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Performance Analysis of Technology for Economic Development (TED) Model Biogas Plant and Comparison with Modified GGC-2047 Model Biogas plant

by

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APPROVAL PAGE

The undersigned certify that they have read and recommended to the Institute of Engineering for acceptance, a thesis entitled "**Performance Analysis of Technology for Economic Development (TED) Model Biogas Plant and Comparison with Modified GGC-2047 Model Biogas plant**" submitted by Bikesh Prasad Jaiswal in partial fulfillment of the requirements for the Degree of Master of Science in Renewable Energy Engineering.

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ABSTRACT

TED model biogas plant is a fixed dome type digester. The size of the plant is 20 m^3 having digester volume 12 m^3 and gaseous volume 8 m^3. There has been mixture of feeding. During the study cow manure, human waste and kitchen waste like rice, fruits, vegetables, eggs, pickles, vegetables etc. was fed into the system. The digester was fed with 84 kg mixed waste per day on average generated from the school. The average gases produced per day have been 5425 liters. The plant is able to save nearly 5 cylinder of LPG per month. The recorded burning time for this amount of gas production is 9-11 hours per day in a stove of size 0.25m^3. The total solid of inlet feedstock and outlet slurry is 14.58% and 8.13%. The volatile solids of the inlet feedstock and outlet slurry have been 78.59% and 48.98%. Percentage reduction in TS and VS have been 44.24% and 37.71% respectively. The average pH of the outlet is found to 7.1 which is around neutral. It is found to have higher reduction in TS and VS when the kitchen waste and cow manure is co-digested anaerobically. The biogas produced from the plant has been 1.01 m^3/kg of TS and 0.22 m^3/ kg of VS. Nitrogen, Potassium and Phosphorus of feedstock has been 0.37%, 0.25%, 1.54% respectively and outlet slurry have been 0.17%, 0.03%, 0.68%. The plant could reduce 12.027 Tonnes of CO_2 equivalent. There have been slightly decreases in the value of the NPK because formation of ammonia gas through formation of ammonium ion. Financial analysis shown that the plants must get subsidized in order to get profitability.

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LIST OF ACRONYMS AND ABBREVIATIONS

ABR	Anaerobic Baffled Reactor
AcoD	Anaerobic Co-Digestion
AD	Anaerobic Digestion
BNS	Bloom Nepal School
CM	Cow Manure
FYM	Farmyard manure
GGC	Gobar Gas Company
GHGs	Green House Gases
GoN	Government of Nepal
HW	Human Waste
LPG	Liquid Petroleum Gas
MGGC	Modified GGC
MSW	Municipal Solid Waste
Mt	Metric ton
NWS	Nepal Sainik War College
OLR	Organic Loading Rate
SMW	Solid Municipal Waste
TED	Technology for Economic Development

CHAPTER ONE: INTRODUCTION

1.1 Background

Energy is a basic need for every human being and plays a vital role in our daily life. Energy helps to create a better world. It has also major role in the economic status of country. There are different sources of energy like fossil fuel, renewable energy and so on. Biogas is one of the clean and affordable type of energy. The rising emphasis on producing biogas from agricultural waste such as animal excrement, wastewater sediment, leftover plant materials, and different organic detritus is motivated by the potential to reduce greenhouse gas emissions (GHGs) and reliance on nonrenewable energy sources(Afotey & Sarpong, 2023). It can help to partially replace the current energy demand in a sustainable manner. Global energy consumption scenario shows a high supply from the commercial sources like by the petrol, Diesel, Coal and Natural Gas. As we can see there is gradual decline in use of fossil fuel from 94.55 % in 1970 to 80.04% in 2015; the use of renewable source is around 1.64% in world scenario (World Energy Outlook 2023 - Event, n.d.). Use of biogas skill can reduce the world greenhouse gas emission by 3,290 to 4,360Mt carbon dioxide equivalent. In southern Asia country like India, Nepal and China have large number of domestic bio-digester working around 50 million.

Human beings use all types of resources like natural and artificial, directly and indirectly for their individual needs and throw the leftover after their fulfillment of their needs. These thrown away of things are known as waste. This waste may be any type of forms of like solid, liquid and gaseous. The waste of solid type takes long time to biodegrade and starts to contribution to different type of pollution like air and water. So, this type of waste needed to disposed to specified area systematically and scientifically in order to get rid of this type of pollution. The unwanted waste when exposed to long term it produces methane, carbon dioxide and other types harmful gases that are responsible for the GHGs emission gases. Nowadays looking at the urbanization of the society, the produced wastes started to accumulate in community that led to negative impact on both to the nature and human beings living int that society.

Nepal is still unable to find the different types of natural sources like the petroleum, natural gas, coal due to the complex geographical diversity and unavailability of latest type of technology and least availability of fund and also shortage of less focus on the field of research and development. Nepal energy demand is fulfilled by the biomass resources like firewood, coal, cattle cake, agricultural residual and also with hydroelectricity. Nepal electrification rate is increasing day by day, till it hasn't reached to all Nepalese people. Till now 69% of Nepal energy demand is fulfilled by the biomass like firewood, coal and agricultural residual. Nowadays due to urbanization, most people shift their focus from the biomass to LPG for cooking, heating and performing all other daily usage. The import of these LPG gases is almost one third of total import in the country. This import causes high trade deficit. The main focus of the alternative energy in Nepal is towards hydroelectricity due to great water resources availability. Although Nepal has huge potential of hydropower due to high capital investment and long construction and production time.

In urban areas due to high population density and mismanagement of waste, it becomes a major environmental problem in all major cities of Nepal. The overuse of the materials and the products that produce hazardous waste, chemicals, solid wastes from the different types of construction site, hospitals, industries etc. which contributes directly or indirectly contributes to pollution and public health hazards in the communities. This shows that wastes are a major concern in todays' world for the urban areas.

Solid waste management can be described as the proper management of the different types of waste in scientific manner which leads to minimization of the adverse effect on both the nature and human beings and maximizes the potential for recycle, reuse. Solid waste management is also associated with the production, generation, collection, transfer and processing and dumping of solid waste according with compliance of the public health, conservation, economics and other environmental effects.

Consequences of the unmanaged and improper waste is known to every country around the world. Each country has made strict policies and regulation related to the waste management. In the same way GoN also has committed some rule and make policies related to the proper waste management. As per the latest report from GoN for fiscal year 2019/20, CBS had conducted a survey on the waste management entitled "Waste Management Baseline Survey of Nepal 2020" which had taken the data from nearly 271 municipalities. The major findings of the survey consist of that most of the waste are of solid types of waste, classified mainly in two parts inorganic waste like rubber, paper, plastics, metals and organic waste as kitchen waste, night soil or human waste, cow manure etc. The generation of the total waste per municipality in the fiscal year was on average around 2232.7 MT annually, which consists of organic, inorganic and other waste with their contribution as 54%, 33.3% and 12%. And one of the most improper and negative things found is that only 4% of the waste generated were recycled which shows how badly we need the biogas plants type technology to mitigate the GHGs emission gases and waste management approach.

Due to the current federal governance, small and incapable towns and cities are declared as the municipalities which lacks the techniques to deal with hygienic and proper waste management. Nowadays, it has been seen that some effort is made by the local level bodies in field of waste management by providing awareness campaign about waste distribution, collection and storage. Also adapting different types of latest technology related to proper disposal of the waste.

1.2 History of biogas in Nepal

In Nepal, biogas was introduced in mid-20th century. But it doesn’t get the pace it needed to evolve throughout the country. Biogas installation get its pace after the energy crisis of 1975. Nepal in 1975/76 were celebrating that year as agriculture year and along with that the government also started to promote biogas as alternative sources of energy. In the encouragement of biogas, ADBL Nepal had played a significant role by not only disbursing loans to the interested individuals but also by providing training and information dissemination.

In 1977, Gobar gas and Agricultural Equipment Development Company (GGC), a private company, established with an aim of encouraging technology related to biogas in Nepal. After their existence in field of biogas they remained the only organization in the country which helps to promote the biogas technology and also involved in providing training to the individual and also to the masons on its construction process.

In 1992, BSPs was initiated to promote biogas in Nepal in the international support of Netherlands Development Organization (SNV). After this initiation, the number of biogas installation started to gradually increase with a good rate. On average there is nearly 20,000 plants installed per year.

In 2000, the Biogas Credit Fund was created with help from Germany. The goal was to give money to organizations that lend money to farmers in Nepal. These farmers couldn't afford to pay for biogas plants themselves. The fund started with 5 million Euros and now works with over 300 lending organizations to help these farmers get biogas. As per the economic Survey 2021/22, the installation of biogas plant in Nepal which is nearly gone past four hundred thousand. The maximum number biogas plants installed between 2014-2016 and least in the 2019/20 fiscal year due to the coronavirus epidemic.

The number of institutional, urban and commercial biogas installed is around 355 plants of this type which is very much less in compared to the installation of the domestic biogas plants. As of first eight months of 2021/22 fiscal year, 3,988 biogas plants and 15 institutional, urban and commercial plants are installed.

Despite the continuous government's support and financing schemes, less than one percent of the total biogas potential has been harnessed. The total biogas potential of Nepal from livestock is estimated to be 3043.58 million m^3/year when the full potential will be utilized. This estimation could be avoided emissions of 4.35 million tonne CO_2eq/year(Lohani et al., 2021).

1.3 Problem statement

The total solid waste production in Nepal is nearly 2500 tons, which is collected from various sources and dumped in unmanaged landfills across the nation. The dumped landfills need proper segregation and scientifical disposal method in order to avoid various problems related to health and environment. Also, cooking in urban part of the nation is heavily dependent on the LPG, which is one of the top three material imports in the country. Similarly, fertilizers used in agricultural field is also imported. These imports have direct contribution in the increasing trade deficit. This study focuses of analyzing and examining the technical and financial aspects of being dependent on alternative and renewable source of energy for cooking to reduce LPG dependency. The finding and recommendation of this will be valuable to the future research and to the people interested in promoting and implementing the biogas as the eco-friendly technology in their premises.

1.4 Objectives

1.4.1 Main objective

The main objective of this study is:

- To analyze the performance of TED model plant and comparison of parameters with Modified GGC-2047 model.

1.4.2 Specific Objectives

The specific objectives of this study are:

- To determine the biogas generation, reduction in TS, VS and NPK of inlet and outlet and its composition
- To compare the gas output with standard GGC modified model
- To perform cost comparison of the plant with GGC modified model

1.5 Scope and limitations of work

- All the data are taken in summer and rainy seasons and at ambient condition.
- Internal temperature of the biodigesters is not taken due to the lack of advance equipment.
- Gas leakage from the pipeline is not considered.
- Microbial testing and analysis are carried out at private lab due to lack of advance laboratory.

CHAPTER TWO: LITERATURE REVIEW

Biogas is the one of the cheapest and easily accessible alternative sources of energy for heating, cooking in the rural area and urban also. It also helps to mitigate the dependency on the expensive and harmful energy sources. It is gaining the popularity nowadays due its various good characteristics. The environment of today's world is degraded by the continuous use of non-renewable energy sources like diesel, coal, petrol, natural gases, kerosene, biological materials, solid wastes, trees and etc. These all help to increase the production of the GHGs, this will lead to create a small cover near lower surface of the earth which strengthen the greenhouse effect and contributes to climate change and also, increase the global temperature of the earth. Among various GHGs, CO_2 is the major contributor nearly 79.4% CH_4 is the secondary contributor which emits from the livestock and other agricultural and animal practices, land use and also municipal solid wastes fills. Most of the developed countries like USA, China, India etc. have most percentage of contribution.(US EPA, 2015) As per the energy usages scenario nearly 88% of energy demand is met by the non-renewables mostly by fossil fuels. The key benefits of installing small scale biogas plant are clean cooking, cheap cooking and also help to produce fertilizers for growing local vegetables and herbs. Also, it helps to reduce our dependency on natural gases and LPG gases, stove etc. Biogas also help to reduce emission of methane and carbon dioxide and other harmful and GHGs gases

In the 17th century, Jan Bapista van Helmont, it was determined that decaying organic matter could possibly evolve as a flammable gas. Also, an Italian scientist Alessandro Volta, 1776, found a direct connection between the amount of the decaying organic matter and the produced inflammable gases.(Nakarmi et al., 2015)

By using biogas plant accessible everywhere, the problem for bio-degradable waste can be solved around the plant. Due to the continuous feeding of kitchen waste materials like fruits, leftover foods, fruit, citrus food, vegetables etc. which makes the pH value in acidic region. Due to this the formed methane concentration begins decreasing and which makes difficult to ignite in the stoves. So, to bring down pH to neutral nearabout 7, there must be addition of the cow manure which are basic in nature.(Gautam & Jha, 2020)

Iqbal et. Al. in 2014 observed that co-digestion of CM and kitchen waste through the AD at temperature of 37°C degraded more rapidly than the kitchen Waste and CM alone. He also observed that when kitchen Waste is treated with alkali (NaOH) at a temperature of 37°C and OLR 200gm/L then the biogas production was almost doubled than untreated kitchen Waste.(Iqbal et al., 2014)

Subedi discussed the status of the current situation of biogas in Nepal and its role and contribution to employment, income generation, direct and indirect contribution in reduction of the GHGs gases(Subedi, 2015).

Dhungana et al. had looked into single-stage degradation of food waste under room temperature conditions mimicking the functioning parameters of a household biogas facility(Dhungana & Lohani, 2020). Production of biogas, compared to the summer season, is lower during the winter. But the improvement in biogas yield can be done by mixing feedstock with lukewarm water during water. Also, construction of greenhouse is required in order to enhance the biogas production. (Lohani et al., 2022)

Kanwar and Guleri compared between the Chinese fixed dome and an Indian plastic tubular digester without greenhouse at an altitude of 1300m and found out that biogas production in the plastic tubular model in winter season dropped by nearly 70% as compared to the production observed in the summer season(Kanwar & Guleri, 1994).

Garfi et al. investigated while comparing Chinese fixed dome and plastic tubular digester that plastic tubular digester was easy to install and implement and handle and is also carried out at lower investment than the former(Pérez et al., 2014).

Agyeman & Tao in 2014 suggested that the rate of production of methane and specific methane yield in the digester can be enhanced and increased by using finer size of feedstock. They also suggested that by reducing feedstock particle size digestate dewaterability was improved significantly(Agyeman & Tao, 2014).

Kumar & Samadder, 2020 had discussed that AD is a very much complex microbial process containing of series of metabolic reactions for disintegration of organic matter into major biogas and minor organic fertilizer. In AD, it is found that conversion of biomass to biogas is heavily influenced or enhanced by different types of microorganisms including methane forming bacteria and acid-forming bacteria. The whole AD process is generally divided into four different stages(Kumar & Samadder, 2020).

Jeppu et al., 2022 has discussed that dilution of feed is necessary, dilution ratio between 1:2 and 1:4, making TS between 4 and 6.7 % is recommended in order to efficient utilization of cow manure along with other waste. He had also shown that the higher dilution of cow manure feed in the semi- continuous batch experiments helps to increase the biogas production yield by nearly 30%. (Jeppu et al., 2022).

Malav et al., 2015 had investigated that the feedstock sample fed must have low fat content in order to maximize the biogas production. The feed with higher fat content had negative impact on the biogas production due to the complexity of the fat compound which required more time for degradation and biogas formation. Along with fat content, he also found out that feed having higher concentration of protein had negative impact on biogas yield due to the release of ammonia during protein degradation which causes the increase in pH and decrease the biodegradation rate. He concluded that for better and efficient working of biodigester combination of various factors like high carbohydrate, low proteins, low fats, high fiber content is required (Malav et al., 2015). AD can provide fertilizer from its output which is high value organic fertilizer. There is possibility of production of biogas from every living being by finding the ways to produce biogas from each the waste and materials. Every waste type which is able to produce biogas should have lignocelluloses.

Table 2.1: Biogas production and energy generation from different feedstocks

Type	Biogas yield per ton of fresh manure (m^3)
Animal Manure	55 – 68
Chicken manure	126
Food wastes	110
Fruit wastes	74
Horse manure	56
Municipal waste	101.5
Pig manure	11
Sewage sludge	47

(Malav et al., 2015)

Christensson et al., 2010 had estimated that biogas mainly consists of methane, carbon dioxide as the main constituents but along there major it also consists of some smaller concentration like nitrogen. Oxygen, hydrogen, hydrogen sulphide. The volume percentages of the constituents are presented in table 2.1(Christensson et al., 2010).

Table 2.2: Estimated volume percentages of various molecular compounds in newly produced biogas from

Molecular compound	Volume % in biogas
Methane, CH_4	55-80
Carbon dioxide, CO_2	20-45
Nitrogen, N_2	0-1
Oxygen, O_2	Trace
Hydrogen, H_2	Trace
Hydrogen Sulphide, H_2S	0-2000 [ppm]

(Christensson et al., 2010)

Li et al., 2011 had categorized organic waste material in three different categories depending upon the TS value of these material which are dry TS higher than 15%, semidry TS from 15-10% and wet TS below 10%. (Li et al., 2011).

Different biomass substrate yield biogas differently as per the reduction of TS and VS.

Table 2.3: Amount of biogas production per kg of TS and VS

Biomass	Typical gas yields	
	m^3 biogas/kg TS	m^3 biogas/kg VS
Biological sludge	0.11 to 0.23	0.10 to 0.20
Cattle manure	0.24	0.21
Chicken manure	0.4	0.35
Deep bedding	0.24 to 0.37	0.21 to 0.32
Floating sludge from sewage treatment plant	0.41 to 0.86	0.36 to 0.75
Grass	0.57	0.35
Maize	0.61	0.37
Mink slurry	0.4	0.35
Offal	0.49 to 0.57	0.40 to 0.46
Pig slurry	0.37	0.32
Primary sludge	0.38	0.33
Source separated households waste	0.43	0.35

(Jørgensen, 2009)

Nakarmi et al., 2015 had explained that cattle manure is a great source of organic fertilizer. The slurry outlet from the biogas plant contains different types of nutrients and this different type of nutrients composition depends on the various external and internal factors like type of feedstock, condition of cow manure before mixing with water, moisture content of the waste fed, breed and age of the animals whose manure is fed, amount of time for exposure to the sun, anaerobic digestion process initiated by different types of bacteria in different stages of AD process. During the AD process, organic matter of about 30% is decomposed and leaving behind only 7% of the dry matter in the outlet. In AD process most of the formed nitrogen in the process is converted in to ammonium. Bio-slurry is an important aspect or byproduct of the biogas system. The positive impact of the effluent can surpass the advantages of biogas production because it contains a higher concentration of essential plant nutrients compared to conventional farmyard manure (FYM) and compost.

Table 2.4: Availability of nutrients in composted manure, digested slurry and farm yard manure

Nutrients	FYM		Composted Manure		Digested Slurry	
	Range (%)	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)
Nitrogen	0.5 to 1.0	0.8	0.5 to 1.5	1	1.4 to 1.8	1.6
P_2O_5	0.5 to 0.8	0.7	0.4 to 0.8	0.6	1.1 to 2.0	1.55
K_2O_5	0.5 to 0.8	0.7	0.5 to 1.9	1.2	0.8 to 1.2	1

(Gupta, 1991)

Night soil or human waste has relatively low C/N ratio than the animal dung but is rich in plant nutrients which has high potential to be served as fertilizer in agricultural field. Likewise, human urine is also rich in nutrients containing more amount of nitrogen in its concentration. When human faeces or night soil when composted or digested with human urine. It increases the quality of the compost to be used as a fertilizer.

Table 2.5: Constituents of human faeces and urine

Approximate Quality	Faeces	Urine
Quantity per capita	135-270 gm	1.0-1.3 liter
pH	5.2-5.6	
C / N ratio	5-10	0.6-1.1
Approximate Composition (Dry Basis)		
Moisture (%)	66-80	93-96
Solids (%)	20-34	4-7
Composition of Solids		
Organic matter, %	88-97	65-85
Nitrogen (N), %	5-7	15-9
Potassium (K), %	0.83-2.1	2.6-3.6
Carbon (C), %	40-55	11-17
Calcium (Ca), %	2.9-3.6	3.3-4.4

(Nakarmi et al., 2015)

CHAPTER THREE: METHODOLOGY

In this chapter, the methodology that is applied for the work from the start of the project till the completion of the project. The theoretical background and previous use of method and technologies are also elaborated. A brief discussion of financial analysis is also presented in this chapter. The methodology used during the study is shown as follows:

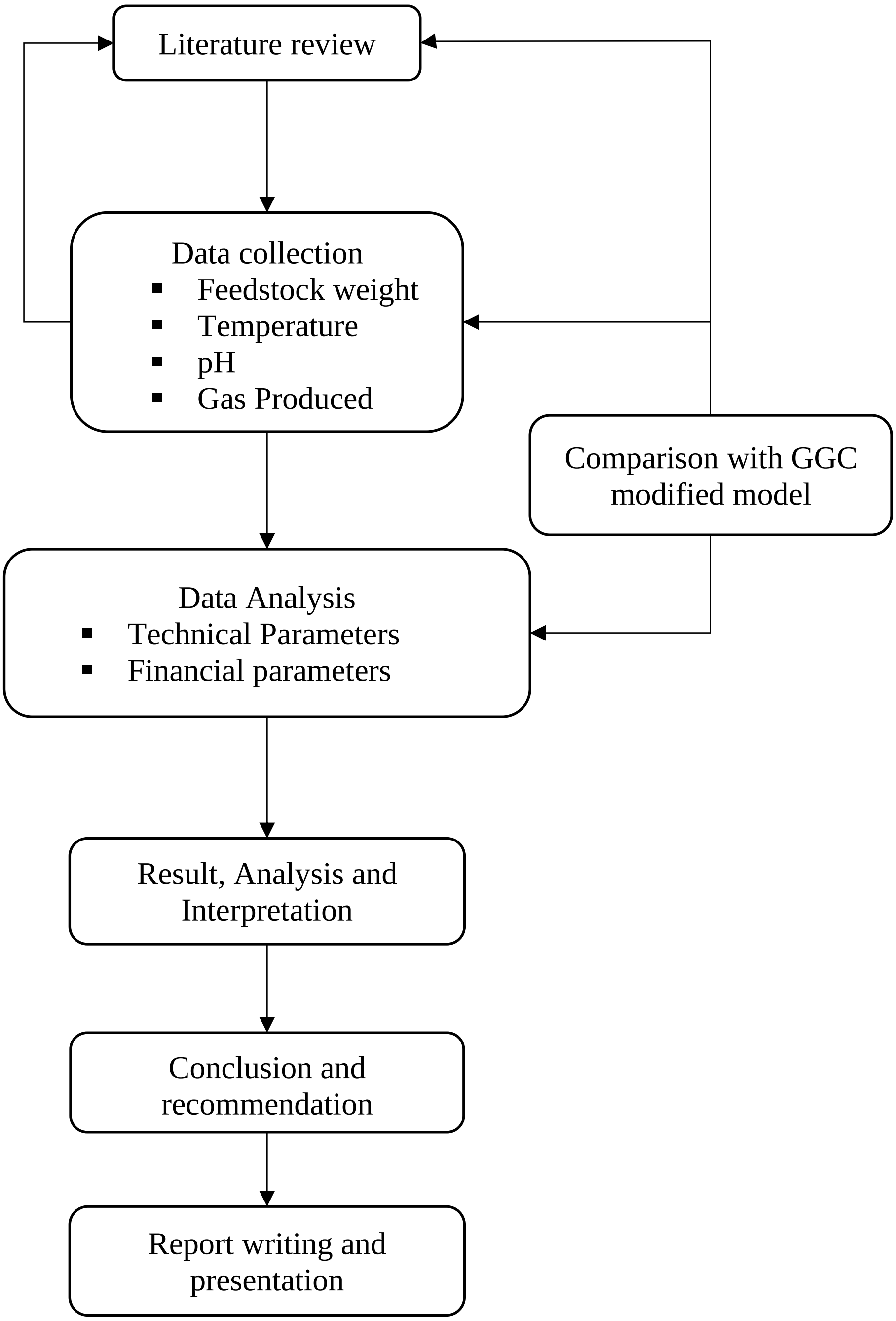

Figure 3.1: Research Methodology Flowchart

3.1 Literature Review

The literature associated to the biogas, feedstock inlet and outlet, domestic biogas, types of biodigester, analysis, interpretation of the results and many other related parameter studies is done from various types of research papers, journals, review reports, books and government reports prepared by the various authorities and researchers to strengthen the knowledge in this field. Also visited various organization which worked in the field of biogas like AEPC, NAST, BSP-Nepal.

3.2 Data Collection

Data collection is one of the most important aspect of any research which helps to determine the quality and output of any research. The study was performed by taking the useful and relevant data from the biogas plant of Bloom Nepal School situated in Mahalaxmi municipality, Lalitpur. The latitude and longitude of the plant was 27.633, 85.362. The geographical location of the plant is attached in Appendices E. The system was installed in the end of 2021, and the data was taken only after the plant or system is well running and better performing condition. The plant was installed on 15th Feb 2022. For the activation of system there need to put 200 kg of cow manure with water. The mixture should be in 2:1 ratio of water and cow manure. Rest part of digester tank has been filling by water until there is flow from the fertilizer outlet. The system was left to stabilize until there has seen gas. Gas has been seen after 12 days of installation and after burning of the gas started, maximum pressure arises after 8 days.

A log sheet containing feedstock inlet weight and daily gas consumption to the caretaker of the plant and kitchen worker. The plant has been visited once a week to look out for relevant data like installation cost, operating and maintenance cost, mechanism, life time of the system. Every day waste produced from kitchen of school canteen; washroom is around 84 liters on average. Waste includes rice, vegetables, dal, bread, pickle, fruit waste, lemon etc. The distance of pipeline is 50 meters from the system to stoves. Beside kitchen Waste, cow manure and human waste has been fed on the system.

3.2.1 Temperature

The temperature of the surrounding of the plant is noted down at regular interval of the time to note down the maximum and minimum temperature. Also. the temperature is slurry is also measured with a digital instrument.

3.2.2 Gas flowmeter

The gas flowmeter is used to find out the total gas used per day. It is installed outside of the kitchen of the school. The kitchen has been operating four times a day, earlier morning (7:00-7:45 A.M.) to prepare breakfast, at noon (12:30-1:00 P.M.) for lunch, at late noon (3:30-4:00 P.M.) for snacks and for dinner at night (7:00-8:00 P.M.). The reading from gas flowmeter (Zhejing Chint instrument and meter co. ltd) has been noted down daily by the plant caretaker and the cook at 5:00 P.M. daily in a provided log-sheet paper. The data has been taken at atmospheric pressure. The data is taken from the 23/06/2022 to 08/08/2022. The initial and final reading of the gas flowmeter during my study in 499.20 and 727.09 m^3 respectively. The image of gas flowmeter is attached in APPENDICES A.

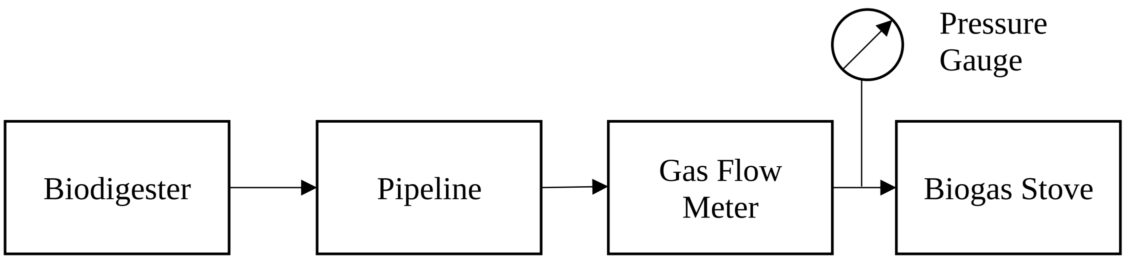

Figure 3.2: Flow diagram of biogas from plant to kitchen

3.2.3 pH

The pH of the system is regularly measured at fixed intervals, once per week. The pH meter used for testing the output slurry is calibrated every time before the use as it provides accurate and precise data. The meter is calibrated by dipping the bulb of the pH meter in beakers containing buffer solution having pH of 4.0 and 7.0. The test duration is same as the gas flow measurement duration. The image of the pH arrangement is attached in APPENDICES A.

3.2.4 Feeding

The feeding of the samples is CM, kitchen Waste, and human waste. CM is fed thrice a week whereas kitchen Waste is fed twice a day, morning at 9:00 A.M. and evening at 8:00 P.M. Human waste is fed directly through connected pipe.

3.2.5 Sample Preparation

The sample is prepared in weightage of 30% CM and 60% kitchen Waste. CM was diluted with 10% water. They all are mixed and stirred gently to form a mixture of waste which has been taking at the lab for performing the test of TS, VS & NPK. One liter of feedstock sample along with digested output slurry of one liter has been taken. There is an expectation in the variation in the results from actual outcome as human waste was not taken inside the sample preparation bottle. The image of the prepared sample is attached in APPENDICES A.

3.2.6 Calculation of TS, VS & NPK

The prepared sample is taken NESS lab situated at Thapathali, Kathmandu. In order to calculate TS, initially, required amount of sample was taken and placed on top of a clean, dirt free, dehydrated and pre-weighed watch glass. Again, it was weighed precisely. Then it was dehydrated in burning air oven at about 105°C of temperature for 5 hours. The identical procedure was often repeated until a desired outcome was attained. Also, in order to calculate VS, A clean watch glass is ignited at 550°C for 1 hour inside a furnace.

Numerically,

Mass of empty watch glass = W

Mass of watch glass + sample added = X

Mass of watch glass + sample after drying at 105°C = Y

Mass of watch glass + remains after ignition at 550°C = Z

$$TS = \frac{Y - W}{X - W}$$

$$VS = \frac{Y - Z}{Y - W}$$

Calculation of biogas production with reduction of TS and VS

m^3 of biogas/kg of TS = Cumulative gas production/ (Total fed x reduction in TS)

m^3 of biogas/kg of VS = Cumulative gas production/ (Total fed x reduction in VS)

Table 3.1: Method used to test TS, VS & NPK at lab

S. N	Parameters	Test methods
1.	Total solids (%)	Method 1664, Total, fixed, and volatile solids in water, solids and biosolids, US-EPA, January 2001, Procedure no.11
2.	Volatile solids, (%)	Method 1684, Total, fixed, and volatile solids in water, solids and biosolids, US-EPA, January 2001, procedure no. 11
3.	Total Kjeldahl Nitrogen, (%)	Modified Kzeldahl, FAO, Fertilizer & Plant Nutrition Bulletin No. 19
4.	Phosphorus as P_2Os, (%)	Vanadomolybdophosphoric acid, FAO, Fertilizer & Plant Nutrition Bulletin No. 19
5.	Total Potassium as K_2O, (%	Flame Absorption, AAS, FAO, Fertilizer & Plant Nutrition Bulletin No. 19

3.3 Research Tool

For the calculation of the feedstock, toilet parameter, HRT and to perform the technical analysis. Biogas Calculation tool version 3.1 provided by AEPC (AEPC, Biogas Calculation Tool Version 3.1, 2014).

3.4 Financial Performance Parameters

The investment analysis is varied based on the financial parameters which characterize the biogas plant system economic performance. The financial parameters which are considered in order to evaluate a biogas plant system are discussed in the section below.

3.4.1 Simple Payback Period

The total payback time to return the capital investment is known as simple payback period, and is an important decision-making indicator for the investment. Usually, shorter payback time is good for the investment. Simply, it is the length of time an investment reaches in a breakeven point. Payback period is calculated using the formula below,

$$\text{Payback Period} = \frac{\text{Cost of Investment}}{\text{Average Annual Cash Flow}}$$ …equation (1)

3.4.2 Net Present Value (NPV)

The most important economic criterion for assessing the system investment is the Net Present Value (NPV). It computes the present value of future cash using the discount rate to determine the investment profit. A profitable investment indicates a positive NPV, while the opposite is true for a negative NPV. The NPV is calculated using the formula below:

$$NPV = -C_0 + \sum_{0}^{N} (C/(1+d)\hat{}N)$$

…equation (3)

Where,

C = The total cash flow in given analysis time frame after tax,

$C0$ = The capital investment,

d = Nominal discount rate and

N = Project Duration

3.4.3 Internal Rate of Return (IRR)

The discount rate at which an investment's net present value equals zero is known as the internal rate of return (IRR). One of the most used capital budgeting strategies is IRR. The hurdle rate is the minimal required rate of return. Setting the NPV to zero and solving for the discount rate, which is the IRR, will allow you to determine the IRR using the formula.

NPV = 0

PV of future cash flow − Initial Investment = 0

$$\left(\frac{\text{CF1}}{(1+r)^1} + \frac{\text{CF2}}{(1+r)^2} + \frac{\text{CF3}}{(1+r)^3} + \cdots\right) - Initial\ Investment = 0$$ …equation (4)

Where,

r = internal rate of return;

CF1 = net cash inflow at period 1

CF2 = net cash inflow at period 2

CF3 = net cash inflow at period 3 and so on ...

3.5 Comparison with GGC Modified Model

The BSP, Nepal has fixed GGC-2047 as the standard model in Nepal for construction, promotion and installation of biogas plant. Data required for the comparison purpose has taken from the Modified GGC-2047 model installed at Nepal Sainik War College, Nagarkot. The data here also includes per day gas production, feedstock per day.

3.6 Thesis Writing and Presentation

The result obtained has been compared with available data from past research, report writing and presentation have done after consulting with expert, mentors, friends and supervisors.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 TED Model vs Modified GGC-2047 Model

Modofied GGC-2047 model is the standard and widely implemented type of biogas plant in Nepal. There are varoius sizes of this model is designed and constructed throughput the country. It comes in different sizees as per the need.

4.1.1 Physical specification

Category	Modified GGC-2047	TED
Type	It is a fixed type dome biogas plants that are constructed from locally available materials and made in Nepal.	It is also a fixed dome type model, made in Lesotho, Africa
Model	It is the modified version of the Chinese model.	It is the modified version of Deenbandhu model.
Life span	It has lifespan of about 25 years	It has lifespan of about 20-25 years.
Biogas production	Less gas to volume ratio	Better gas to volume ratio
Shape	Rectangular base wall with hemispherical dome	Nearly hemispherical
Base size	Concave type	Base is angular.
Treatment	No any post treatment of slurry is available	Treatment of slurry is available with anaerobic baffle reactor

4.1.2 Technical specification

The TED model has the system volume of 20 m^3, gas tank volume of 8 m^3 and digesters tank of 12 m^3. The height and length of the system is 4.1m & 6.5m and the radius of the hemisphere is the 2.72m. The biogas plant also has a water treatment system known as Anaerobic Baffled Reactor (ABR). The ABR consists of the 9 sections of total length

8.85 m length and each section having cross section area of 0.45 x 0.45m^2 and depth of 2.15m. The last three sections of the ABR consist of graveled type structures up to a height of 1.3m of two different type of gravel.

The technical specification of the TED model is shown in the table 4.1

Table 4.1:The technical specification of the TED model

System volume	20 m^3
Gas tank volume	8m^3
Digester tank volume	12m^3
Dimension assembled	6.5m x 4.1m
Radius of dome	2.72m
Gas pipe length	Up to 20meter
Daily kitchen waste input	22 kg (avg.)
Daily animal manure input	10 kg (avg.)
Night soil	52 kg (avg.)

Modified GGC-2047 model which a fixed dome type digester is size of 20 m^3. The plant is constructed by the Byangnasi Nirman and Suppliers Pvt. Ltd, and installed in the Nepal Sainik War College, Nagarkot. The plant has feeding of near 30 kg of kitchen waste on average and night soil of 40kg per day. The maximum average temperature of the plant was about 27.34°C.

4.2 pH Variation

When the system is at stable condition and running well, then we have only started to perform the testing of pH material. The testing was performed on weekly basis for a month only. pH value of feedstock is found to be about 6-8. Initially, pH has been not low, not up to the optimum value required as feeding has been dominant with kitchen Waste over CM and human waste. Low value of pH for over a long period of time has direct negative effect on biogas production. Earlier CM is used once in week but due to low value, CM proportion has increased to get pH better. After addition of more CM, thrice a week, the pH increases near the neutral about 7.0. As the input of the CM is increased, pH of the input feedstock acts very significant in the biogas creation. When there is better production of the biogas, pH value remains between the value of 7 and 8. Kitchen waste as the only feedstock don't help to run the AD process effectively and efficiently(X). When there is co-digestion between the human waste or water with kitchen Waste, the effectiveness of AD increases subsequently than previous. and when there is co-digestion of kitchen waste, water and CM, then there is stability in the AD process and higher pH is obtained as result.

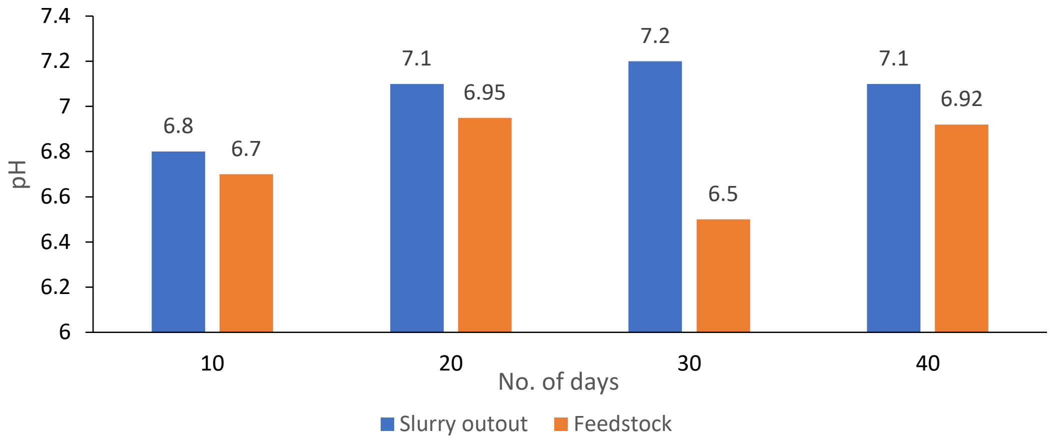

Figure 4.1: pH output of the system

4.3 Temperature

The average maximum temperature of the ambient was found to be 27.71°C by the help of digital meter in the school premises. Also, the temperature of the outlet slurry is measured with the help of the digital temperature meter HTC-2 and the average maximum temperature was found to be 27°C. The temperature found in the slurry temperature is less than the normal operating temperature which is 35-37°C.

4.4 Biogas Output

The data has been taken for 45 days. It has started from 23rd June,2022 to 8th August,2022. The data is more of constant throughout the inspection time. Initially, the value at the gas flowmeter was 499.20 m^3 as the biogas plant is running since 15th Feb, 2022 and the last day of meter shows 740.33 m^3.

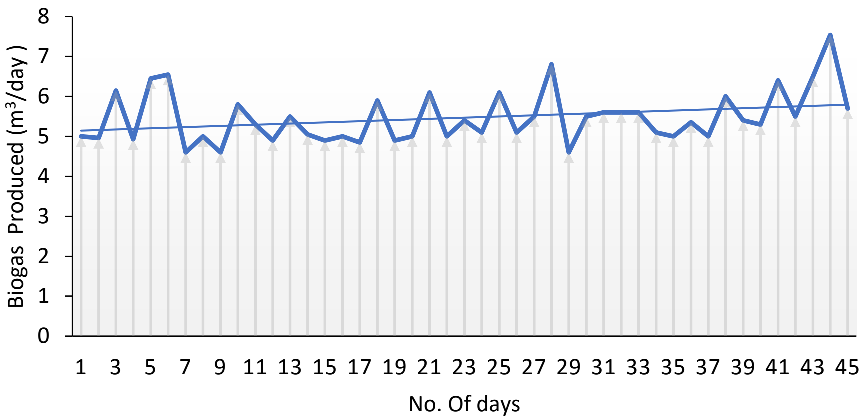

Figure 4.2: Daily gas production/ consumption in m^3

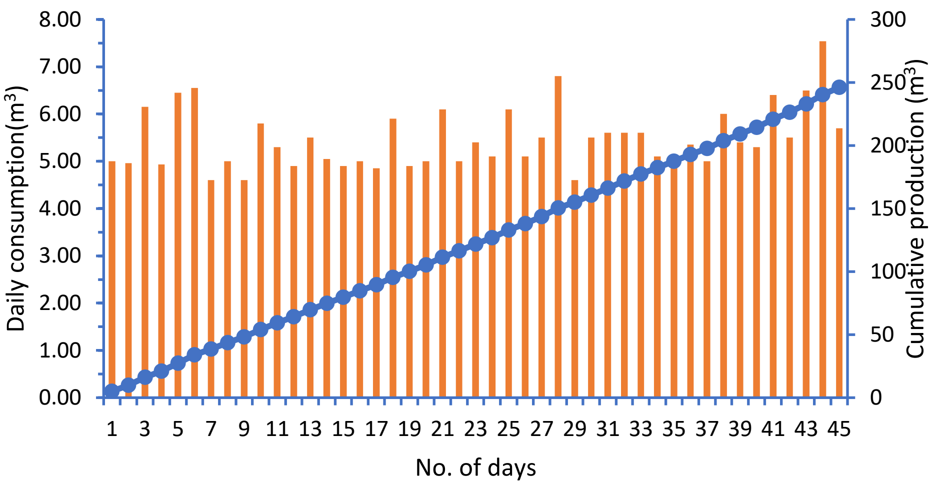

Figure 4.3: Cumulative Gas Output with daily gas consumption in m^3

The gas output per day has been 5.425 m^3 on average. The data is taken regularly for 45 days of time interval. The cumulative gas output curve relation is almost linear with time. The cumulative gas output is about 246.13 m^3. Production of gas varies from 0.29 m^3 to 8.2 m^3 i.e., 290 liters to 8200 liters per day.

4.5 Biogas Composition

Biogas consists of various other gases along with methane. With the help of Gasboard-3200 plus portable biogas analyzer, percentage of methane content is 46.5%, percentage of CO_2 is 20.62% and the concentration of the H_2S is 9999 ppm which is good range.

Concentration of the H_2 and CO was 0 ppm. The above is data is present in the table given below.

Gas Component	Mean Concentration
Methane (CH_4)	46.5%
Carbon dioxide (CO_2)	20.62%
Carbon monoxide (CO)	0 ppm
Hydrogen Sulphide(H_2S)	9999 ppm

4.6 Biogas pressure

The pressure of the biogas is measured by Biogas Pressure Gauge Manometer having diameter 59 mm and thickness 37.6 mm and also the range is 0-16 kPa. Every day at morning the biogas gauge shows a maximum pressure of 9.5 kPa but after the use for 1-2 hours, the pressure gets reduced to 5-7 kPa. The data is taken for 45 days in weekly interval The biogas stoves operator is advised to use the stove only when the pressure is equal or above to 5 kPa. The image of the instrument is attached in appendices A.

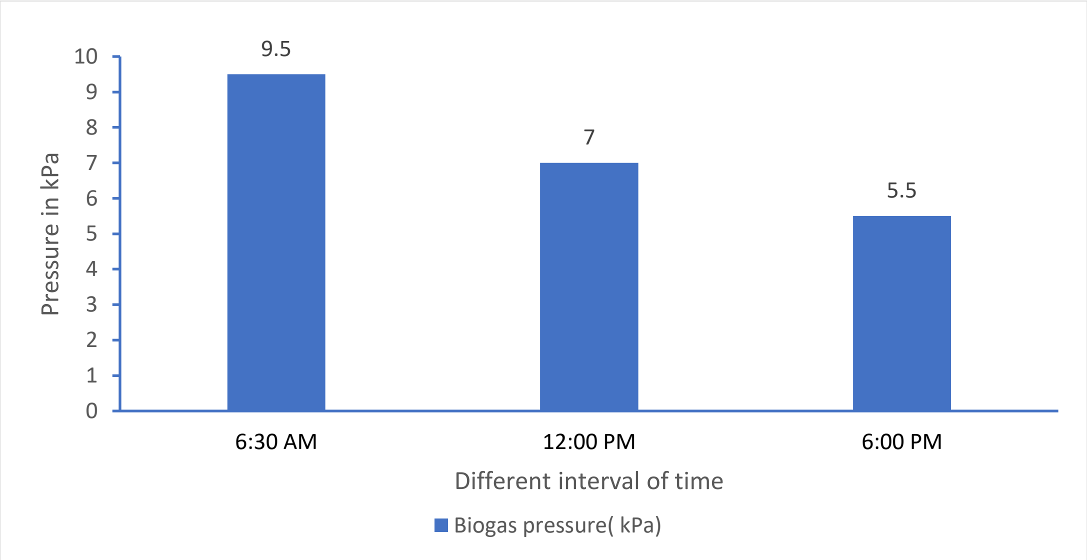

Figure 4.4: Biogas pressure at different time

4.7 Biogas Production

In the modified GGC-2047 model, the gas output is about 4.1m^3 per day. The maximum average temperature of the plant was about 27.34°C. While in case of the TED model the average feeding of feedstock is nearly 84 kg and gas output per day is 5.425 m^3 per day and at maximum average temperature is 27.71°C. Feeding includes the kitchen

Waste, HW, and CM. The average production of biogas per day in TED model and modified GGC-2047 model at Nepal Sainik War College is shown in below figure 4.6.

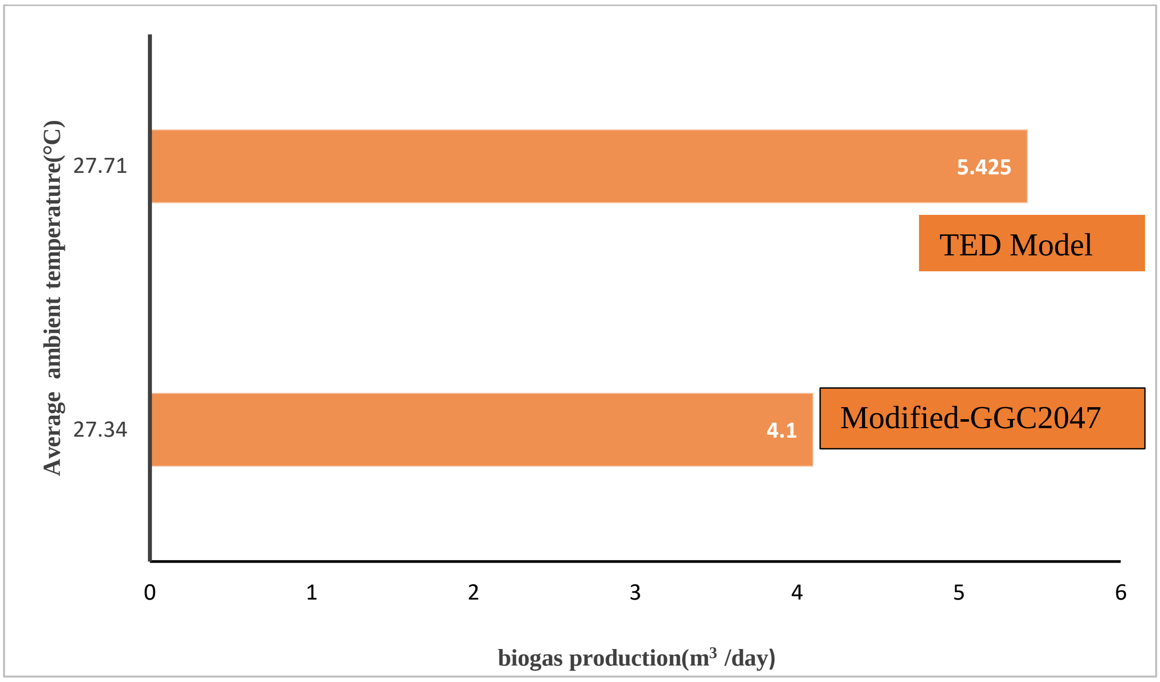

Figure 4.5: Comparison of biogas production from TED model and modified GGC-2047 model

4.8 CO_2 Reduction in emission from the biogas plant

The reduction of CO_2 annually from the installation of the biogas plant is shown in the table 4.2. As the plant is of institutional type, so there are some annual public holidays is deducted from the total operating of the plant. So, as the school is of hostel type only long holidays are counted as holidays and is deducted. So. Nearly 50 public holidays are considered for reduction.

Table 4.2: Reduction in CO_2 emission from the biogas plant

Total waste fed per day	84	kg
Conversion factor	2.20	kg of CO_2 equivalent
Total CO_2 equivalent	0.0381	Tonnes of CO_2 equivalent
Total CO_2 equivalent/ per annum	12.027	Tonnes of CO_2 equivalent

(Dhakal et al., 2015)

4.9 Reduction in TS & VS

TS and VS are the significant and important parameters in biogas production and also help to assess the potential energy content and efficiency of the biogas production process. In order to get maximum biogas production, the value of TS must be around 10% which is the optimum value required. (Orhorhoro et al., 2017)

The report of sample taken to lab for testing is attached in APPENDICES C. The data obtained from the report is as follows:

Table 4.3: Obtained data from lab report of the sample

Parameter	Inlet feedstock(mg/g)	Outlet slurry(mg/g)
Total solids (TS)	14.58	8.13
Volatile solids (VS)	78.59	48.95

Average feeding of feedstock: 84 kg

Average daily gas production: 5.425 m^3= 5425 liters

Table 4.4: Percentage change in TS & VS

Parameter	Inlet feedstock (%)	Outlet slurry (%)	Difference	Change (%)
Total solids (TS)	14.58	8.13	6.45	44.24
Volatile solids (VS)	78.59	48.95	29.64	37.71

m^3 of biogas/kg of TS = 1.01 m^3 of biogas/ kg of TS

m^3 of biogas/kg of VS = 0.22 m^3 of biogas/ kg of VS

The methane production is nearly 46.5% on average of the biogas produced so the methane produced during reduction of TS & VS is 0.469 m^3 of CH_4 /kg of TS and 0.102 m^3 of CH_4/kg of VS respectively. The degradation rate of the total solid contents is 86.8% and the volatile solid contents is nearly 35.46% which is found to be good a biogas plant. The biogas produced during the TS and VS reduction is 1.01 m^3 of biogas/ kg of TS and 0.22 m^3 of biogas/ kg of VS respectively. the output of the organic mixture of kitchen Waste & black water gives a maximum of 0.520 m^3 of CH_4/ kg of VS also the output of the FVW & FW is 0.30 & 0.56 m^3 of CH_4/ kg of VS respectively. the potential of methane in the FW falls in the range of 0.3-1.1 m^3 of biogas/ kg of VS, which is generally higher than other AD substrates like CM, HW and lignocellulosic biomass.(Gautam & Jha, 2020)

4.10 Reduction in NPK

The output from the biogas system is methane as biogas and fertilizer, both are useful in daily life and also good in context of the environment as the plant helps to minimize the odor and bad smell of the degraded material and also has very low toxicity. The fertilizers produced in this way has high value of nutrients and which helps in vegetation and plantation. The digested slurry has also low quantity of metals and compared to the synthetic and industrial fertilizers. Digested slurry when mixed with synthetic fertilizers, it helps to increase the nutrient needed for the plants to grow.

During AD process, there is formation of nitrogen, phosphorus and potassium. The amount of the nitrogen gets converted in the ammonium, which is readily available for the plant growth. Some phosphorus also gets converted to phosphorus which are in a soluble form. The digested slurry has N, K_2O_5 and P_2O_5 are 3.1, 1.7, and 3.2% respectively (Gautam & Jha, 2020).

Table 4.5: Amount of fertilizer in the feed & slurry

Parameters	Inlet (%)	Outlet (%)
Nitrogen(N)	0.37	0.17
Phosphorus(P_2O_5)	1.54	0.68
Potassium(K_2O_5)	0.25	0.03

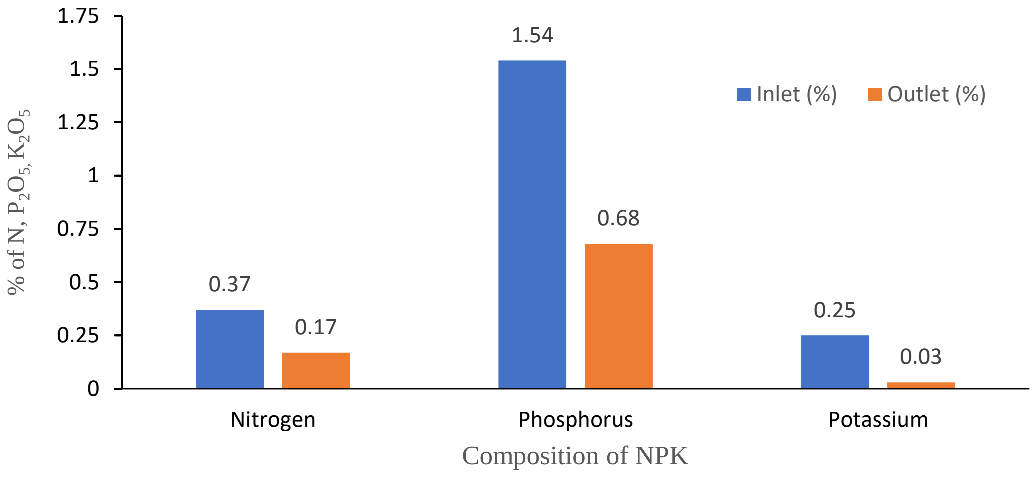

Figure 4.6: Composition of NPK in feedstock and slurry

For Modified GGC-2047 model, the digested slurry has average concentration of Nitrogen (N) 1.6%, Potassium (K_2O_5) 1.55% and Phosphorous (P_2O_5) 1% (Nakarmi et al., 2015).

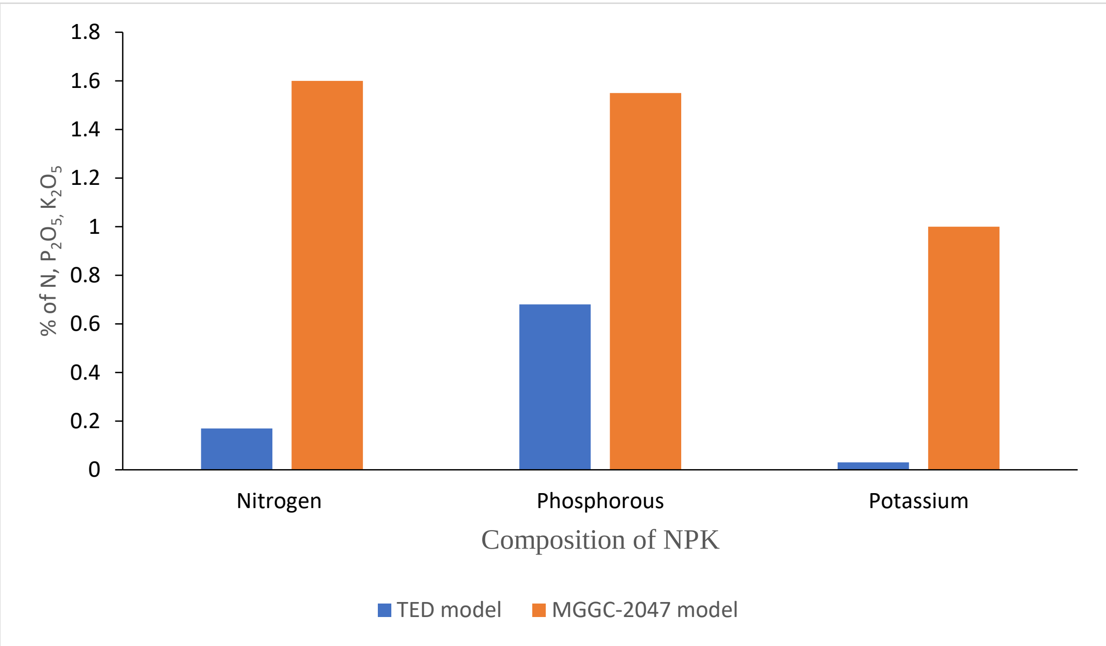

Figure 4.7: NPK Comparison for TED model and MGGC-2047 Model

The concentration of Nitrogen and potassium is very low as compared to modified GGC model. The low percentage is due to the non-favorable conditions of slurry handling techniques or very much negligence. Frequently, the entirety of the nitrogen produced is lost because the ammonia nitrogen, highly soluble in slurry, tends to volatilize. In the same manner other nutrients also get lost when the digested or outlet slurry is exposed to open environment or to the sun for long time.

4.11 Combustion of biogas

The average biogas production or consumption from the biogas plant is 5.425 m^3. The methane content is nearly 46.5% in the produced biogas. The stove used is of sized 0.25 m^3. So, the consumption of the bigas per hour was also approx. 0.25 m^3/h. The recording time for this amount of volume considering the methane content was 9-11 hours per day.

4.12 Financial Analysis

Financial analysis of the TED model is done by evaluating the payback period, internal rate of returns (IRR) and net present value (NPV). The calculation is shown in the table 4.6 and the financial analysis of modified GGC-2047 model is shown in the table 4.7.

4.12.1 TED model (20m^3)

- **Without subsidy**

Table 4.6: Financial analysis of TED model

Total cost	Rs. 1,893,927	
Annual O & M cost	Rs. 12000	
Cost per cylinder	Rs.1900	
1 m^3 of biogas	0.234	m^3 of LPG
Mass of LPG	14.2	kg/ cylinder
Volume of liquid LPG	28	L/cylinder
Volume of gas LPG	7.52	m^3 /cylinder (1 L of liquid LPG= 270.00 L of LPG gas)
Total biogas produced	163.6	m^3 /month
Total biogas-LPG eq produced	38.29	m^3 biogas-LPG eq/month
Total cylinder saved	5.09	
Annual revenue from gas production (baseline on LPG)	Rs. 116,105	
Annual revenue from waste management & safety tank saving	Rs.25,000	
Net cash flow per year	Rs.129,105	
Simple payback period	14.66	years
NPV	Rs. -1,063,293	@15%
IRR	4%	

- **With subsidy**

Government of Nepal provides provide subsidy only to that biogas plant which are designed and constructed on the basis of Modified GGC-2047 model in our country. And the subsidy is provided for the both thermal application and electricity generation. The subsidy amount is given on the basis of thermal application per CuM of biogas produced per day at Normal Temperature and Pressure and also an additional subsidy for electricity generation per kW (baseload for 24hours).

If the plants based on TED model also get the subsidy likewise modified GGC-2047 model then the simple payback period will be around 11.8 years with NPV Rs. –877,077 and IRR is 6%.

As per a latest research from González-Arias et al., 2021 has found that 50% of investment for small biogas plants must be subsidized in order to obtain profitability(González-Arias et al., 2021). So, in order to obtain profitability, the plants must get subsidized.

4.12.2 Modified GGC-2047 model (20m^3)

Table 4.7: Financial analysis of Modified GGC-2047 model

Total investment	Rs. 681,919
Subsidy amount	Rs.240,000
Total Cost	Rs.441,919
Annual O & M	Rs.12,000
Gas production m^3 /month	123
Total biogas-LPG eq produced m^3 biogas-LPG eq/month	28.782
Total LPG produced cylinder/month	3.83
Annual revenue from gas production (baseline on LPG)	Rs. 82,697
Net cash Flow per year	Rs.70,698
Simple payback period	5.86 years
NPV @15%	Rs. 44,780
IRR	17%

(Source: AEPC)

As we can see from the table 4.6 and table 4.7, we have found that the payback period of the TED model is 14.6 years whereas GGC model is of 5.86 years. As GGC have been constructed with the assistance of subsidy, if the TED model is also provided with subsidy, then the payback period will be reduced to 11.8 years.

4.13 Sensitivity Analysis

The input feedstock is of different types i.e., cow manure, kitchen waste and night soil. All are fed in different concentration. Cow manure, kitchen waste and night soil fed are 12%, 27% and 62% respectively.

Table 4.8: Amount of daily input feedstock

Feedstock	Amount	unit
Cow Manure	10	kg/day
Kitchen Waste	22	kg/day
Night soil	0.4	kg/day/person
Total night soil of 130 people	52	kg/day

Biogas produced from cow manure, kitchen waste and night soil are 0.04 m^3/kg, 0.041 m^3/kg, 0.07 m^3/kg.

Table 4.9: Gas production from each feedstock

Types of feedstocks	Biogas produced	unit
Cow Manure	0.4	m^3/day
Kitchen Waste	0.91	m^3/day
Night soil	3.6	m^3/day
Total	4.95 ~ 5	m^3/day

The sensitivity analysis of the feedstock input and biogas production is shown in Table 4.7.

Table 4.10: Sensitivity analysis of biogas production with daily amount of input feedstock

Mass of feedstock (kg)	Biogas produced per day (m^3 /day)
84	5
95	5.56
105	6.15
115	6.73
120	7.03

Assuming the kitchen waste and night soil as constant as there is less change in their quantity due to the number of students is almost fixed. So, by increasing the feed of cow manure, change in biogas production is shown with help of sensitivity analysis.

Table 4.11: Sensitivity analysis of biogas production when cow dung is increased

Mass of cow dung	Biogas produced per day	Total feedstock	Biogas produced per day (m^3/day)
10	0.4	84	5
20	0.8	95	5.8
30	1.2	105	6.2
40	1.6	115	6.6
50	2	125	7

4.14 Modification

4.14.1 Temperature Increment

Temperature plays a vital role in biogas production. The biogas production increases with the increase in temperature at an optimum level of 40°C. The favorable temperature for biogas production is 35-37°C. In order to maintain that level of temperature at all the time a solar water heater system can be adopted to do so with the help of a heat exchanger. A temperature sensor is also mounted in the solar water heater so that excess heated water can't be supplied in the system. The heat exchanger material is of copper due to its better thermal conductive and other thermal properties.

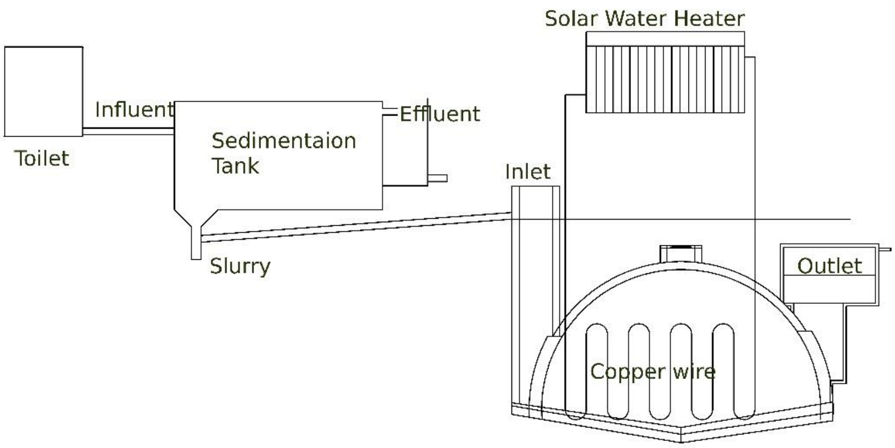

Figure 4.8: Modification in plant

The temperature is to increase from 27 to 40°C. So, theoretical heat requirement

Total heat requirement = $Q_R + Q_L$

Where, Q_R = Rate of Heat transfer to raw material.

Q_L = Heat loss through the surface of digester of walls.

$$Q_R = M_T \times C \times (T_D - T_S)$$

Where,

M_T = Total mass of raw material in the biodigester

C = Specific heat

T_D = Desired temperature = 40°C

T_S = Average slurry temperature = 27°C

Specific heat of water, C_1 = 4.186 kJ/kg °C

Specific heat of cow dung, C_2 = 2.799 kJ/kg °C

Specific heat of night is considered same as that of water.

Average specific heat capacity, $C = \frac{C_1 + C_2}{2} = 3.493$ kJ/kg °C

Mass of influent = 272 kg (84 kg raw material and 188 L of water)

$$Q_R = M_T \times C \times (T_D - T_S)$$

$$= 272 \times 3.493 \times 13$$

$$= 12349.8 \text{ kJ}$$

Rate of heat loss = 12349.8 kW

There is also heat loss from the digester walls. So, the parameters for heat loss

Heat loss from dome,

$$E_1 = \frac{k}{x} \times A \times (T_D - T_S)$$

$$= \frac{0.585}{0.150} \times 39.26 \times 13$$

$$= 1990.5\ W$$

where,

Concrete wall, k =0.585 W/mK, x =0.150 m

Heat loss from the digester walls,

$$E_2 = \frac{k}{x} \times A \times (T_D - T_S)$$

$$= \frac{0.5}{0.220} \times 39.26 \times 13$$

$$= 1160\ W$$

where, Brick wall, k = 0.5 W/m K, x = 0.220 m

Heat loss from bottom of the digester,

$$E_2 = \frac{A \times (T_D - T_S)}{\frac{x_1}{k_1} + \frac{x_2}{k_2}}$$

$$= 21.38 \times \frac{13}{0.581}$$

$$= 476\ W$$

where,

concrete wall, thickness x_1 =0.12 m & thermal conductivity (k) =0.585 W/mK)

gravel thickness, x_2 =0.15 m & thermal conductivity (k_2 = 0.4 W/mK) (Dalla Santa et al., 2017)

Total heat loss = E_1 + E_2+ E_3 = 3626.5 W = 3626.03 joule = 3.621 kJ

Total heat required = $Q_R + Q_L$ = 12349.8 + 3.621 kJ= 12.35 MJ

So, this amount of heat is needed from the solar water heater to provide the desire slurry temperature. And the increase in temperature up to this temperature helps the gas production rate.

4.14.2 Dilution maintains

The plant is getting too much of toilet water in the biodigester which results in higher dilution of feedstock. Due to the high feed dilution, there is less production of biogas in the digester. So, in order to supply only required amount of water to the digester a sedimentation tank is added between the inlet of plant and the toilet. In the sedimentation tank, the human waste sludge sits on the base of the tank which is connected to inlet of plant and the waste water is collected into a separate tank where water level indicator is mounted and as per the need water is supplied to biodigester and rest of the waste water is directly connected to ABR along with outlet slurry of the digester where both the human water and slurry gets treated.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Following conclusions have been drawn based on the study

- The percentage of methane content is 46.5%, percentage of CO_2 is 20.62% and the concentration of the H_2S is 9999 ppm which is good range. Concentration of the H_2 and CO was 0 ppm. TS of the inlet feedstock and outlet slurry were 14.58% and 8.13%. It is found that there is good reduction rate in TS with 44.24 %. Also, the VS inlet feedstock and outlet slurry were 78.59 % and 48.95%. The degradation rate in VS was 37.71 %. From the plant it is also found out that 1.01 m^3 of biogas/ kg of TS and 0.22 m^3 of biogas/ kg of VS respectively was produced. And 0.469 m^3 of CH_4 /kg of TS and 0.102 m^3 of CH_4/kg of VS respectively methane was produced. The NPK of inlet feedstock were 0.37%, 1.54%, 0.25% and outlet slurry were 0.17%, 0.68%, 0.03% respectively.
- The average gas production per day was 5.425 m^3 i.e., 5425 liters. The cumulative gas consumption/production was 246.13 m^3. So, per hour biogas production from TED model was 226.04 liter at maximum average temperature of 27.11°C whereas from modified GGC-2047 plant was 4.1m^3 per day at maximum average temperature of 27.34°C
- Financial analysis has shown that due to large investment of the plant in compare with standard model the payback period is high and NPV is also in negative even if it gets subsidy only a little improvement is found the payback period and NPV.

5.2 Recommendations

Based on the study carried out, following recommendations was carried out

- In order to get more accurate and precise data, the study should be done for more than one year which helps to get the data of both summer and winter seasons.
- Sample testing needs to tested more times to get the concurrent and exact results.
- Change in temperature and pH value of the mixture should be measured daily by providing appropriate lab facilities

- Other analysis like microbial analysis during the digestion period and nutrient level analysis should be carried out.
- Modified GGC-2047 Model is still suitable than TED Model due to higher rate of return, greater net present value, lesser payback period and also due to availability of subsidy.

REFERENCES

Afotey, B., & Sarpong, G. T. (2023). Estimation of biogas production potential and greenhouse gas emissions reduction for sustainable energy management using intelligent computing technique. *Measurement: Sensors*, *25*, 100650. https://doi.org/10.1016/j.measen.2022.100650

Agyeman, F. O., & Tao, W. (2014). Anaerobic co-digestion of food waste and dairy manure: Effects of food waste particle size and organic loading rate. *Journal of Environmental Management*, *133*, 268–274. https://doi.org/10.1016/j.jenvman.2013.12.016

Christensson, K., Björnsson, L., Dahlgren, S., Eriksson, P., Lantz, M., Lindström, J., & Mickelåker, M. (2010). *Gårdsbiogashandbok*. Svenskt Gastekniskt Center AB.

Dalla Santa, G., Peron, F., Galgaro, A., Cultrera, M., Bertermann, D., Müller, J., & Bernardi, A. (2017). Laboratory Measurements of Gravel Thermal Conductivity: An Update Methodological Approach. *Energy Procedia*, *125*, 671–677. https://doi.org/10.1016/j.egypro.2017.08.287

Dhakal, N., Karki, A. K., & Nakarmi, M. (2015). Waste to Energy: Management of Biodegradable Healthcare Waste through Anaerobic Digestion. *Nepal Journal of Science and Technology*, *16*(1), Article 1. https://doi.org/10.3126/njst.v16i1.14356

Dhungana, B., & Lohani, S. (2020). Anaerobic digestion of food waste at varying operating conditions. *Detritus*, 99–105. https://doi.org/10.31025/2611-4135/2020.14026

Gautam, B., & Jha, A. K. (2020). *Performance Analysis of Homebiogas and Comparison with Modified GGC-2047 Model Biogas Plant*. https://www.researchgate.net/publication/344557711_Performance_Analysis_of_Homebiogas_and_Comparison_with_Modified_GGC-2047_Model_Biogas_Plant

González-Arias, J., Baena-Moreno, F. M., Gonzalez-Castaño, M., Arellano-García, H., Lichtfouse, E., & Zhang, Z. (2021). Unprofitability of small biogas plants without subsidies in the Brandenburg region. *Environmental Chemistry Letters*, *19*(2), 1823–1829. https://doi.org/10.1007/s10311-020-01175-7

Gupta, D. R. (1991). Bio-fertilizer from biogas plants. *Changing Villages*, *10*(1), 25–26.

Iqbal, S. A., Rahaman, S., Rahman, M., & Yousuf, A. (2014). Anaerobic digestion of kitchen waste to produce biogas. *Procedia Engineering*, *90*, 657–662. https://doi.org/10.1016/j.proeng.2014.11.787

Jeppu, G. P., Janardhan, J., Kaup, S., Janardhanan, A., Mohammed, S., & Acharya, S. (2022). Effect of feed slurry dilution and total solids on specific biogas production by anaerobic digestion in batch and semi-batch reactors. *Journal of Material Cycles and Waste Management*, *24*(1), 97–110. https://doi.org/10.1007/s10163-021-01298-1

Jørgensen, P. J. (2009). Biogas-green energy. *Faculty of Agricultural Sciences, Aarhus University*.

Kanwar, S. S., & Guleri, R. L. (1994). Performance evaluation of a family-size, rubber-balloon biogas plant under hilly conditions. *Bioresource Technology*, *50*(2), 119–121. https://doi.org/10.1016/0960-8524(94)90063-9

Kumar, A., & Samadder, S. R. (2020). Performance evaluation of anaerobic digestion technology for energy recovery from organic fraction of municipal solid waste: A review. *Energy*, *197*, 117253. https://doi.org/10.1016/j.energy.2020.117253

Li, Y., Park, S. Y., & Zhu, J. (2011). Solid-state anaerobic digestion for methane production from organic waste. *Renewable and Sustainable Energy Reviews*, *15*(1), 821–826. https://doi.org/10.1016/j.rser.2010.07.042

Lohani, S. P., Dhungana, B., Horn, H., & Khatiwada, D. (2021). Small-scale biogas technology and clean cooking fuel: Assessing the potential and links with SDGs in low-income countries – A case study of Nepal. *Sustainable Energy Technologies and Assessments*, *46*, 101301. https://doi.org/10.1016/j.seta.2021.101301

Lohani, S. P., Pokhrel, D., Bhattarai, S., & Pokhrel, A. K. (2022). Technical assessment of installed domestic biogas plants in Kavre, Nepal. *Renewable Energy*, *181*, 1250–1257. https://doi.org/10.1016/j.renene.2021.09.092

Malav, L., Malav, M., Khan, S., & Kumar, S. (2015). Biogas Slurry: Source of Nutrients for Eco-friendly Agriculture. *International Journal of Extensive Research*, *2*, 42–46.

Nakarmi, A., Karki, A. B., Dhital, R. P., & Kumar, P. (2015). *Biogas as Renewable Source of Energy in Nepal. Theory and Development.* AEPC. https://www.researchgate.net/publication/303787356_Biogas_as_Renewable_Source_of_Energy_in_Nepal_Theory_and_Development

Orhorhoro, E., Ebunilo, P., Godwin, E., Sadjere, G., & Ejuvwedia, G. (2017). Experimental Determination of Effect of Total Solid (TS) and Volatile Solid (VS) on

Biogas Yield. *American Journal of Modern Energy*, *3*, 131–135. https://doi.org/10.11648/j.ajme.20170306.13

Pérez, I., Garfí, M., Cadena, E., & Ferrer, I. (2014). Technical, economic and environmental assessment of household biogas digesters for rural communities. *Renewable Energy*, *62*(C), 313–318.

Subedi, S. K. A. (2015). *Domestic biogas production and use in Nepal: A simple, reliable, clean and cost-effective solution to provide energy security to the rural households : a thesis presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy (PhD) in Energy Management at Massey University, Palmerston North, New Zealand* [Thesis, Massey University]. https://mro.massey.ac.nz/handle/10179/8274

US EPA, O. (2015, December 23). *Overview of Greenhouse Gases* [Overviews and Factsheets]. https://www.epa.gov/ghgemissions/overview-greenhouse-gases

World Energy Outlook 2023—Event. (n.d.). IEA. Retrieved August 7, 2023, from https://www.iea.org/events/world-energy-outlook-2023

APPENDICES A: EXPERIMENT SETUP

Biogas Pressure Gauge

TED model

Sample Preparation

Gas flowmeter

pH meter

Temperature Meter

APPENDICES B: CN RATIO FOR DIFFERENT MATERIAL

CN ratio for different material (Planet Natural Research Center, 2020)

S.N.	Particulars	CN Ratio
1.	Wood Chips	400:1
2	Saw Dust	325:1
3.	Newspaper, shredded	175:1
4.	Corn stalks	75:1
5.	Straw	75:1
6.	Leaves	60:1
7.	Fruit Waste	35:1
8.	Peanut shells	35:1
9.	Ashes, wood	25:1
10.	Garden waste	30:1
11.	Weeds	30:1
12.	Green woods	25:1
13.	Hay	25:1
14.	Vegetable Scrap	25:1
15.	Clover	23:1
16.	Food waste	20:1
17.	Grass clippings	20:1
18.	Seaweed	19:1
19.	Horse Manure	18:1
20.	Cow manure	16:1
21.	Chicken Manure	12:1
22.	Pigeon Manure	10:1
23.	Fish	7:1
24.	Urine	1:1

APPENDICES C: LAB REPORT

Nepal Environmental & Scientific Services (P.) Ltd.

G.P.O. Box 7301, Thapathali, Kathmandu, Nepal
Phone: +977-1-5344989, 5901101, Fax No.: +977-1-5326028.
Email: ness@mos.com.np, Website: www.nesspltd.com

Page 2 of 2

NESS/Lab, M-03/QSR2.3

Test Report / Certificate

NS Accreditation No. Pra. 01/053-54

Entry No. : NCL - 621 (Oth) (2) - 07 - 2023
Sample : Bio-slurry (Outlet Slurry)
Client : Bikesh Jaiswal
Sampled By : Client
Location : Mahalaxmi, Lalitpur

Date Received : 29 - 06- 2023
Issue Date : 12 - 07 - 2023
Sampling Date : 29 - 06- 2023
Test Initiation : 02 - 07 - 2023
Test Completed : 10 - 07- 2023

S. N.	Parameters	Test Methods	Observed values
1.	Total Solids, (%)	Method 1684, Total, fixed, and volatile solids in water, solids and biosolids, US-EPA, January 2001, Procedure no.11	1.91
2.	Volatile solids, (%)	Method 1684, Total, fixed, and volatile solids in water, solids and biosolids, US-EPA, January 2001, Procedure no.11	50.72
3.	Total Kjeldahl Nitrogen, (%)	Modified Kzeldahl, FAO, Fertilizer & Plant Nutrition Bulletin No. 19	0.17
4.	Phosphorus as P_2O_5, (%)	Vanadomolybdophosphoric acid, FAO, Fertilizer & Plant Nutrition Bulletin No. 19	0.68
5.	Total Potassium as K_2O, (%)	Flame Absorption, AAS, FAO, Fertilizer & Plant Nutrition Bulletin No. 19	0.03

Note: The value was reported in received basis sample. The gravimetric analysis was carried out in controlled temperature (20°C) condition.
AAS: Atomic Absorption Spectrophotometer: IS: Indian Standard; USEPA: United States Environmental Protection Agency.

(Analyzed By) (Checked By) (Authorized Signature)

Note:
1. This report/certificate is in reference to Laboratory Quality System Manual, QSM (2023).
2. The result listed refer only to the tested samples & applicable parameters. Endorsement of products is neither inferred nor implied.
3. Liability of our institute is limited to the invoiced test parameters & amount only.
4. Samples will be destroyed after one month from the date of issue of test certificate unless otherwise specified.
5. This report should not be reproduced wholly / partially for any advertising media without our permission.
6. The clients are requested to take back their hazardous samples along with the report/certificate.

Nepal Environmental & Scientific Services (P.) Ltd.

G.P.O. Box 7301, Thapathali, Kathmandu, Nepal
Phone: +977-1-5344989, 5901101, Website: www.nesspl.com.np
Email: info@nesspl.com.np / nesspltd@gmail.com, Page 1 of 1

NESS/Lab. M-03/QSR2.3

Test Report / Certificate

NS Accreditation No. Pra. 01/053-54

Entry No. : NCL - 109 (Oth) (1) - 09 - 2023
Date Received : 17 - 09 - 2023
Sample : Bio-slurry (Outlet Slurry)
Issue Date : 20 - 09 - 2023
Client : Bikesh Jaiswal
Sampling Date : 17 - 09 - 2023
Sampled By : Client
Test Initiation : 17 - 09 -2023
Location : Mahalaxmi, Lalitpur
Test Completed : 19 - 09- 2023

S.N.	Parameters	Test Methods	Observed values
1.	Total Solids, (%)	Method 1684, Total, fixed, and volatile solids in water, solids and biosolids, US-EPA, January 2001, Procedure no.11	8.13
2.	Volatile solids, (%)	Method 1684, Total, fixed, and volatile solids in water, solids and biosolids, US-EPA, January 2001, procedure no.11	48.98

Note: *Total solids was reported in received basis sample. The gravimetric analysis was carried out in controlled temperature (20°C) condition. The duplicate analysis was performed for both total solids and volatile solids and the average value was reported.*
USEPA: United States Environmental Protection Agency.

(Analyzed By) (Checked By) (Authorized Signature)

Note:
1. This report/certificate is in reference to Laboratory Quality System Manual, QSM (2023).
2. The result listed refer only to the tested samples & applicable parameters. Endorsement of products is neither inferred nor implied.
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NESS
Nepal Environmental & Scientific Services (P.) Ltd.
G.P.O. Box 7301, Thapathali, Kathmandu, Nepal
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Email: ness@mos.com.np, Website: www.nesspltd.com

NESS/Lab, M-03/QSR2.3

Test Report / Certificate

NS Accreditation No. Pra. 01/053-54

Entry No. : NCL - 621 (Oth) (2) - 07 - 2023
Sample : Bio-slurry (Inlet Feed)
Client : Bikesh Jaiswal
Sampled By : Client
Location : Mahalaxmi, Lalitpur

Date Received : 29 - 06- 2023
Issue Date : 12 - 07 - 2023
Sampling Date : 29 - 06- 2023
Test Initiation : 02 - 07 -2023
Test Completed : 10 - 07- 2023

S.N.	Parameters	Test Methods	Observed values
1.	Total Solids, (%)	Method 1684, Total, fixed, and volatile solids in water, solids and biosolids, US-EPA, January 2001, Procedure no.11	14.58
2.	Volatile solids, (%)	Method 1684, Total, fixed, and volatile solids in water, solids and biosolids, US-EPA, January 2001, procedure no.11	78.59
3.	Total Kjeldahl Nitrogen, (%)	Modified Kzeldahl, FAO, Fertilizer & Plant Nutrition Bulletin No. 19	0.37
4.	Phosphorus as P_2O_5, (%)	Vanadomolybdophosphoric acid, FAO, Fertilizer & Plant Nutrition Bulletin No. 19	1.54
5.	Total Potassium as K_2O, (%)	Flame Absorption, AAS, FAO, Fertilizer & Plant Nutrition Bulletin No. 19	0.25

Note: The value was reported in received basis sample. The gravimetric analysis was carried out in controlled temperature (20°C) condition.
AAS: Atomic Absorption Spectrophotometer: IS: Indian Standard; USEPA: United States Environmental Protection Agency.

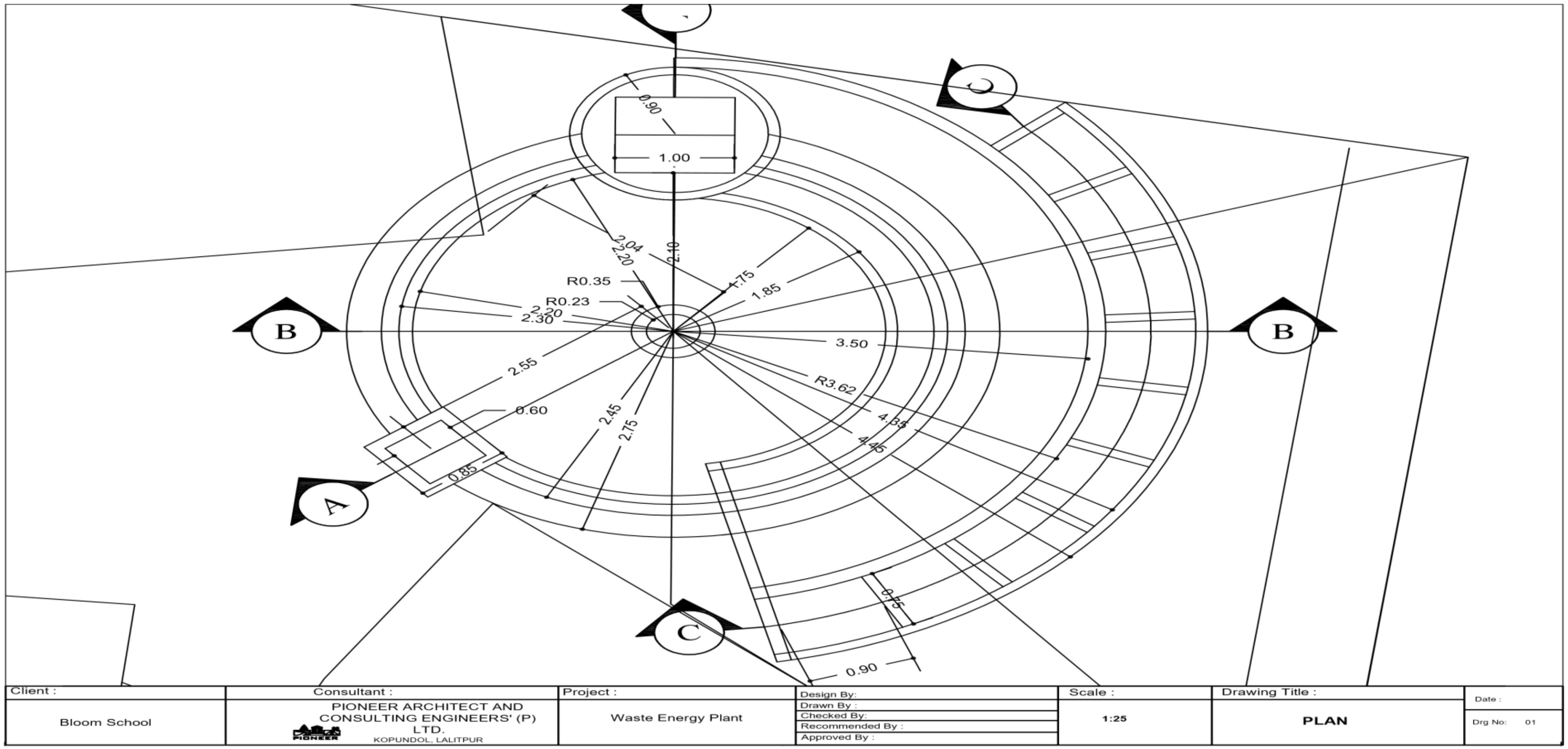
(Analyzed By) (Checked By) (Authorized Signature)

APPENDICES D: DATA SHEET

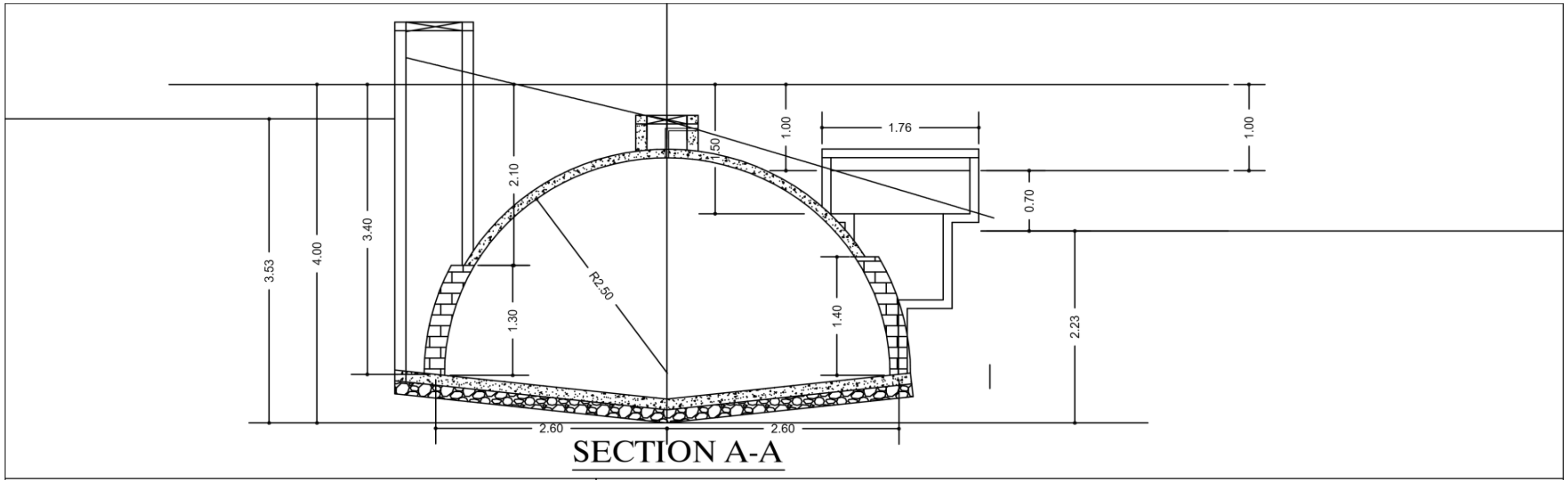
S.N	Date	KW&CM	HM waste	Total feed	Gas Flow meter(m3)	Daily Consumption (m^3)	Cumulative consumption/production	Ambient temperature (Tmax),
1	6/23/2022	56	60	116	499.2	5.00	5.00	27
2	6/24/2022	37	60	97	504.16	4.96	9.96	28
3	6/25/2022	18	60	78	510.31	3.45	16.11	28
4	6/26/2022	15	60	75	515.24	4.93	21.04	30
5	6/27/2022	14	60	74	521.69	6.45	27.49	27
6	6/28/2022	24	60	84	528.24	6.55	34.04	28
7	6/29/2022	25	60	85	532.84	4.60	38.64	25
8	6/30/2022	18	60	78	537.84	5.00	43.64	26
9	7/1/2022	15	60	75	542.44	4.60	48.24	30
10	7/2/2022	26	60	86	548.24	5.80	54.04	30
11	7/3/2022	21	60	81	553.54	5.30	59.34	28
12	7/4/2022	17	60	77	558.44	4.90	64.24	26
13	7/5/2022	18	60	78	563.94	5.50	69.74	24
14	7/6/2022	18	60	78	568.99	5.05	74.79	29
15	7/7/2022	20	60	80	573.89	4.90	79.69	28
16	7/8/2022	19	60	79	578.89	5.00	84.69	28
17	7/9/2022	17	60	77	583.74	4.85	89.54	27
18	7/10/2022	27	60	87	589.64	5.90	95.44	28
19	7/11/2022	17	60	77	594.54	4.90	100.34	30
20	7/12/2022	19	60	79	599.54	5.00	105.34	31
21	7/13/2022	30	60	90	605.64	6.10	111.44	30
22	7/14/2022	11	60	71	610.64	5.00	116.44	27
23	7/15/2022	12	60	72	616.04	5.40	121.84	27
24	7/16/2022	11	60	71	621.14	5.10	126.94	27
25	7/17/2022	20	60	80	627.24	6.10	133.04	26
26	7/18/2022	22	60	82	632.34	5.10	138.14	25
27	7/19/2022	25	60	85	637.84	5.50	143.64	27
28	7/20/2022	30	60	90	644.64	6.80	150.44	30
29	7/21/2022	12	60	72	649.24	4.60	155.04	28
30	7/22/2022	20	60	80	654.74	5.50	160.54	28
31	7/23/2022	21	60	81	660.34	5.60	166.14	25
32	7/24/2022	24	60	84	665.94	5.60	171.74	28
33	7/25/2022	17	60	77	671.54	5.60	177.34	26
34	7/26/2022	13	60	73	676.64	5.10	182.44	27
35	7/27/2022	14	60	74	681.64	5.00	187.44	28
36	7/28/2022	18	60	78	686.99	5.35	192.79	28
37	7/29/2022	22	60	82	691.99	5.00	197.79	30
38	7/30/2022	23	60	83	697.99	6.00	203.79	28
39	7/31/2022	20	60	80	703.39	5.40	209.19	27
40	8/1/2022	17	60	77	708.69	5.30	214.49	28
41	8/2/2022	30	60	90	715.09	6.40	220.89	30
42	8/3/2022	20	60	80	720.59	5.50	226.39	27
43	8/4/2022	32	60	92	727.09	7.50	232.89	27
44	8/5/2022	39	60	99	734.63	7.54	240.43	28
45	8/6/2022	41	60	101	740.33	5.70	246.13	27
	AVERAGE	**21.88888889**	**60**	**81.88888889**		**5.47**		**27.71**

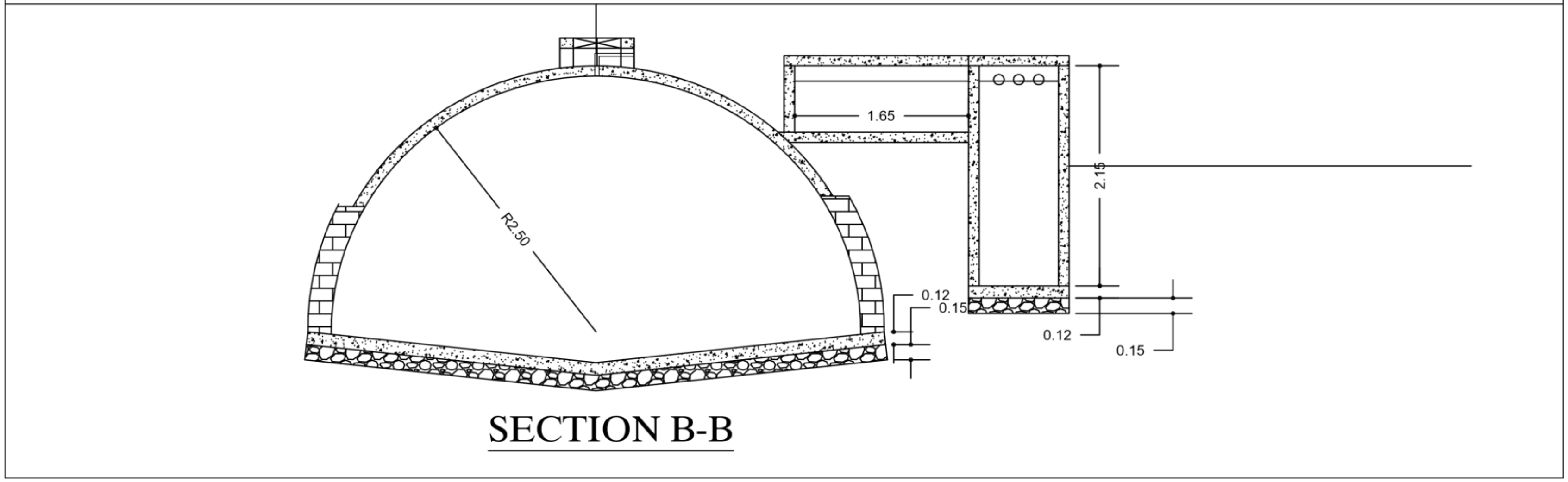
APPENDICES E: DRAWING OF TED MODEL PLANT

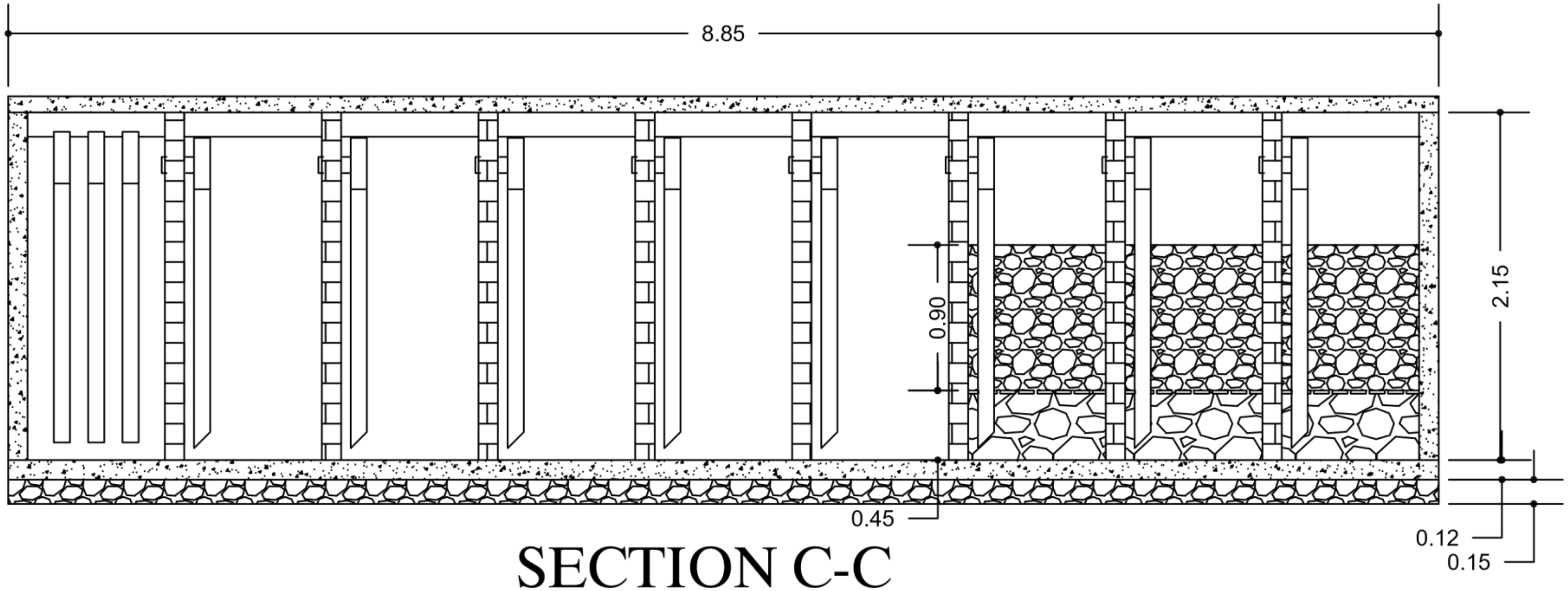
PLAN VIEW 1



Section View

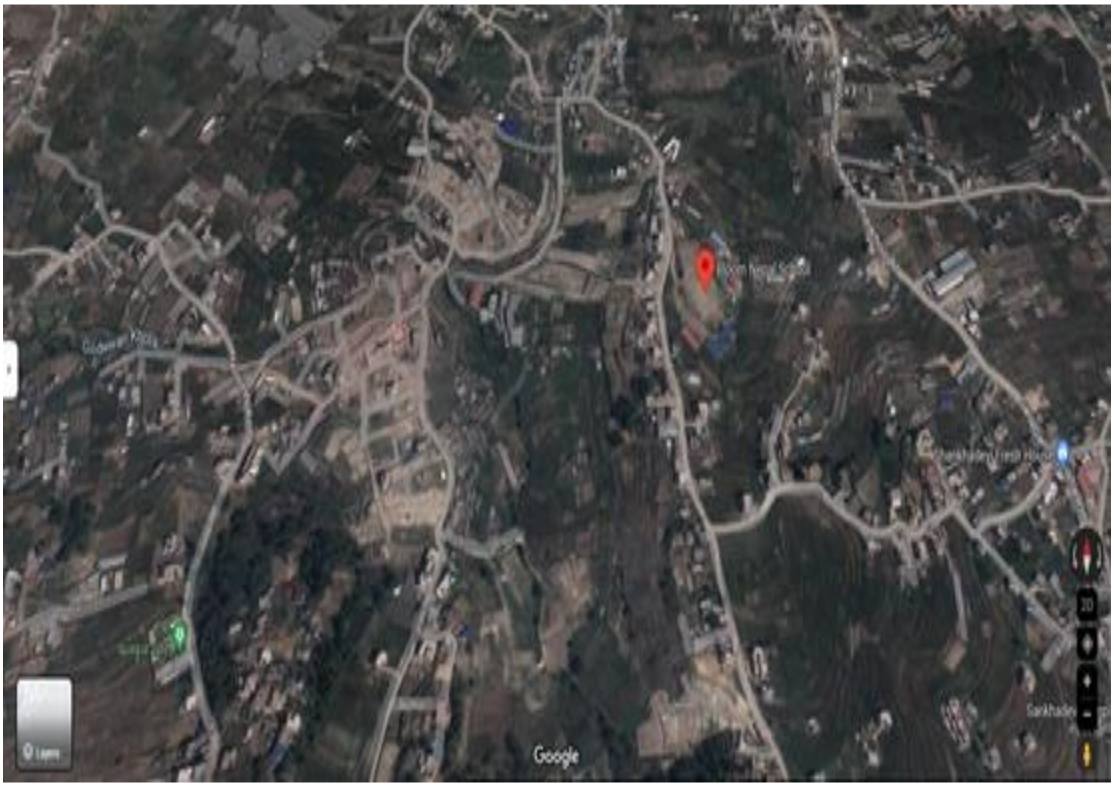






SECTION C-C

APPENDICES E: LOCATION OF THE PLANT



Performance Analysis of Technology for Economic Development (TED) Model Biogas Plant and Comparison with Modified GGC-2047 Model Biogas plant

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