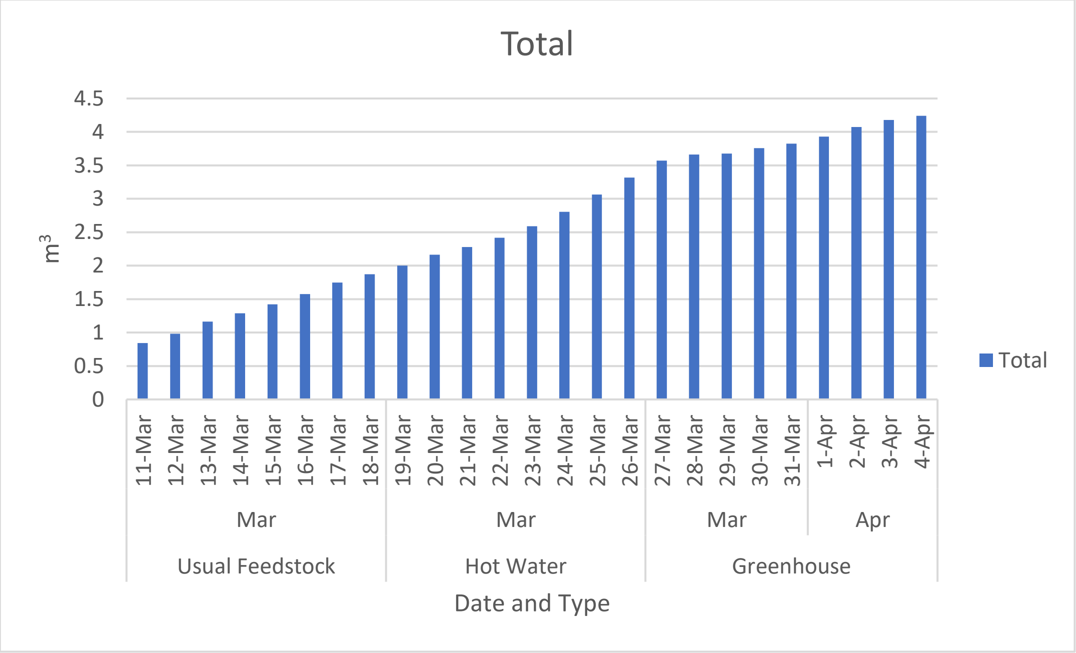


Figure 4.1 Cumulative gas output from Portable Biogas Plant

The quantity of feedstock was daily recorded and the same is compared with the daily gas production. It is then compared in Figure 4.2.

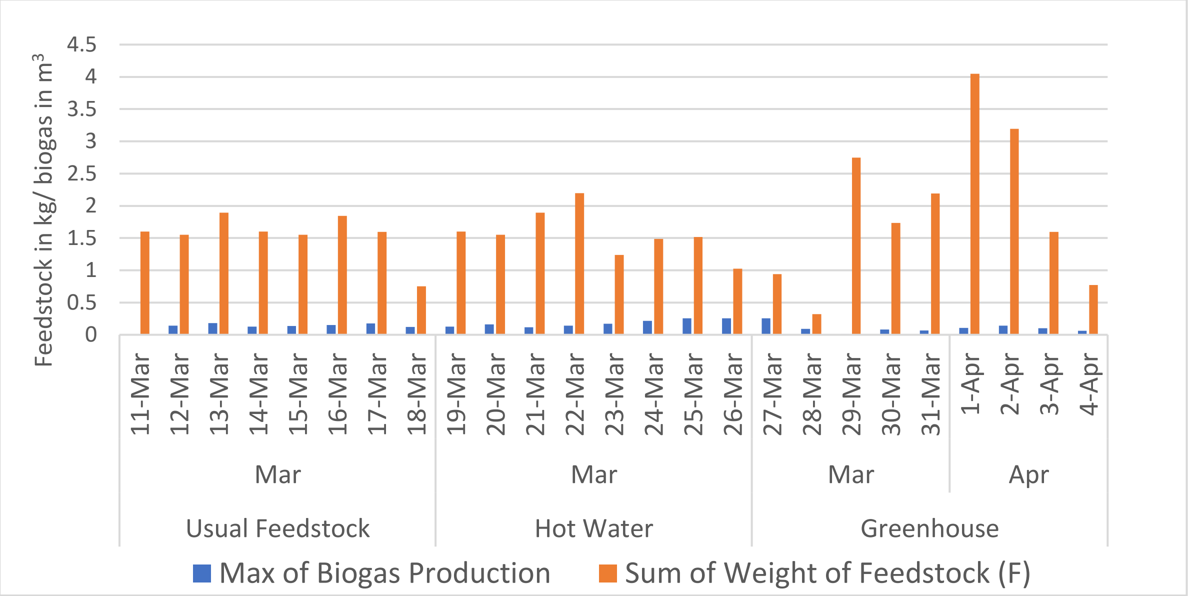


Figure 4.2 Cumulative weight of feedstock into Portable Biogas Plant

It was observed that the gas production is almost directly proportional to the amount of feedstock during the period without green house. The rate of gas production is significantly lower with respect to the quantity of daily feedstock added after the green house was added.

4.2 pH Variation

The pH of the feedstock was measured every day before adding it to the digester. Same for the digestate is measured after the slurry flows out after addition of feedstock. The slurry is taken in a beaker for pH measurement and the reading is taken using handheld pH meter mentioned in literature review. It is measured Daily variation of pH in input and output slurry is shown in Figure 4.3

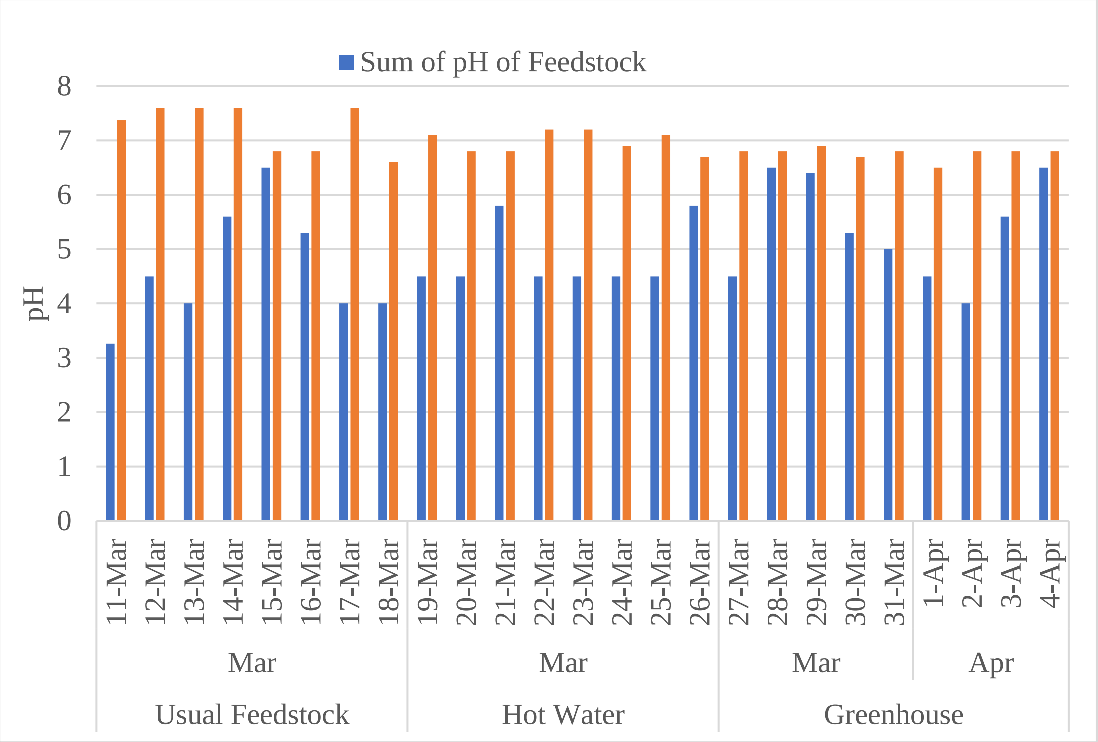


Figure 4.3 Variation of pH in Feedstock and Output Slurry in Portable Biogas Plant

The system was observed to have almost neutral pH. Digestion is being carried out without external pH control mechanism. This could be because the feedstock is mixed with equal quantity of fresh water which led to high buffer capacity (Nayano et al., 2010). The ideal pH for methanogens ranges from 6.80 to 7.60, and their growth rate will be greatly reduced below pH 6.60. A pH less than 6.10 or more than 8.30 will cause poor performance and even the failure of a fermenter (Lay, et al., 1997). The pH of the system was seen to be dropping at the later stage of the research which demanded for addition of cow manure to stabilize the system again.

4.3 Temperature Variation

The temperature inside and outside a greenhouse was monitored for a day to record the variation of it throughout the day. This has been shown in Figure 4.4

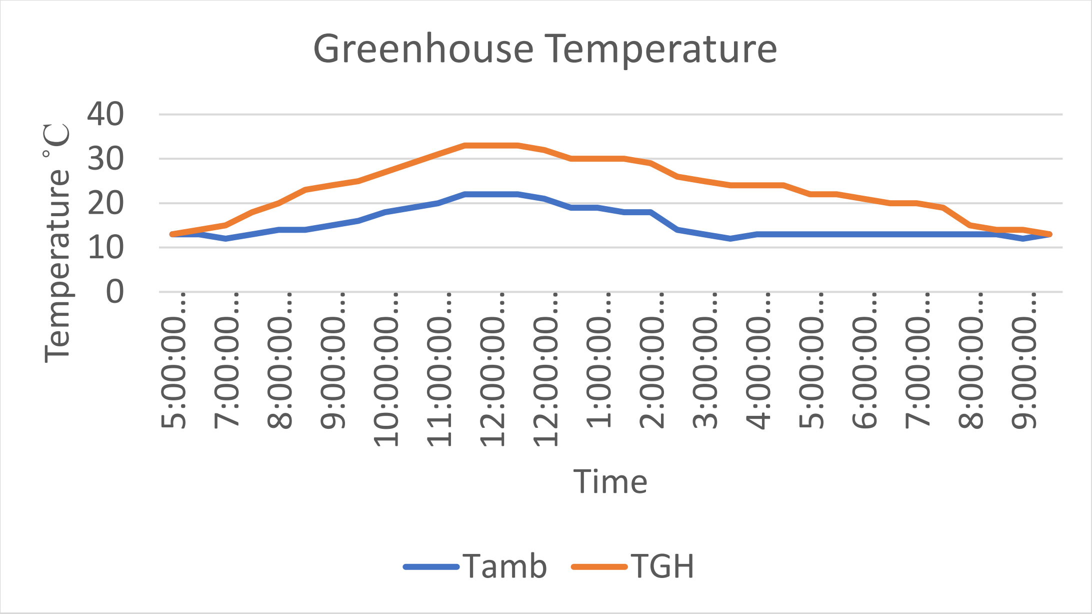


Figure 4.4 Temperature variation inside greenhouse

The average ambient temperature during the tests were below 18˚C with maximum temperature reaching 22 ˚C which suggest the biogas production caused by psychrophilic bacteria. After the fabrication of greenhouse shed, the average temperature was 27˚C with maximum of 35 ˚C. The sudden rise of temperature may have had deleterious effect on the production process.

4.4 Methane content

The methane content was monitored at site using gas analyzer of Cubic Ruiyi company's Gasboard 3200 Plus model. The methane content was found to be low at around 35% under normal condition which gradually increased to 38% and reached a maximum of 43% after fabrication of a greenhouse. The methane content is observed to be below minimum content of methane in biogas as mentioned in previous studies. The daily variation on methane content is elaborated in Figure 4.5

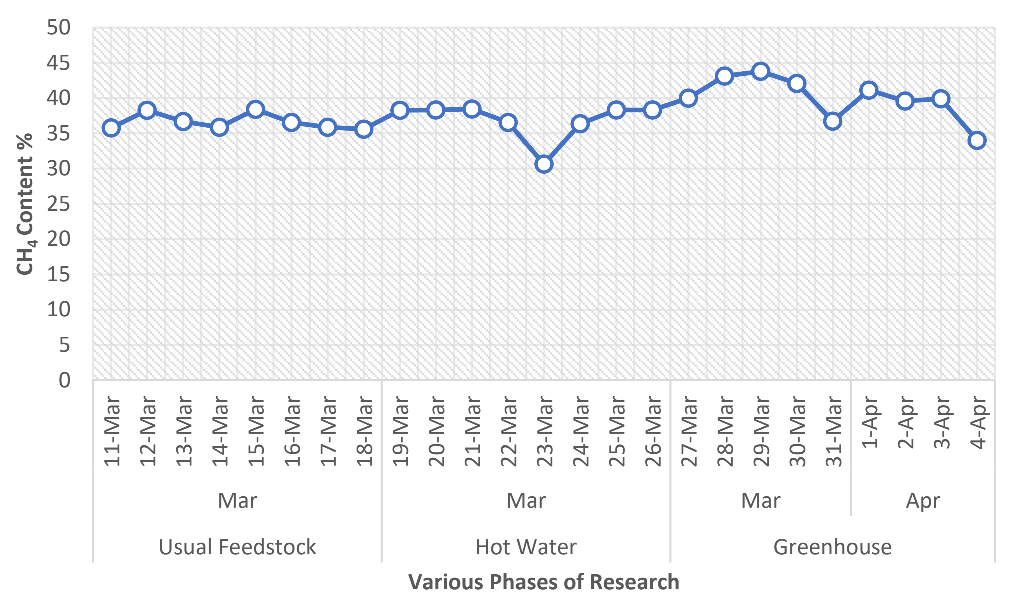


Figure 4.5 Methane Content in different scenarios of the research

The composition of biogas was monitored for the fluctuation of methane content throughout the experimentation period. The output of the data is described in Figure 4.6. The figure shows the total gas produced and the quantity of methane present in it.

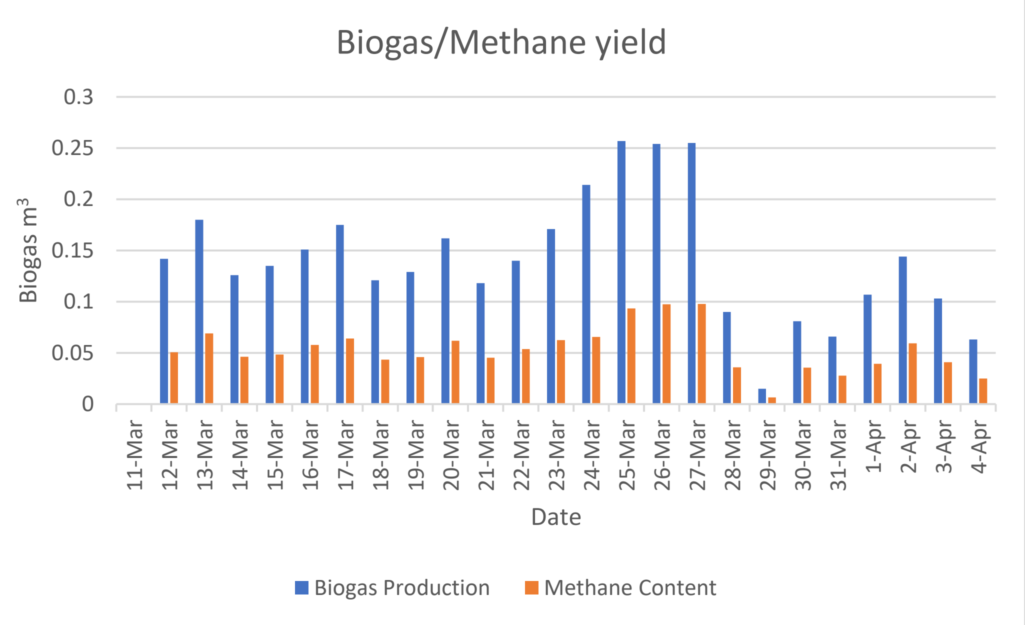


Figure 4.6 Total biogas and methane yield

4.5 Organic Materials Removal

During the fermentation process, the organic matter is reduced into the product (biogas) and the remaining unfermented material in the residue simultaneously in a fermentation process (Jha, et al., 2013). Three samples of feedstock and output slurry were tested for

TS and VS content. Total solids and volatile solids of inlet feedstock and digested slurry are shown in Fig 4.4-1 and 4.4-2.

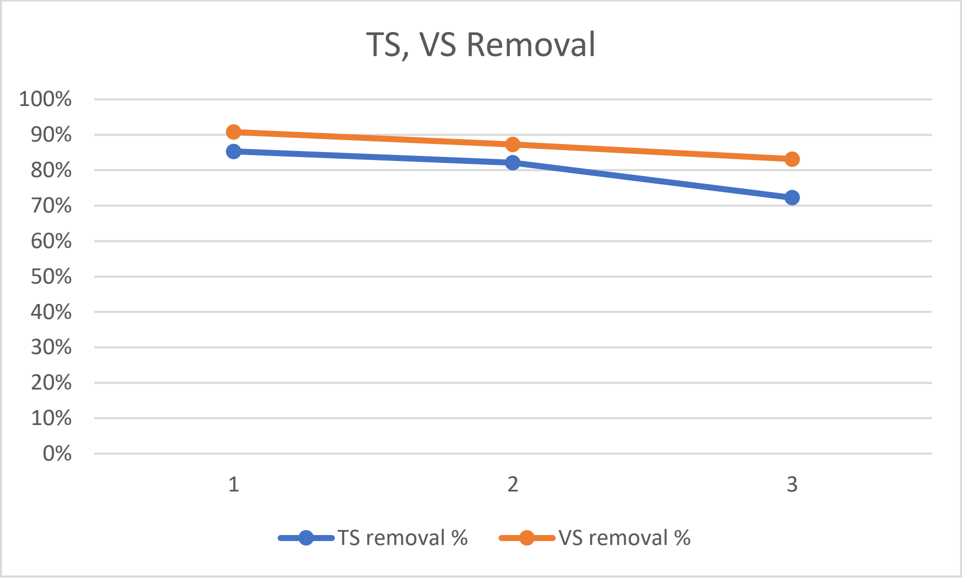


Figure 4.7 TS and VS removal efficiency

The degradation was seen to be 72-85% in TS and 83-90% of VS. Co-digestion is supposed to allow higher organic loading rate and give more stable anaerobic digestioin process (Zhang et al., 2012). The highest methane potential of food waste is in the range of 0.3-1.1m^3 CH_4/kg VS added, generally higher than other anaerobic digestion substrates such as lignocellulosic biomass, animal manure and sewage sludge (Mao et al., 2015; Gautam et al., 2020).

4.6 NPK content

The anaerobic digestion process produces byproduct (digested residual) which has a value as a fertilizer or soil amendment. The bio-fertilizer has no detrimental effects on the environment (Li, et al., 2011). The contents are tabulated in Table 4.1 NPK content of feedstock and digested slurryIn feedstock, the nitrogen content was 411.6mg/L, phosphorus (P_2O_5) was 47.46 mg/L and potassium (K_2O_5) was 17.21 mg/L. While in output slurry the nitrogen content was 753.2mg/L, phosphorus (P_2O_5) was 27.54 mg/L and potassium (K_2O_5) was 14.9 mg/L. These results show that even after energy recovery the slurry proves good as organic fertilizer.

Table 4.1 NPK content of feedstock and digested slurry

Parameters	Inlet feedstock mg/L	Output slurry mg/L
Nitrogen (N)	411.6	753.2
Potassium (K_2O_5)	17.21	14.9
Phosphorus (P_2O_5)	47.46	27.54

4.7 C:N Ratio

The C:N ratio was tested for one sample of feedstock. The sample was prepared by thoroughly mixing and grinding the contents in an electric mixer. The sample was tested in the lab using procedures mentioned in previous chapters. The C:N was found to be 26.35. The ratio corresponds to the findings by Karki et.al.

4.8 Financial Analysis

Table 4.2 Parameters for Financial Analysis

Particular	Portable FRP Biogas Plant	GGC 2047 model 6m^3
Cost of Plant	NRs. 76,840	NRs. 72,500
Thermal Subsidy (average)	NRs. 26,000	NRs. 36,000
Debt	NA	NA
Subsidy Investment Ratio	36.67%:63.33%	50%:50%
NPV Period	10 Years	10 Years
Required Rate of Return (RRR)	12%	12%
Operational Cost	Nominal	Nominal
Revenue Streams	Biogas	Biogas
Monetization of Revenue	Equivalent to LPG savings for thermal	Equivalent to LPG savings for thermal

Particular	Portable FRP Biogas Plant		GGC 2047 model 6m^3	
Cost of Baseline Energy Sources	LPG: NRs. 1800 per cylinder		LPG: NRs. 1800 per cylinder	
Cost of Compost	Compost not envisaged to sell		Compost not envisaged to sell	
Capital investment cost (biogas plant, ancillaries and generator)	NRs. 48,840.00		NRs. 36,000.00	
Labour costs	Included above		Included above	
Annual Biogas Production	93.875	m^3	237.22	m^3
LPG equivalent	45	kg	113	kg
Cost of LPG per 14.2kg cylinder	1900	NRS	1900	NRS
Operational and maintenance costs	Labour	No, home owners will manage plant also.	Labour	No, home owners will manage plant also.
	Water	-	Water	-
	Food for animals	-	Food for animals	-
	Maintenance cost with spare parts	Nominal	Maintenance cost with spare parts	Nominal
Revenue streams	LPG Savings	NRs. 501/month	LPG Savings	NRs. 1260/month

Particular	Portable FRP Biogas Plant		GGC 2047 model 6m^3	
	Fertilizer Production / sales	-	Fertilizer Production / sales	-
	Electricity Savings	-	Electricity Savings	-
	Yearly Savings & Revenue	NRs 6021/year	Yearly Savings & Revenue	NRs 15,120/year

Table 4.3 Cash flow for Portable FRP and GGC-2047 model

	Portable FRP		GGC-2047 model	
Year	Cash Flow (NPR)	Cummulative Cash Flow (NPR)	Cash Flow (NPR)	Cummulative Cash Flow (NPR)
0	-48,840	-48,840	-36,000	-36,000
1	5,600	-43,240	15,120	-20,880
2	5,600	-37,640	15,120	-5,760
3	5,600	-32,040	15,120	9,360
4	5,600	-26,440	15,120	24,480
5	5,600	-20,840	15,120	39,600
6	5,600	-15,240	15,120	54,720
7	5,600	-9,640	15,120	69,840
8	5,600	-4,040	15,120	84,960
9	5,600	1,560	15,120	100,080
10	5,600	7,160	15,120	115,200
NPV		(17,198.75)		49,431.37
IRR		3%		41%

The financial indicators have been calculated using biogas calculation tools prepared by standard methods for financial evaluation. The subsidy provided is as per RE subsidy policy 2078 for hilly region.

Since the NPV is negative and IRR is lower than the discount rate considered, the project is financially not feasible. The payback period is 9 years compared to considered project life of 10 years. However, the plant can run after 10 years also. Thus the financial indicators show the FRP is not feasible.

The GGC-2047 costs marginally lower than the FRP tank and has a potential for higher economic returns than the FRP. It also has a positive NPV and significantly high IRR of 41%. However, these results are for the optimum daily feeding rate for the GGC. If equivalent feedstock as of PBP, is provided to GGC the gas output may be same.

CHAPTER FIVE : CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Following conclusions have been drawn from the study

It is concluded that the Portable biogas plant is feasible for urban area of Nepal. It can solve the waste management problem and provide fertilizer for terrace garden. In a stabilized biodigester, if the feeding material was exclusively kitchen waste, the pH of the system goes on decreasing. The average gas production per day was 0.142 m^3. Total energy in a month was 27.51 kWh. The gas composition was methane 43.79%, carbon dioxide 25.97%, oxygen 0%, hydrogen sulphide 9999ppm and other gases in negligible amount. It can replace a maximum of 3.671 kg of LPG per month. From economic point of view, GGC 2047 is more economic since it has high IRR, positive NPV and lower payback period.

5.2 Recommendations

Following recommendations have been drawn from the study

The plant was observed with solely domestic waste. It was observed that in many occasions, it was difficult to maintain the minimum specified feedstock quantity due to low generation. In future research, the plant should be observed for mixed feeding of waste and dung.

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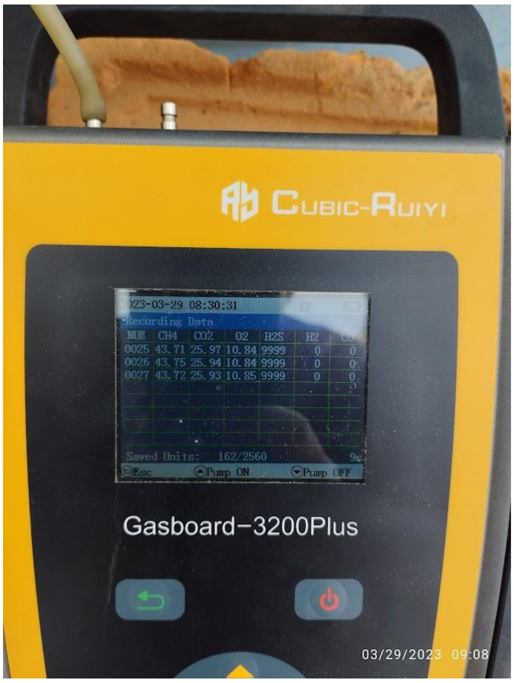
ANNEX

Annex -1 Site Photographs

Flow Meter

pH meter



```
023-03-29 08:30:31
Recording Data
NUM  CH4   CO2   O2    H2S   H2  CO
0025 43.71 25.97 10.84 9999   0   0
0026 43.75 25.94 10.84 9999   0   0
0027 43.72 25.93 10.85 9999   0   0
Saved Units:   162/2560          9s
Esc       Pump ON        Pump OFF
```

Gas Analyzer

Weighing of waste

Annex - 2 Laboratory Equipments

Dessicator and Oven

Muffle Furnace

Annex-3 Laboratory Test Results

SWAT/F/C/04
Version no: 01
Issue no: 01
Revision no: 01
Effective date: 2021/08/01

Soil Water and Air Testing Labaratories Pvt. Ltd.
VAT No: 605928743
Tel: +977-01 4249480
Email: swatlab2017@gmail.com
PO Box: 25752, Kathmandu, Nepal
Sisir Marga 11, Babarmahal, Kathmandu, Nepal

ANALYSIS REPORT

Name of Client:	Center For Pollution Studies	**Lab Code:**	23/03-956
Collector:	Srijana Sharma	**Location:**	Tarkeshwor Na. Pa. Ward-05
Source:	Output of Biogas Digester (Slury)	**Sampled By:**	Saurav Singh Bishal Bhattacharya
Sampling Date/Time:	2023/03/17, 10:00 A.M.	**Test Performance Date:**	2023/03/17-2023/03/18
Receipt Date:	2023/03/17	**Issue Date:**	2023/03/21

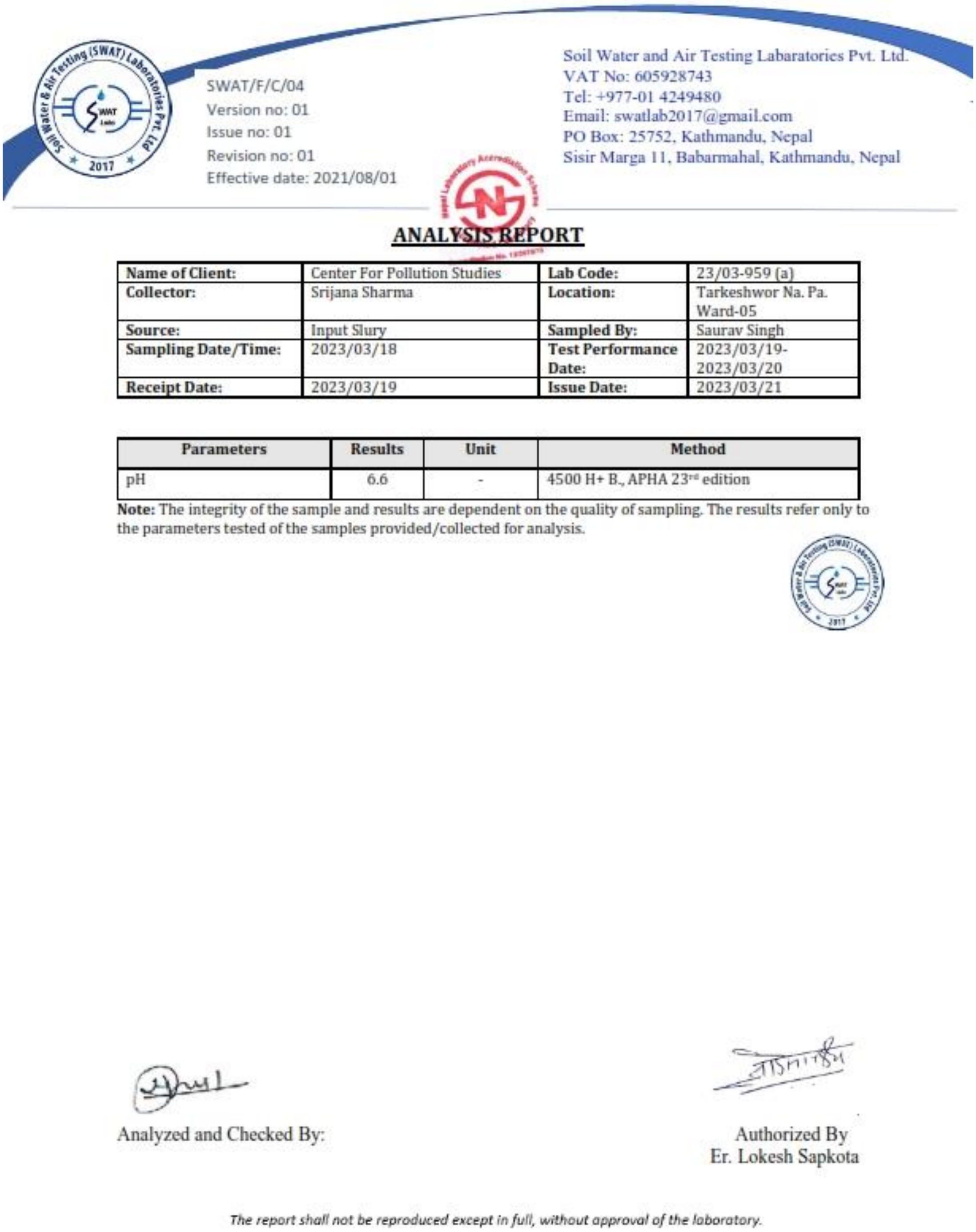
Parameters	Results	Unit	Method
pH	7.6	-	4500 H+ B., APHA 23rd edition
Total Solids	5734	mg/L	2540 B. APHA 23rd edition
Volatile Solids	3650	mg/L	2540 C. APHA 23rd edition

Note: The integrity of the sample and results are dependent on the quality of sampling. The results refer only to the parameters tested of the samples provided/collected for analysis.

Analyzed and Checked By:

Authorized By
Er. Lokesh Sapkota

The report shall not be reproduced except in full, without approval of the laboratory.



SWAT/F/C/04
Version no: 01
Issue no: 01
Revision no: 01
Effective date: 2021/08/01

Soil Water and Air Testing Labaratories Pvt. Ltd.
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Tel: +977-01 4249480
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Sisir Marga 11, Babarmahal, Kathmandu, Nepal

ANALYSIS REPORT

Name of Client:	Center For Pollution Studies	**Lab Code:**	23/03-959 (a)
Collector:	Srijana Sharma	**Location:**	Tarkeshwor Na. Pa. Ward-05
Source:	Input Slury	**Sampled By:**	Saurav Singh
Sampling Date/Time:	2023/03/18	**Test Performance Date:**	2023/03/19- 2023/03/20
Receipt Date:	2023/03/19	**Issue Date:**	2023/03/21

Parameters	Results	Unit	Method
pH	6.6	-	4500 H+ B., APHA 23rd edition

Note: The integrity of the sample and results are dependent on the quality of sampling. The results refer only to the parameters tested of the samples provided/collected for analysis.

Analyzed and Checked By:

Authorized By
Er. Lokesh Sapkota

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PO Box: 25752, Kathmandu, Nepal
Sisir Marga 11, Babarmahal, Kathmandu, Nepal

ANALYSIS REPORT

Name of Client:	Center For Pollution Studies	**Lab Code:**	23/03-959 (b)
Collector:	Srijana Sharma	**Location:**	Tarkeshwor Na. Pa. Ward-05
Source:	Kitchen Waste (Input)	**Sampled By:**	Saurav Singh
Sampling Date/Time:	2023/03/18	**Test Performance Date:**	2023/03/19-2023/03/20
Receipt Date:	2023/03/19	**Issue Date:**	2023/03/21

Parameters	Results	Unit	Method
pH	4.0	-	4500 H+ B., APHA 23rd edition
Total Solids	31998	mg/L	2540 B. APHA 23rd edition
Volatile Solids	28626	mg/L	2540 C. APHA 23rd edition

Note: The integrity of the sample and results are dependent on the quality of sampling. The results refer only to the parameters tested of the samples provided/collected for analysis.

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GAS ANALYSIS REPORT

Name of Client:	Center For Pollution Studies	**Lab Code:**	23/03-959 (c)
Collector:	Srijana Sharma	**Location:**	Tarkeshwor Na. Pa. Ward-05
Source:	Gas from biogas pilot reactor	**Sampled By:**	Saurav Singh
Sampling Date/Time:	2023/03/18	**Test Performance Date:**	2023/03/19-2023/03/20
Receipt Date:	2023/03/19	**Issue Date:**	2023/03/21

Parameters	Results	Unit
Methane (CH_4)	~35.88	%
Carbon dioxide (CO_2)	~32.47	%
Hydrogen Sulphide (H_2S)	9999	ppm

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[illegible]   CO2    O2    H2S
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[illegible]02 35.90 32.48 0.00 9999   0
0003 35.89 32.45 0.00 9999   0
0004 35.91 32.4[illegible] 0.00 9999   0
0005 35.79 32.47 0.00 9999   0
0006 35.87 32.44 0.00 9999   0
[illegible] 35.89 32.43 0.00 9999   0
[illegible]08 35.89 32.53 0.00 9999   0
U:022 G:03/03  GPS:No Data
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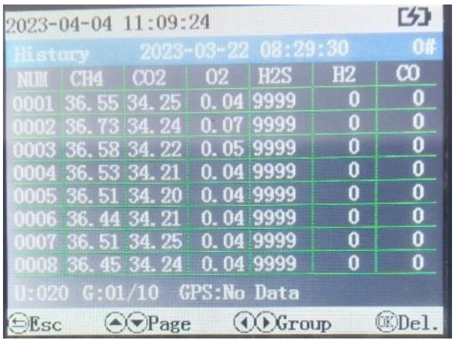
Sisir Marga 11, Babarmahal, Kathmandu, Nepal

GAS ANALYSIS REPORT

Name of Client:	Canter For Pollution Studies	**Lab Code:**	23/03-961 (c)
Collector:	Srijana Sharma	**Location:**	Tarkeshwor Na. Pa. Ward-05
Source:	Gas From Biogas Pilot Reactor	**Sampled By:**	Bishal Bajracharya/Saurav Singh
Sampling Date/Time:	2023/03/22, 8:29 A.M.	**Test Date:**	2023/03/24
Receipt Date:	2023/03/23	**Issue Date:**	2023/04/05

Parameters	Results	Unit
Methane (CH_4)	~36.54	%
Carbon dioxide (CO_2)	~34.23	%
Hydrogen Sulphide (H_2S)	9999	ppm



2023-04-04 11:09:24

History 2023-03-22 08:29:30 0#

NUM	CH4	CO2	O2	H2S	H2	CO
0001	36.55	34.25	0.04	9999	0	0
0002	36.73	34.24	0.07	9999	0	0
0003	36.58	34.22	0.05	9999	0	0
0004	36.53	34.21	0.04	9999	0	0
0005	36.51	34.20	0.04	9999	0	0
0006	36.44	34.21	0.04	9999	0	0
0007	36.51	34.25	0.04	9999	0	0
0008	36.45	34.24	0.04	9999	0	0

U:020 G:01/10 GPS:No Data

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Accreditation No. 12/2075/76

ANALYSIS REPORT

Name of Client:	Center For Pollution Studies (CPS)	**Lab Code:**	23/03-965 (a)
Collector:	Srijana Sharma	**Location:**	Tarkeshwor Na. Pa. Ward-05
Source:	Slurry	**Sampled By:**	Saurav Singh Bishal Bajracharya
Sampling Date/Time:	2023/03/28, 10:00 A.M.	**Test Performance Date:**	2023/03/28-2023/03/29
Receipt Date:	2023/03/28	**Issue Date:**	2023/03/30

Parameters	Results	Unit	Method
Total Solids	6522	mg/L	2540 B. APHA 23rd edition
Volatile Solids	3522	mg/L	2540 C. APHA 23rd edition
C:N Ratio	22.44	-	-

Note: The integrity of the sample and results are dependent on the quality of sampling. The results refer only to the parameters tested of the samples provided/collected for analysis.

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Er. Lokesh Sapkota

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Version no: 01
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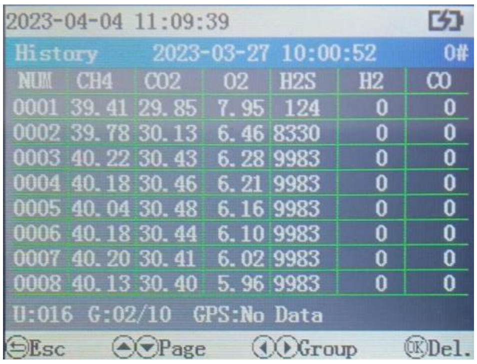
GAS ANALYSIS REPORT

Name of Client:	Center For Pollution Studies	**Lab Code:**	23/04-971 (a)
Collector:	Srijana Sharma	**Location:**	Tarkeshwor Na. Pa. Ward-05
Source:	Gas From Biogas Pilot Reactor	**Sampled By:**	Bishal Bajracharya /Saurav Singh
Sampling Date/Time:	2023/03/27, 10:00 A.M.	**Test Performance Date:**	2023/04/05
Receipt Date:	2023/04/04	**Issue Date:**	2023/04/05

Parameters	Results	Unit
Methane (CH_4)	~40.02	%
Carbon dioxide (CO_2)	~30.32	%
Hydrogen Sulphide (H_2S)	~8544	ppm



2023-04-04 11:09:39

History 2023-03-27 10:00:52 0#

NUM	CH4	CO2	O2	H2S	H2	CO
0001	39.41	29.85	7.95	124	0	0
0002	39.78	30.13	6.46	8330	0	0
0003	40.22	30.43	6.28	9983	0	0
0004	40.18	30.46	6.21	9983	0	0
0005	40.04	30.48	6.16	9983	0	0
0006	40.18	30.44	6.10	9983	0	0
0007	40.20	30.41	6.02	9983	0	0
0008	40.13	30.40	5.96	9983	0	0

U:016 G:02/10 GPS:No Data

Note: The integrity of the sample and results are dependent on the quality of sampling. The results refer only to the parameters tested of the samples provided/collected for analysis.

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Annex-4 Summary of data taken

Data observation for TS, VS for feedstock (F) and output slurry (S), ambient Temperature **T**$_{amb}$, temperature inside greenhouse **T**$_{GH}$ for the three scenarios.

Date	T-S (F) (mg/L)	V-S (F) (mg/L)	Weight (F)	Cum Wt (F)	T_{amb}	T_{GH}	T-S (S)	V-S (S)	Type
11-Mar	38318	31394	1.6	1.6	18	-	5624	2898	Usual Feed
12-Mar			1.552	3.152	18.5	-			Usual Feed
13-Mar			1.892	5.044	17.4	-			Usual Feed
14-Mar			1.6	6.644	17.7	-			Usual Feed
15-Mar			1.552	8.196	17	-			Usual Feed
16-Mar			1.843	10.039	17	-			Usual Feed
17-Mar			1.596	11.635	12	-	5734	3650	Usual Feed
18-Mar	31998	28626	0.75	12.385	13	-			Usual Feed
19-Mar			1.6	13.985	14	-			Hot Water
20-Mar			1.552	15.537	13	-			Hot Water
21-Mar			1.892	17.429	12.2	-			Hot Water
22-Mar			2.1971	19.6261	15.6	-			Hot Water
23-Mar			1.237	20.8631	17	-			Hot Water
24-Mar			1.486	22.3491	16	-			Hot Water
25-Mar			1.518	23.8671	16.5	-			Hot Water
26-Mar			1.024	24.8911	16	35			Hot Water
27-Mar			0.942	25.8331	16	32			Greenhouse
28-Mar	23494	20900	0.319	26.1521	14	27	6522	3522	Greenhouse
29-Mar			2.747	28.8991	18.3	27.5			Greenhouse
30-Mar			1.734	30.6331	19.9	24.6			Greenhouse
31-Mar			2.191	32.8241	14	22			Greenhouse

Date	T-S (F) (mg/L)	V-S (F) (mg/L)	Weight (F)	Cum Wt (F)	T_{amb}	T_{GH}	T-S (S)	V-S (S)	Type
1-Apr			4.045	36.8691	14	21			Greenhouse
2-Apr			3.193	40.0621	14.5	22			Greenhouse
3-Apr			1.596	41.6581	18	29			Greenhouse
4-Apr			0.774	42.4321	22	35			Greenhouse

Data observation for pH of feedstock (F), output slurry (S), Methane, carbon dioxide, oxygen and hydrogen sulphide for various scenarios.

Date	pH (F)	pH (S)	Flowmeter Reading	CH_4	CO_2	O_2	H_2S (PPM)	Type
11-Mar	3.26	7.37	0.841	35.76	32.47	0	9999	Usual Feedstock
12-Mar	4.5	7.6	0.983	38.29	29.98	0.17	9999	Usual Feedstock
13-Mar	4	7.6	1.163	36.68	34.23	0	9999	Usual Feedstock
14-Mar	5.6	7.6	1.289	35.88	32.47	0	9999	Usual Feedstock
15-Mar	6.5	6.8	1.424	38.39	29.98	0.17	9999	Usual Feedstock
16-Mar	5.3	6.8	1.575	36.54	34.23	0	9999	Usual Feedstock
17-Mar	4	7.6	1.75	35.88	32.47	0	9999	Usual Feedstock
18-Mar	4	6.6	1.871	35.61	32.47	0	9999	Usual Feedstock
19-Mar	4.5	7.1	2.000	38.29	29.98	0.17	9999	Hot Water
20-Mar	4.5	6.8	2.162	38.34	30.04	0	9999	Hot Water
21-Mar	5.8	6.8	2.28	38.45	30.04	0	9999	Hot Water
22-Mar	4.5	7.2	2.42	36.54	34.23	0	9999	Hot Water
23-Mar	4.5	7.2	2.591	30.65	27.17	10.48	9999	Hot Water
24-Mar	4.5	6.9	2.805	36.38	34.17	0	9999	Hot Water
25-Mar	4.5	7.1	3.062	38.34	30.04	0	9999	Hot Water

Date	pH (F)	pH (S)	Flowmeter Reading	CH_4	CO_2	O_2	H_2S (PPM)	Type
26-Mar	5.8	6.7	3.316	38.34	30.04	0	9999	Hot Water
27-Mar	4.5	6.8	3.571	40.02	30.32	0	8544	Greenhouse
28-Mar	6.5	6.8	3.661	43.12	24.34	0	9528.5	Greenhouse
29-Mar	6.4	6.9	3.676	43.79	25.97	0	8979.13	Greenhouse
30-Mar	5.3	6.7	3.757	42.1	26.99	0	9999	Greenhouse
31-Mar	5	6.8	3.823	36.75	28.31	16.25	9999	Greenhouse
1-Apr	4.5	6.5	3.93	41.15	28.03	11.47	9999	Greenhouse
2-Apr	4	6.8	4.074	39.61	28.62	11.60	5290.75	Greenhouse
3-Apr	5.6	6.8	4.177	39.91	30.24	11.65	9999	Greenhouse
4-Apr		6.8	4.24	34.01	29.95	17.06	9999	Greenhouse

Annex - 5 Cost estimate for modified GGC 2047 model biogas plant

S.N.	Item	Unit	Quanity	Rate	Amount
1.	Cement	bags	14	750	10500
2.	Bricks	cu.m.	1400	15.5	21700
3.	Aggregate	cu.m.	0.82602	4900	4047.48
4.	Sand	cu.m.	1.65203	4500	7434.15
5.	Reinforcement	kg	16	120	1920
6.	Mixer	pc	1	2000	2000
7.	Inlet pipe 110mm pvc	m	4	667.667	2670.67
8.	15mm CPVC pipe	m	4	210	840
9.	Dome Gas Pipe	pc	1	1000	1000
10.	Gas Valve	pc	1	913	913
11.	Gas tap	pc	1	913	913
12	Nippe, Socket, Elbow, Tee 1/2" CPVC	pc	9	58	522
13.	Labor cost	sq.m.	4.52389	4000	18095.6
Total					72,555.9

Quantities are adapted from presentation on Biogas by Dr. SR Shakya, 2016 (Shakya, 2016)

Performance Analysis and Modification of Portable Biogas Plant

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