BIOPTIMIZE: A CLOSED-LOOP BIODIGESTER SYSTEM THAT UTILIZES MACHINE LEARNING FOR PH LEVEL OPTIMIZATION TO INCREASE BIOGAS PRODUCTION, AND IOT APPLICATION FOR MONITORING SYSTEM

A Project Study Presented to the Faculty of

Electronics Engineering Department

College of Engineering

Technological University of the Philippines

In Partial Fulfillment of the Course Requirements for the Degree of

Bachelor of Science in Electronics Engineering

Submitted by:

Elvambuena, Angelli Kyll B.

Garcia, Sean Cristopher D.

Rosete, Jean Venice Mae B.

Soriano, Remuel A.

Tarasona, John Michael D.

Adviser:

Engr. Nilo M. Arago

August 2023

APPROVAL SHEET

This project study entitled "**BIOPTIMIZE: A CLOSED-LOOP BIODIGESTER SYSTEM THAT UTILIZES MACHINE LEARNING FOR PH LEVEL OPTIMIZATION TO INCREASE BIOGAS PRODUCTION, AND IOT APPLICATION FOR MONITORING SYSTEM"**, has been prepared and submitted by the following proponents:

Elvambuena, Angelli Kyll B.
Garcia, Sean Cristopher D.
Rosete, Jean Venice Mae B.
Soriano, Remuel A.
Tarasona, John Michael D.

In partial fulfillment of the requirements for the degree of **Bachelor of Science in Electronics Engineering** is hereby recommended for approval:

ENGR. NILO M. ARAGO
Project Adviser

ENGR. JAY FEL C. QUIJANO
Panel Chairman

ENGR. TIMOTHY M. AMADO
Panel Member

ENGR. VILLAMOR M. AMON
Panel Member

ENGR. EDMON O. FERNANDEZ
Panel Member

ENGR. EDMUND G. MONILAR
Panel Member

Accepted and approved in partial fulfillment of the requirements for the degree of **Bachelor of Science in Electronics Engineering.**

ENGR. TIMOTHY M. AMADO
Head, ECE Department

ENGR. NILO M. ARAGO
Dean, College of Engineering

ABSTRACT

Bioptimize: A Closed-Loop Biodigester System That Utilizes Machine Learning for pH Level Optimization to Increase Biogas Production, and IoT Application for Monitoring System

The Philippines is facing an energy crisis due to the expected depletion of energy sources by 2024. To address this problem, the energy sector is promoting the use of fossil fuels and renewable energy sources. Biogas technology, which utilizes organic waste to produce energy, is a sustainable and effective solution for both energy production and solid waste management. Bioptimize proposes a new approach to increase biogas production in small-scale biodigesters through the integration of machine learning and a control system. This system increases biogas production by correlating pH level with biogas production, enabling it to identify the optimal pH level that yields maximum biogas production at a given temperature value. It also uses sensors to record parameters such as temperature, pH, gas, and pressure, which are transmitted to a microprocessor that runs an optimization algorithm. The system then returns a specific pH value, and the electronic solenoid valve regulates the flow of pH accordingly. Experiments were conducted to assess the effectiveness of an approach in enhancing biogas production. The study compared two biodigester setups: one without pH control and mixing, and another with pH control and intermittent mixing. Results demonstrated that the biodigester with pH control and mixing yielded a maximum of 34,030 ppm of methane, while the biodigester without pH control and mixing produced a maximum of 12,142 ppm of methane. This indicates a significant increase in biogas yield when combining pH control and intermittent mixing. Therefore, incorporating a pH control system with intermittent mixing is considered a key parameter in biogas production, offering a clean and efficient alternative energy source for the future.

ACKNOWLEDGEMENT

The proponents would like to express their deepest gratitude to the following individuals and groups who have been instrumental in the successful completion of their research project:

Engr. Nilo M. Arago, for his invaluable guidance, unwavering support, and expert advice throughout the duration of this study. His extensive knowledge and dedication as the proponents' group adviser and project study professor have played a crucial role in shaping the direction of this research and ensuring its quality.

The proponents would also like to extend our heartfelt appreciation to the **Electronics Engineering Faculty** for their continuous encouragement and valuable inputs. Their expertise and enthusiasm have been pivotal in enriching the proponents' understanding of the subject matter and enhancing the overall quality of this work.

Furthermore, the proponents would like to acknowledge the very kind assistance and unwavering support extended by the Backyard pig farm owners, **Mrs. Riza Limbo Lubigan-Roxas** and **Mr. Nicolas Zafra Roxas,** together with their family. Their willingness to share their insights, experiences, and resources has been invaluable to this research.

Lastly, the proponents would like to express their sincere gratitude to all the individuals who supported us throughout this endeavor. Their encouragement, understanding, and patience have been a constant source of motivation for the proponents.

Without the invaluable contributions of these individuals and groups, this research would not have been possible. The proponents are deeply grateful for their contributions and extend their heartfelt appreciation to each and every one of them.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
THE PROBLEM AND ITS BACKGROUND

1.1 Introduction

The Philippines is experiencing a scarcity of electricity, which leads to a discrepancy in the electrification rate between cities and rural areas [1]. Electricity is currently in short supply in the Philippines. The Malampaya gas fields, which supply 30% of Luzon's energy consumption, are expected to be depleted by 2024, precipitating an energy crisis [2]. Energy sources have always been vital, as they power the majority of people's needs, especially today because it is one of the critical aspects of our continuously developing technology. Since there is a limitation in some of our primary energy sources, particularly the non-renewable ones, there is an undeniable rising need for an alternative power source.

Renewable energy, sometimes known as clean energy, is produced from naturally replenished sources or processes [3]. Clean and renewable energy sources like geothermal, hydro, wind, biomass and solar energy are among the Philippines' few competitive advantages – especially since it has no significant deposits of fossil fuels [4]. In the Philippines, these energy resources produced around 25% of the country's energy production in 2017. This yielded approximately 23.19 million megawatt-hours (MWh) in 2017, up 5.5% from the 21.98 million MWh consumed in 2016. Geothermal energy was the most commonly used renewable energy source (44.3%), subsequently hydropower (41.5%), solar (5.2%), wind (4.7%), and biomass (4.4%) [5]. There is a dire need for biomass as it can be an additional energy source that can minimize the scarcity of electricity in the Philippines, particularly in provincial areas.

Biogas technology is now being used in the Philippines; due to growing awareness of the polluting tendencies of animal manure and environmental concerns, it is slowly gaining support among the government and the general public, particularly in provincial areas [11].

Therefore, animal manure can be utilized as an input on a biodigester to produce electricity. Small-scale biodigesters have a lot of potential in backyard farms, which will account for 70% of the pig population from 2020 to 2022; this could be an additional energy source in provincial areas where energy is in short supply.

Animal manure may be used as a feedstock for biodigesters that can produce biogas [8]. The distribution of Swine inventory by farm type from 2020 to 2022 increased, and more than 70% of the swine inventory belongs to backyard farms [7]. The Philippines consists of large livestock production, and more than 42% of the total production volume (in metric tons) in the Philippines belonged to Pigs in 2020. Before that year, according to livestock and poultry statistics in the Philippines, their numbers are constantly high. It only shows that pig poultry is one of the dominant poultry industries in the Philippines [8]. Pig poultry farming is a field of livestock farming that involves the growing and rearing domestic pigs as livestock. Pigs are raised primarily for food and provide products such as pork, bacon, gammon, and skins. Pig production is also known as hog or swine production. For decades, pig farming has been a profitable business in the Philippines. Its significance can be seen in provincial backyards owing to the fact that proper feeding and disease management programs can be implemented with a small investment in structure and equipment. Considering pigs grow so promptly, the Philippines is known as the world's eighth-largest producer of pigs as livestock [9]. Biogas production from animal waste could be the key to unlocking the financial and environmental benefits of managing manure from livestock operations and organic waste from the food processing industry [8].

Anaerobic digestion to produce biogas from organic waste is a proven and environmentally sustainable approach for contemporaneous waste materials treatment and energy recovery, among the several method approaches that have been proposed [12]. Because it provides considerable environmental and economic advantages, Anaerobic Digestion (AD) from organic waste has gained interest over the years. It can minimize waste through recycling, saving resources, lessening greenhouse gas emissions, and increasing economic resilience in the face of an uncertain future for energy generation and garbage disposal. An effective and efficient anaerobic digestion process includes essential factors such as appropriate temperature, pH level, a solid inoculum for substrate ratio, and proper mixing [13].

Biogas is a naturally produced biofuel derived from the decomposition of organic matter [6]. It is produced in an enclosed chamber through microorganisms breaking down the biodegradable components of the manure in the absence of oxygen [7]. Biogas is a mixture of carbon dioxide (CO_2), methane (NH_4), and other nitrogen (N_2), as well as other trace gasses present in small amounts within the chamber's environment. Methane is perhaps the most common combustible gas contributing to more than 50-70% of the biogas. It performs identically to traditional fossil fuel natural gas, providing the same benefits and applications. And as one of the cleanest and most efficient alternative energy sources [10].

1.2 Background of the Study

In recent years, a sustainable alternative clean energy resource has gained prominence [14]. Many developed and developing nations and international organizations are interested in biogas systems as an alternative energy source that may also be used to manage livestock and agricultural waste [11].

A study that considered biogas production facilities' scope explained that micro-scale digesters are for emerging countries; small-scale digesters were used on farms and communities; large-scale digesters comprising centralized systems were located in regions and cities [18]. Three biodigesters were constructed for a study, each having a 50 50 cm^2 base area, a 60 cm depth, and a thermally insulated polystyrene-covered plywood interior chamber. This study constructed a biodigester tank for the breakdown of organic materials consisting of a cylindrical polyethylene drum with a capacity of 16 L in 2/3 of the drum space. Additionally, it was placed in an incubator box, maintained, and warmed by two 25-watt bulbs, each, at a thermophilic temperature of 50°C to 60°C. Using a TC-1000 thermistor, the facility in which the biodigester was housed was maintained at 60 °C, and the relative humidity varied from 44% to 60%. The three biodigesters also have a gas hose to regulate the methane concentration during the anaerobic digestion process. Therefore, the anaerobic biodigester function sufficiently for methane production in this study reached up to 36.7 % in 33 days of retention time at thermophilic temperatures between 50°C to 60°C [16].

Biogas technology through anaerobic digestion has been around for years and continues to progress. The study of healthy-smart concept biogas production, a household scale biogas digester, has various production parameters such as pH, temperature, alkalinity, volatile fatty acid (VFA) concentration, volatile solids, and C/N ratio, and they aimed to observe all of those. Digestion processes determine temperature control. This study used mesophilic procedures (30°C to 40°C). Therefore, thermophilic methods (50°C to 60°C) have grown considerably in recent years. According to this study, to produce optimal biogas with safe and efficient operation, software must monitor all parameters in real-time [15].

Remote monitoring and control of the biodigester become vital. In 2017, research presented an architecture for monitoring metrics such as pH, temperature, pressure, and the total amount of gas generated and consumed to determine the effectiveness of a biodigester. A GSM-based data transfer technology was utilized in this study to address the problem of data connectivity in rural areas. The device is tested using an Arduino microcontroller system to monitor gas production and consumption. In this study, they have an operator that can monitor the parameters using a portal that illustrates the usage statistics [17].

The three functions of the proposed biodigester structure for 2020 are model predictive control for anaerobic digestion processes, a parameter estimation system, and a feedstock determination controller. For the input-output relationship of producing biogas from organic compounds and the state of methane fermentation, a prediction model for anaerobic digestion processes was constructed in a state-space model—a system for parameter estimation in the prediction model using data from proper procedures. The adaptive classification approach was used to create the process data. Depending on the model predictive control, the feedstock-determination controller was constructed on biogas production management [19].

1.3 Research Gap

Based on recent studies, biogas is one of the responses of many advanced and developing countries to the need for sustainable alternative energy sources; the following studies demonstrate the current state of biogas technology development. It shows that there are attempts to create a closed-loop control system by controlling the temperature [16] since it also indicates that maintenance and monitoring of parameters are vital for biogas production, both small-scale and plants [15]. Another study implemented a control system that utilizes a predictive model to control the output for power plant-based biodigesters [19]. IoT-based monitoring is also being studied and developed for monitoring the parameters. The recent studies have similarities with this; however, the proponents will use machine learning applications to optimize the parameters and have the capability of self-learning in order to find an optimal value of parameters. This proposed study aims to introduce a new way to increase biogas production for small-scale biodigesters by integrating the machine learning application into the control system. With the Gradient Descent optimization algorithm, optimizing the pH level based on the changes of other parameters is possible.

1.4 Research Objectives

The main goal of the study is to develop a biodigester, equipped with a solar-powered closed-loop system that utilizes machine learning algorithm to increase biogas production by optimizing the pH level based on the detected temperature of the biomass (swine manure).

1. To design and construct a closed-loop biodigester system. The design comprises the biodigester's sensors (gas, pressure, temperature, pH), motor, solenoid valve, microcontrollers and storage for substances needed for pH control.
2. To identify the algorithm that will optimize pH level using different Machine Learning algorithms that will best fit the system.
3. To create a mobile application for monitoring system using IoT.
4. To test the device and evaluate the system using the ISO standards.

1.5 Significance of the Study

This study will primarily focus on developing a system that increases biogas production, which can be used for electricity or cooking—this can supply the energy demand for rural areas. Biodigester has a lot of potential in backyard farms; thus, it will be deployed in small-scale backyards, with farmers and pig farmers as the beneficiaries of this research. This aims to help the beneficiary save money as they don't have to buy LPG and will minimize their electricity bill. Because manure is the primary component of this study, it will aid farmers and piggery owners in manure management; pig manure will be recycled to produce biogas. In addition to producing fertilizer as a byproduct, this biodigester will benefit its users and help reduce chemical fertilizer use.

The study will contribute to the existing Biogas Technology but will focus on small-scale and backyard farms. Control systems for backyard biodigesters that use machine learning to optimize biogas production can introduce new ideas and potentially more innovative ways to use technology to provide renewable energy sources. Consequently, this study intends to benefit the following: Alternative Energy Research Trends (ALERT)

Program of the National Integrated Basic Research Agenda (2) Industry, Energy and Emerging Technology.

Moreover, the study also contributes to Sustainable Development Goals: (1) Affordable and Clean Energy. Rural areas are suffering as the Philippines faces energy issues such as a rapidly growing electricity demand and a frequently inadequate electricity supply. Increasing biogas production will benefit rural residents because it has the potential to serve as a source of affordable alternative energy; (2) Industries, Innovation, and Infrastructure. Small-scale biodigesters can help energy gain to move a step from absolute energy poverty in rural areas with places with higher energy deficit; (3) Sustainable Cities and communities. Biogas has the potential to increase renewable energy, prevent tons of carbon emissions from entering our air, improve waste management, and produce a reliable agricultural byproduct.

1.6 Scope and Limitations

The fundamental purpose of this project is to develop a system that will increase the production of biogas on a modest scale and act as a source of alternative energy using a closed loop control system that optimizes the pH level based on the recorded temperature. The study will include a storage for the produced biogas as well as a mobile IoT application for monitoring. However, the production of fertilizer is not the focus of this study since it is just a byproduct of the system. The ideal place for putting a biodigester is a backyard or a pig farm with ready access to manure. For best biogas production, water must typically be added to the waste and other feedstocks placed in the digester; most biogas plant manuals propose adding water to waste at a ratio of 1:1 [20]. Wet pig manure for biogas production is preferable; hence wet manure will be used. Using IoT, the parameters acquired by the sensor will be shown in a Web application for monitoring and control purposes.

This study will be limited to what backyard piggery owners can access and will not include technical plant operations and parameters, such as the OLR, technical measurements and consistency of the manure as an input to the biodigester, as well as the operations being done for continuous process since this study is focused on by batch feeding process of anaerobic digestion. Another limitation is that the speed of connectivity of the backyard farm owners to the internet is beyond the reach of this study. Finally, since the focus of this study was on biogas production, testing of the system's byproduct was excluded.

1.7 Definition of Terms

Anaerobic - refers to an environment or process that occurs in the absence of oxygen, such as anaerobic digestion, where microorganisms break down organic matter without the presence of oxygen to produce biogas.

Biodigester - a specialized system that utilizes anaerobic digestion to convert organic waste into biogas for renewable energy production.

Biofuel - is a liquid or gaseous sustainable energy source derived from biomass.

Biogas - a naturally occurring gas produced by the decomposition of organic waste by anaerobic bacteria, is utilized to produce energy.

Biomass - is an organic material that is renewable and derived from plants and animals.

Closed-loop control system - is an electrical device that manages a system without human intervention to maintain the desired state or set point.

Gradient Descent - is a training procedure for neural networks and machine learning models.

IoT (Internet of Things) - ecosystem is made up of web-enabled smart devices that employ embedded systems, such as processors, sensors, and communication gear, to gather, communicate, and act on data they get from their surroundings.

Methane - a colorless and odorless hydrocarbon gas, primarily composed of carbon and hydrogen atoms (CH_4), which is the main component of natural gas and a potent greenhouse gas.

Mesophilic - refers to microorganisms or biological processes that thrive and exhibit optimal activity at moderate temperatures, typically ranging from 20 to 40 degrees Celsius, in the context of biogas production.

Psychrophilic - refers to microorganisms or biological processes that thrive and exhibit optimal activity at low temperatures, typically below 20 degrees Celsius, in the context of biogas production.

Thermophilic - refers to microorganisms or biological processes that thrive and exhibit optimal activity at high temperatures, typically ranging from 40 to 70 degrees Celsius, in the context of biogas production.

Wet fermentation - is characterized by a high liquid content and a low total solids content, which is often below 10 percent.

CHAPTER 2
REVIEW OF RELATED LITERATURE AND STUDIES

2.1 Biogas Production

2.1.1 Biogas

Biogas is widely used to refer to the combustible combination of gasses created by the anaerobic decomposition of organic matter. 40%-70% (typically 55%-65%) of the mixture consists of methane, carbon dioxide, and traces of other gasses. Biogas is a high-calorie fuel that may be used to create power indirectly [21].

Table 1. Shows the biogas composition from the study of Feroskhan in 2016 [22].

Composition	Value
Methane (CH_4)	50% - 70%
Carbon Dioxide (CO_2)	25% - 50%
Hydrogen (H)	1% - 5%
Nitrogen (N_2)	0.3% – 3%
Water Vapor (H_2O)	0.30%
Hydrogen Sulfide (H_2S)	Traces

H_2S production

In the study of Rollo et al. they found out that in a small scale biodigester, from their results, swine manure produces 0-1 ppm of H_2S after three trials. They also recorded their CO_2 contents, and swine manure produced 0.04 to 0.12%. Their method of purifying these impurities which is water scrubbing for CO_2 and steel wool for H_2S is effective by removing 90% of the impurities [38].

2.1.2 Parameters Affecting Biogas Production

Temperature

Temperature is undeniably one of the most important operating parameters in anaerobic digestion since it can significantly affect the growth and metabolism of microorganisms. Anaerobic digestion can go under three categories of microorganisms, and they favor different ranges of temperatures, psychrophilic, mesophilic, and thermophilic. In contrast, Psychrophilic conditions are conducted at temperatures below 20 degrees Celsius, Mesophilic conditions are performed at temperatures between 32 and 42 degrees Celsius, and Thermophilic conditions are performed at temperatures between 55 and 70 degrees Celsius. Anaerobic digestion may be carried out under any of the three conditions; however, some have disadvantages. In thermophilic conditions, high temperature is associated with enhanced ammonia toxicity, [23][24].

Additional factor why temperature is an important factor for biogas production is because it affects the pressure inside the biodigester. A good representation of this is the Gay Lussac's Law which states that the pressure of the system is directly proportional to the temperature. This leads them for the temperature and pressure to form a linear equation. According to Dornelas, most researchers were able to correct and normalize the pressure and volume of the biogas through the combination of the Gay Lussac’s Law and Boyle’s Law. [24]

Another effect of temperature in the biodigester is the pH level of the sludge. According to Babaei, there is a significant relationship between the pH, and temperature. They follow the same pattern therefore they concluded that increasing the temperature results in increasing the pH level of the sludge. This is mainly due to the pH level of the digester liquid and its stability are important [25].

pH Level

In proper anaerobic digestion, the pH level is one of the factors that must be maintained. pH affects the growth and metabolism of the microorganisms where it is necessary to have a suitable range. Lacking a sufficient pH range or having an extremely high or low pH level may result in the death or inactivation of microorganisms because its effects inhibit the microorganism's growth and impact its activity, which is essential for the digestive process [23].

Mixing

Another vital parameter to consider and maintain is proper mixing. It is essential that microorganisms have excellent contact with the molecules they digest. It also promotes the appropriate distribution of their enzymes across a large volume of the substrate. Mixing also maintains contact between the microorganisms, which leads to providing uniformity during the process. Another purpose of mixing is to prevent materials from accumulating on the bottom of the digester [24].

Organic Loading Rate (OLR)

Organic Loading Rate or Loading refers to the number of new materials added to the digestion process per unit of time. It is also important since it affects the microbial populations during digestion. It is important to provide the appropriate loading rate for the digestion to have a good biogas process since it can also affect and make the digestion unstable. One of the concerns that might arise due to overloading is the likelihood of acidification since overloading of organic material can lead to excess undecomposed material that can build up to fatty acids that can reduce or halt methane production.

According to them, to start a new process, it is common and advisable to start an OLR from as low as 0.5 kilogram of organic matter per active volume of the digester and then it is increased successively along with the growth of the microorganism [23][24].

Retention Time

Retention time refers to the time the entire volume of material in the digestion tank takes before replacement. During the anaerobic process, regular intervals of substrate addition are needed since organic matter's content decreases, which turns the material into gas and digestate. However, regular removal of digestate is also required, resulting in a constant volume maintained in the process [23].

Hydraulic Retention time or HRT refers to the time the feed material stays in the digester. Since it influences the efficacy of the biogas process, it is essential to ensure that the right HRT value is considered. Low HRT can lead to wasting active biomass, including the methanogens, and high HRT can result in low productivity. Solid Retention Time, or SRT, is the amount of time solids remain in the digester; in most circumstances, SRT and HRT are identical [24].

Effects of Ammonia

According to the book Biogas Technology by Deng et al. free ammonia and ammonium can accumulate in anaerobic digestion. Ammonia of 80mg/L can inhibit digestion and above 150mg/L can poison methanogens. On the other hand, Ammonium of a low concentration can help the methanogens and be their nitrogen source, but when the concentration increased to 1500 - 3000 mg/L it can also inhibit the process and at high levels it can also be poisonous to methanogens. It is shown here that the increase of pH level can also increase the concentration of Ammonium and Ammonia [26]. The ammonia/ammonium proportion increases as the pH level increases with an influence of the temperature. At a temperature of 30 degrees Celsius, the ammonia percentage starts increasing beyond neutral levels, it is at 20% at roughly 8.5 pH and it reaches 100 at 11 pH level. As the temperature rises, the required pH level decreases to result in higher ammonia percentage. At 55 degrees Celsius, the ammonia percentage starts increasing at pH 7, which means that the higher the temperature, the anaerobic digestion will have higher risks of ammonia toxicity [27].

According to the study of Kalamaras et al. Reduction of methane production can occur when ammonia accumulates in the biogas plants, and it occurs when Nitrogen rich substrates has a significant part of the feedstock which is also called ammonia toxicity. In this paper, they studied the effects of the concentration of ammonia toxicity in reducing the production of methane. They used two periods of operations with two different ammonia inhibition levels (3200 mg/L to 4400 mg/L of Ammonium nitrogen). The first and second period resulted in reduction of Methane production of 3% and 14% respectively due to ammonia toxicity [28].

From the study of Utami et al. (2020) in which the researcher manipulated the internal gas pressure of the tank, revealed that the internal gas pressure had an influence on gas production. According to their data, the internal gas pressure influences every variable utilized in the study, although the major focus is its effect on the Methane generated. Their findings demonstrate that after 9–10 days, the reactor with regulated pressure generates more methane. However, in the uncontrolled area, the methane is directly proportional to the pressure [29].

2.1.3 Anaerobic Digestion

2.1.3.1 Anaerobic Digestion Conditions based on Temperature

Mesophilic Condition

Mesophiles are microorganisms that thrive at temperatures ranging from 20 to 45 degrees Celsius, with the optimal growth temperature spanning from 30 to 39 degrees Celsius. They have been isolated from both soil, and aquatic settings, and Bacteria, Eukarya, and Archaea kingdoms have species. Mesophiles may reproduce either by mitosis or sexually with male or female bacteria [30].

Microorganisms thrive in the mesophilic temperature range. The ideal temperature for methane producers is between 35 and 37 degrees Celsius. When the temperature falls below the optimum, fermenting organisms that are less sensitive to temperature fluctuations continue to produce a variety of fatty acids and alcohols. Because the methane producers are no longer as active, they are unable to digest all of the fermentation products that are produced. As a result, these quickly accumulate, causing the pH to drop and the process to halt [31].

Thermophilic Condition

Thermophiles are organisms that can survive at temperatures above 45 degrees Celsius and can be found in all three domains of life: bacteria, archaea, and eukarya. These bacteria flourish in high-temperature environments like deep-sea vents and terrestrial hot springs, where their phylogenetic and metabolic diversity is astounding.

There are advantages under thermophilic conditions, such as reduced retention time (HRT), which results in a faster and more efficient digestive process. Apart from that, it has improved solid sublayer digestion and the ability to separate liquid and solid fractions. Although it has advantages over other temperature conditions, it does have some disadvantages: 1) increased energy consumption as a result of the high temperatures; 2) higher degree of instability; and 3) ammonia inhibition risks are higher [32].

High temperature causes higher rates of biochemical reactions in the thermophilic condition, implying an increase in biogas methane yield, higher solubility, and lower viscosity.Increased biogas production offsets the thermophilic process's higher energy consumption. Thermophilic methanogenic bacteria are much more sensitive to temperature fluctuations (+/-10 C), requiring a longer period to adapt to the new temperature in order to achieve maximum biogas productivity, whereas mesophilic bacteria can withstand temperature fluctuations of +/-30 C without affecting biogas production significantly.

Psychrophilic Condition

Psychrophiles are cold-loving organisms under the domains of bacteria or archaea, defined as organisms with an optimal growth temperature of 15°C or lower, a maximal growth temperature of 20°C, and a minimal growth temperature of 0°C or lower. It was kept referring to organisms that can grow at low temperatures but have optimal and maximal growth temperatures of 15 and 20 degrees Celsius, respectively [33].

Biodigesters operating in psychrophilic conditions may have limitations due to the fact that: (i) Microbial activity is slowed because the optimal temperature for bacteria and archaea growth is 37 degrees Celsius; (ii) the concentration of methane in the biogas decreases as organic matter is removed, and a portion of this biogas is solubilized in the digestate.; and (iii) due to the foregoing, the digestate contains organic matter that is converted to ammonia (NH3) and methane (CH4) during storage and use in the soil. As a result of the gaseous emissions, this translates to a loss of energy efficiency and a greater environmental impact [33].

The study of Parralejo, A. I., et al, Animal manure of the Iberian pig, calf, and lamb was studied in this experiment. The methane production in the co-digestion process of the mentioned animal manure was examined. In consideration of this, they were used as substrates in co-digestion with tomato pulp, grape byproduct, and olive agro-food byproduct silages. This research revealed that in many tests of anaerobic co-digestion, a combination of animal manure and agricultural residues was able to maximize biogas production and sustain the anaerobic digestion process by meeting the necessary criteria. In addition, this research compares assays that are utilized on agro-food byproducts. Therefore, the researchers found that lower methane production relates to tests with less animal manure, whereas greater methane production corresponds to assays with more animal manure than agro-food waste [18].

The study of Sarker et. al, shows the importance of the operational parameters that have an impact in biogas production in existing technologies. To increase the methane yield in the biogas production, the optimization of the operational parameters will be one of the most used techniques applied in an anaerobic application process in industrial or lab-based studies. The study shows that multi-temperature staged digesters are suggested by recent investigations since diverse microorganisms are in their suitable environment and results in high biogas yield. High temperature or thermophilic conditions also enhance methane production but high temperature operations are expensive to apply. Another parameter that affects the production is pH level, addition of acid and basic solutions are traditionally the options to control the pH to the desired value which is neutral or 7. HRT and SRT refers to the biomass retention time in an operating digester and are both optimized by the OLR. High HRT is required since methane producing microorganisms grow slowly. OLR refers to the amount of daily treatment of feedstocks to the digesters. Variation of OLR allows optimizing of other parameters, and can be used to suppress ammonia inhibition, however it can affect the biogas production, such as bacteria wash out when OLR is too high [34].

The study of Singh, Szamosi and Siménfalvi in 2020 focuses on the effect of mixing to the production of biogas as it plays one of the important roles in anaerobic digestion. This study evaluates how the speed, design or impeller geometry and mixing time can affect the efficiency of the production and emphasizes that it is needed to pay attention to these details in order to find the optimum mixing mode. In this paper, they found out that intermittent mixing is more favorable than continuous mixing since it has a positive effect on the production and requires less power consumption [35].

This study of Stollenwerk, D., et al. proposes a new version of a biogas plant that is simpler to parametrize while maintaining the consistency needed for output prediction. It is based entirely on the control system approach to system identification and is substantiated by laboratory results from an authentic biogas production testing site. In this study, the researcher used one 1st order differential equation to model the biogas production. The proponents concluded that the process can be characterized using only two parameters: a transfer coefficient and a time constant. An extra feeding at an arbitrary time t can be used to determine the parameters for each substrate. This enables operation-based judgment. It's important to remember that the rapid reaction of the kinetics can't be modeled with a single first-order transfer function at first. The validation demonstrates that the model is qualitatively acceptable. The outcome quantitatively does not meet the set point specification due to a lot of circumstances, mainly the water content of the substrate.to various factors, particularly the substrate's water content, the result quantitatively does not match the set point specification [36].

The study of Menacho, W. A., et al., suggests two-stage digesters for biofuel production and uses Aspen Plus to model anaerobic digestion while applying three different fat content levels of 20%, 40%, and 60%, increasing Organic Loading Rates and Hydraulic Retention Time. At a thermophilic condition with a temperature of 55°C, the model of this study used a two-stage digester setup. The findings of this study showed that the maximum methane production attained was 74.82% and 77.10%, between 2 l/day and 5 l/day at an Organic Loading Rate and a fat concentration level of 40% and 60% [37].

According to the study of Chávez-Fuentes, 20 million and 10 million tons of dry and organic matter respectively can be produced by agricultural animals through their manure daily, and if mishandled, it can cause significant environmental problems since it is rich in organic compounds and nutrients. With anaerobic digestion process, their manure can be turned into 1900 million Nm^3 of methane everyday, which is equivalent to a recovery rate of about 21,000 GWh of energy. With this, it can provide a large contribution to climate change and depletion of resources, since it can bridge manure management and energy production making its impact high on a global scale. However, not every region in the world can have high potential for biogas production since it follows certain geographical and socio-economic patterns. But the application of anaerobic digestion to manure can be expected in future years to play a major role in most countries [38].

A local study of Rollo et al., from Mindanao Journal of Science and Technology experimented with the total production of biogas of three different manures, chicken, swine, and cow. They found out that among the three, swine manure produced the most biogas, where they used a batch feeding process, where they don’t input more organic matter daily. They used 15 kg of manure and mixed it with water with a 1:2 ratio respectively. This study also shows the hydrogen sulfide and carbon dioxide contents of the gas produced. The most CO2 and H2S was detected in chicken manure, and they proved the effectiveness of the purification they used. They used water scrubbing for the CO2 and they filtered the H2S with the use of steel wool. They were able to reduce the H2S from chicken manure from 102-132 ppm to 1 ppm, and CO2 from 9.99% to 0.14 and 0.08% [39].

Author	Year	Title	Relevant Findings	Significance to BIOPTIMIZE
Parralejo, A. I., et al.	2019	Small-scale biogas production with animal excrement and agricultural residues (study) 2019	A combination of animal manure and agricultural residues was able to maximize biogas production and sustain the anaerobic digestion process by meeting the necessary criteria.	Greater methane production corresponds to assays with more animal manure than agro-food waste.
Sarker, S., et al.	2019	A review of the Role of Critical Parameters in the design and operation of Biogas Production Plants (study)	The importance of the operational parameters that have an impact in biogas production in existing technologies.	To increase the methane yield in the biogas production, the optimization of the operational parameters will be one of the most used techniques applied in an anaerobic application process.
Singh, B., et al.	2020	Impact of mixing intensity and duration on biogas production in an anaerobic digester: a review (study)	The effect of mixing to the production of biogas as it plays one of the important roles in anaerobic digestion.	The intermittent mixing is more favorable than continuous mixing since it has a positive effect on the production and requires less power consumption.
Stollenwerk, D., et al.	2016	Biogas Production Modeling: A Control System Engineering Approach	A new version of a biogas plant that is simpler to parametrize while maintaining the consistency needed for output prediction.	The process can be characterized using only two parameters: a transfer coefficient and a time constant.
Menacho, W. A., et al.	2022	Modeling and analysis for biogas production process simulation of food waste using Aspen Plus	At a thermophilic condition with a temperature of 55°C, the model of this study used a two-stage digester setup.	This study showed that the maximum methane production attained was 74.82% and 77.10%, between 2 l/day and 5 l/day at an Organic Loading Rate and a fat concentration level of 40% and 60%.

Author	Year	Title	Relevant Findings	Significance to BIOPTIMIZE
Chávez-Fuentes, J. J., et al.	2017	Manure from our agricultural animals: A quantitative and qualitative analysis focused on biogas production (study)	With anaerobic digestion process, their manure can be turned into 1900 million Nm^3 of methane everyday, which is equivalent to a recovery rate of about 21,000 GWh of energy.	It can provide a large contribution to climate change and depletion of resources, since it can bridge manure management and energy production making its impact really high in global scale.
Rollo, E.P., et al.	2017	Analysis of biogas production from cow, chicken and swine manure.	Among the three, swine manure produced the most biogas, where they used a batch feeding process, where they don't input more organic matter daily. The impurities produced per feedstock.	They used a small scale biodigester design and Swine manure produced the most biogas. It is also shown in this study that swine manure produced the lowest percentage of impurities which is 0-1 percent.

2.2 Biodigester

2.2.1 Small-scale Biodigester Types

Fixed dome

The fixed dome plants are totally constructed below ground, conserving space and reducing their susceptibility to damage and daily temperature changes. They are the most often constructed digester in the region's hot environment [40]. The costs of a biogas plant with a fixed dome are comparatively modest. There are no moving components, therefore it is straightforward. Also, there are no rusting steel components, therefore a plant lifespan of at least 20 years may be anticipated. Underground construction protects the plant from physical harm and conserves space [41]. Fixed dome digesters are the most widely used type in rural China because of their simple construction and operation; they are suited for the economic development level of rural regions due to their cheap cost; and since they are often constructed underground, they are receptive to heat [42].

Floating dome

In floating drum plants, the gas holder is composed of stainless steel, which adds to the digester's cost, but its functioning is simpler to comprehend than in fixed dome plants since the gas holder is located above the ground [40]. In order to run floating drum digesters, manure and water are fed into the digester's inlet pipe. The slurry enters the bottom of the digester through the entrance pipe. On the bottom is a layer of biosolids, and above that is a layer of liquid effluent. The floating-drum design consists of a steel drum mounted on a guiding frame. Either a water jacket surrounds the digester, or the drum floats directly in the digesting slurry [41]. This kind of aboveground digester is often exclusively marketed in India since it is constructed of metal and is readily corroded, hence lowering its service life; it has poor insulation [42].

Biodigester Volume

According to the International Renewable Energy Agency (IRENA) knowing the plant volume of the small scale biodigester can help calculate the gas production, but in most cases, the volume measurement of the digester volume and gas storage volume in a biodigester cannot be measured directly. IRENA presented a table of the average measurements or ratio of digester and gas storage volume in a biodigester. It shows that the average volume for Fixed dome type has 8:2 the

Floating drum has 7:3 and balloon or bag digester has 7.5:2.5 digester to gas storage ratio [20].

According to the study of M. Ghiandelli in 2017, the proponents aimed to develop and assess a small-scale PVC balloon biogas system that might give a solution to the challenges faced by the fixed-dome biodigester. By installing this balloon biodigester, farmers would use less fossil fuel and less wood for cooking; it can be readily carried and installed due to its lightweight and foldable design. After developing the prototype, it was determined that, due to the high cost of materials, it was not economically viable for farmers since it had a negative rate of return [43].

According to the study of A. Canales-Gutiérrez et al. in 2021, an anaerobic biodigester was developed for methane production; it is capable of biodegrading sludge in anaerobic circumstances and has enough space left over to store biogas. Different temperatures of 50°C, 60°C and at 60°C were used to regulate the biodigesters. Controlling the pH and ensuring the temperature did not rise over 60°C allowed the methane content of the biogas to rise [44].

Author	**Year**	**Title**	**Relevant Findings**	**Significance to BIOPTIMIZE**
Ghiandelli, M.	2017	Development and implementation of small-scale biogas balloon biodigester in Bali, Indonesia	By installing this balloon biodigester, farmers would use less fossil fuel and less wood for cooking; it can be readily carried and installed due to its lightweight and foldable design.	The findings of the study determined that balloon biogas system was not economically viable for farmers since it had a negative rate of return.

Author	Year	Title	Relevant Findings	Significance to BIOPTIMIZE
Canales-Gutiérrez, Á. et al.	2021	Design of an anaerobic biodigester model as an alternative for methane generation	an anaerobic biodigester was developed for methane production; it is capable of biodegrading sludge in anaerobic circumstances and has enough space left over to store biogas.	The controlling of pH and ensuring the temperature did not rise over 60°C allowed the methane content of the biogas to rise.

2.3 Closed Loop Control Systems for Biodigesters

2.3.1 Raspberry Pi as Controller

The Raspberry Pi was launched in 2012, the original Pi had a single-core 700MHz CPU and just 256MB RAM, and the latest model has a quad-core CPU clocking in at over 1.5GHz, and 4GB RAM. All over the world, people use the Raspberry Pi to learn programming skills, build hardware projects, do home automation, implement Kubernetes clusters and Edge computing, and even use them in industrial applications. It has a very cheap computer that runs Linux, but it also provides a set of GPIO (general purpose input/output) pins, allowing you to control electronic components for physical computing and explore the Internet of Things (IoT) [45].

Raspberry pi 4 is the most recent model of the inexpensive raspberry pi computer. In its most basic form, it is a credit-card-sized electrical board without a casing. As the Raspberry Pi 4 is quicker and capable of decoding 4K video, has faster storage through USB 3.0, and faster network connections via genuine Gigabit Ethernet, many new applications are possible. It is also the first Raspberry Pi to enable twin 4K@30 monitors, a benefit for creatives who need extra desktop space [46].

2.3.2 Parameter Monitoring and Regulation Equipment

Temperature Sensor

An integrated circuit sensor is a temperature sensor. The output voltage is proportional to the temperature in degrees Celsius. Microwave ovens, refrigerators, home equipment, air conditioners, and environment and water temperature monitoring are all examples of temperature sensor uses. It is capable of measuring both hot and cold bodies. Non-Contact temperature sensors and contact temperature sensors are the two types of sensors. Temperature sensors are the most important components in determining overall thermal performance because temperature variations are the primary objective, whereas other parameters like the jacket flow rate or stirring speed are more like process conditions that are set once and then kept constant. If there is a lot of change in these parameters, these sensors should be examined [47].

pH Sensor

pH is an observable parameter, and a pH meter is an electronic tool that assesses the pH of a liquid (or, in certain situations, semi solid substances). A conventional pH meter's most significant component is a precise measurement probe (a glass electrode) or, for special applications, an ion-selective field-effect transistor (ISFET), which is coupled to an electronic meter that measures and displays the pH level. All pH meters are calibrated against known hydrogen ion activity buffer solutions [48]. Colorimetric methods, which use indicator fluids or papers, and electrochemical methods, which use electrodes and a millivoltmeter, are the two ways for measuring pH (pH meter). The invention of the glass electrode, which can be used in a range of conditions, as well as the pH meter, has allowed for the extensive use of pH measurement and control. In the food sector, determining and controlling pH is critical [49].

Gas Sensor

Gas sensors are commonly considered to provide a measurement of the concentration of a target molecule, such as CO, CO2, NOx, or SO2, without addressing the several underlying approaches, including light absorption, electrical conductivity, electrochemical (EC), and catalytic bead. Many other gas sensors, on the other hand, measure a physical feature of the environment surrounding them, such as simple temperature, pressure, flow, thermal conductivity, and specific heat, or more complex qualities for gaseous fuels, such as thermal efficiency, super compressibility, and octane number. The latter may require capital-intensive (engines) or destructive testing, such as combustion, or include the measurement of a variety of characteristics that will be used as inputs to a correlation with the complicated attribute of interest [50].

Motor

Control systems commonly involve DC motors. Coils of wire are installed in slots on an armature, which is a cylinder of magnetic material in a DC motor. The armature can rotate freely and is mounted on bearings. It's formed in a magnetic field created by field poles. Permanent magnets or an electromagnet with its magnetism created by a current traveling through the so-called field coils might produce this magnetic field. The stator is the exterior casing of the motor, whether it is made of permanent magnets or electromagnets. Depending on how the field and armature windings are coupled, DC motors with field coil motors are classed as series, shunt, compound, or individually energized. The armature and field coils are in sequence in a series-wound motor. This motor boasts the highest no-load speed and the maximum initial torque. A series-wound motor, on the other hand, may run at too high a speed with light loads. Since both the current in the armature and the field coils are reversed, adjusting the polarity of the source towards the coils has no impact on the direction of motor rotation [51].

Pressure sensors

Pressure sensors, particularly temperature sensors, are one of the most common sensors and are used mostly in everyday life. Pressure sensors can be used to detect pressure directly, such as in a microphone or hydrophone, or indirectly, such as altitude, fluid/gas flow speed, calibration, and so on. To sense pressure, a variety of engineering techniques and physics phenomena are used. Materials with piezoresistive and piezoelectric properties, potentiometric, electrostatic, or magnetic changes caused by diaphragm displacement, along with optical deformation, have been utilized to sense pressure [52].

Propeller

According to the study of N. Pannucharoenwong, the proponents investigated three kinds of impellers, including 6-straight blade (SB-6), 6-marine blade (MP-6) and 4-pitch blade (PB-4), as it was discovered that increasing the number of agitators increases the biogas production rate. It was shown that, compared to the other two propellers, the MP-6 propeller gave off the highest and most steady amount of methane [53].

According to Kulkarni**,** Organic agriculture is a farming method that aims to produce food with minimal impact on ecosystems, animals, or humans. It includes a variety of environmentally friendly practices such as avoiding pesticide use, increasing species abundance, increasing soil fertility, reducing soil erosion, and lowering energy consumption and nitrogen (N) losses in the system. Closed-loop systems for increasing agricultural productivity while facilitating long-term sustainable development. Closed-loop systems promote Water-Waste-Energy-Food (WWEF) models by integrating food production and waste upcycling (agricultural, animal, food, and human) into the water, sanitation, and energy nexus. In small-scale agriculture, sustainable decentralized technology that recovers nutrients, water, and energy from waste streams to provide clean streams, concentrated fertilizers, and energy is essential.

Nijaguna identified three main designs for the most commonly used rural digesters, which are, in decreasing order, the fixed dome, the floating cover, and the bag-tube type. Gensch demonstrates the use of biogas for an adapted stove and pressure lamps (modified to biogas). Biogas is either used directly or stored in the dome.

Floating biodigesters that can be used for both water sanitation and renewable energy production. In these cases, the biodigester is fed primarily with pig manure and human excrement. As a result, direct pollution to water is reduced because waste products are instead used as a resource. Methane is a byproduct of biogas that can be used in the home. It reduces the use of wood for cooking, which causes both health problems and deforestation. A fixed dome digester, such as the Sinidu model GGC 2047, is made up of a dome atop a fermentation tank, both of which are built underground out of concrete. The gas is stored in the digester's upper portion. The slurry in the digestion tank overflows into the outlet tank once gas production begins. The biogas can be collected at the top of the fixed dome. Fixed domes can also be masonry structures, and ferrocement structures exist—specifications are generally determined by local availability of materials and skilled labor, both of which have a direct impact on the system's cost. The fluctuating gas pressure and the need for highly skilled technicians for initial installation are significant disadvantages of this system.

The fixed biogas dome or floating drum design is commonly used in small-scale rural systems, but the tubular flexible balloon model is mentioned as a low-cost alternative. Interestingly, in some of the cases reviewed, a large proportion of the design and construction expense is borne by a sponsor, with the owners themselves only bearing operational expenses. Furthermore, while progress is being made in LMICs to adapt closed-loop WWEF systems to the local climate, economy, and sociocultural environment, the review found that documentation to support this is largely lacking. This emphasizes the importance of disseminating lessons learned from completed projects [54].

The study of Fawzy et. al in 2021 presents the use of model predictive control to create an adaptive control system for a biogas power system. In this study, the state variables used for the MPC are all biodegradable volatile concentrations in the reactor, volatile concentrations in the influent, acidogens, and methanogens. The proponents validate the applicability of the proposed MPC-based controller, the proposed model is evaluated under constant load. To analyze the performance of the biogas power plant while it feeds a constant load, the biogas plant is simulated with and without the MPC included. First, the effect of the MPC-based controller on MT torque and speed is investigated. The effect on methane generated by the reactor and kept in the storage tank is next explored. The constant load is assumed to be 100 kW, which is less than the plant full load of 400 kW, in order to examine the influence of the proposed controller on the storage system. Thus, the system was developed in the MATLAB/Simulink environment and tested under various loading parameters. The simulation results demonstrated the efficiency and reliability of the proposed MPC system in optimizing the operation of a biogas power plant under different operational conditions. Whilst also reducing the duration and magnitude of disturbances, the proposed controller system could prevent the MT from damage caused by unbalanced load operation. In this research the proponents concluded that, the errors for the MT torque, generator speed, and generator output voltage fall from 18% to 2%, 50% to 10%, and 15% to 0%, respectively, when the performance index is measured [55].

According to Ocana et al., Development and testing of the control strategies are important to adapt in some unstable circumstances in biomass production processes. Control systems are rarely used in biogas production, but the variation in the operation of different conditions affects the implementation of the system in industrial scale. According to Cortes, the temperature of the system is directly proportional to the instability of the pH level. Thus, it is important to optimize and control the parameters that affect the biogas production. According to Cortes, control schemes based on optimization have increased efficiency compared to the PID controllers by 19.67%, and LQR controllers by 5.42%. With this the proponents are claiming that optimization will yield better results than the closed-loop systems that are being implemented in the present journals and studies [56].

Author	Year	Title	Relevant Findings	Significance to BIOPTIMIZE
Kulkarni, I. et al.	2021	Closed-Loop Biodigesters on Small-Scale Farms in Low- and Middle-Income Countries: A Review	The biodigester is fed primarily with pig manure and human excrement. As a result, direct pollution to water is reduced because waste products are instead used as a resource.	The fixed biogas dome or floating drum design is commonly used in small-scale rural systems, but the tubular flexible balloon model is mentioned as a low-cost alternative.
Fawzy, S. et al.	2020	Adaptive Control System for Biogas Power Plant Using Model Predictive Control	The simulation results demonstrated the efficiency and reliability of the proposed MPC system in optimizing the operation of a biogas power plant under different operational conditions.	The use of model predictive control to create an adaptive control system for a biogas power system.
Ocana, L. C. et al.	2018	Optimal Control Scheme on Anaerobic Processes in Biodigesters	Control schemes based on optimization have increased efficiency compared to the PID controllers by 19.67%, and LQR controllers by 5.42%.	Control systems are rarely used in biogas production, but the variation in the operation of different conditions affects the implementation of the system in industrial scale.

2.4 Biogas Technology

The authors of “Recent Advances in Biogas Production” discussed recent advancements in biogas production technology, conducted a scientometric analysis, and concluded that researchers working on biogas technology in various fields (Environmental Science (21%), Energy (14%), Chemical Engineering (12%), and Engineering (12%)) are studying biogas as a clean, sustainable alternative energy source. The study proved that effective biogas usage could help to promote environmental sustainability. Reducing greenhouse gas emissions and implementing a recycling society are two of the most important objectives. However, the efficient use of biogas is constrained by insufficient feedstock conversion and inadequate gas storage systems [14].

This study of Tabatabaei et al., the researchers examined the upstream, mainstream, and downstream methods to biogas production. Upstream approaches such as fungal, microbial consortium, and enzymatic pretreatment, as well as other biological approaches such as micro aeration, composting, ensiling, and genetic and metabolic engineering, were discussed and explored in detail. Mainstream techniques include bioaugmentation, anaerobic co-digestion, and integrated biogas production. Finally, the downstream biological approaches for removing CO2, H2S, as well as other contaminants are addressed. Bioaugmentation is highly recommended among the mainstream biological approaches to expedite commercial scale start-up, while anaerobic co-digestion is recommended to not only improve biogas production throughout the operation but also to take use of numerous waste streams. Such mainstream approaches could enable digesters to improve their economic situation [57].

Author	Year	Title	Relevant Findings	Significance to BIOPTIMIZE
Prasad et al.	2017	Recent Advances in Biogas Production	The study proved that effective biogas usage could help to promote environmental sustainability.	The efficient use of biogas is constrained by insufficient feedstock conversion and inadequate gas storage systems
Tabatabaei et al.	2020	A comprehensive review on recent biological innovations to improve biogas production	Bioaugmentation is highly recommended among the mainstream biological approaches to expedite commercial scale start-up.	Anaerobic co-digestion is recommended to not only improve biogas production throughout the operation but also to take use of numerous waste streams. Such mainstream approaches could enable digesters to improve their economic situation.

2.5 Machine Learning

2.5.1 Gradient Descent-based algorithms

There are three types of gradient descent algorithms. These are the Batch Gradient Descent, Stochastic Gradient Descent, and Mini-batch Gradient Descent. Among the three, the most popular in research journals is the Stochastic Gradient Descent, but the most popular in the field/industry is the Mini-batch Gradient Descent. Batch Gradient Descent is also called Vanilla gradient descent since it is the root program of all new algorithms that are being implemented nowadays. Stochastic gradient descent is the best for our study since it is much less complicated than the Mini-Batch Gradient Descent and updates automatically [58].

According to Ruder, Stochastic Gradient Descent is the best use for the research journals. Nevertheless, its optimization rate is slower than adaptive learning rates such as Adagrad, RMSprop, AdaDelta, etc. The adaptive learning rates are advised if the programmer desires a quicker optimization rate [59].

Stochastic Gradient Descent (SGD)

Stochastic Gradient Descent enables the deficiency of the Batch Gradient Descent. SGD allows it to continuously improve and process in real-time since it can operate online.

For large datasets, the batch gradient descent technique recomputes the gradients for comparable cases before each parameter change, resulting in redundant calculations. SGD avoids duplication by executing updates one at a time. Therefore, Stochastic Gradient Descent is much faster and also used and operated online.

The downside of SGD is that it continually overshoots, making convergence to the precise minimum more difficult. However, Ruder managed to argue and showed that when we decrease the learning rate of the SGD, it performs the same as the BGD [60].

Momentum

SGD's biggest downfall is the navigation of the slope in areas where the surface curves are steep. These areas are common in the local optima. Without momentum, our navigation makes hesitant progress in finding the local optimum, which results in an inaccurate or slow process. With this downfall, momentum has been created to accelerate the SGD to beat the ravines and dampen

the oscillation. When using the momentum algorithm, we accelerate the momentum as it rolls downhill, making our navigator much faster on the way. Therefore, we gain faster convergence and reduced oscillation [59].

We can combine SGD with Momentum (SGDM). According to Liu, SGDM has an empirical advantage over SGD, but the role of momentum is still unclear since their analysis can either provide worse convergence or assume quadratic objectives. Liu argued that the SDGM had reached a test accuracy of 93% around 200 epochs, providing faster convergence and advantages [60].

Mini Batch Gradient Descent

The mini-batch gradient descent technique computes the gradients for small fixed-size data groups at each iteration; these subsets are chosen randomly and referred to as mini-batches. Just like the Stochastic, it can perform an online and continuous process. Mini-Batch Gradient Descent is much faster compared to SGD and BGD, but it offers much more complexity in code [61].

The data sparsity can be exploited to speed up the convergence of the Mini-Batch Gradient Descent [61]. But Mini-Batch Gradient Descent offers a disadvantage, specifically when the stable error gradient descent, we cannot see any noises that may help us find the local minima which stochastic gradient descent has. Mini Batch Gradient Descent needs a lot of memory to process and store, which might not be a good algorithm.

Author	Year	Title	Relevant Findings	Significance to BIOPTIMIZE
Sebastian R., et al.	2016	An overview of gradient descent optimization algorithms	Compare and contrast the different optimizer in order to understand what is the best to use and their advantages and disadvantages	This research will compare and contrast the three most used gradient descent algorithm a proper understanding of their advantages and disadvantages is a huge help in this study
Mustapha , A., et al.	2020	An overview of gradient descent algorithm optimization in Machine Learning: Application in the ophthalmology field	Mustapha et al. developed and implemented a case and differentiate study in ophthalmology field batch gradient descent, stochastic gradient descent, and mini-batch gradient descent	In the research the proponents can adapt the algorithm comparison in order to find the most suitable algorithm that can be used in the study.
Khirirat et al.	2017	Mini Batch Gradient Descent: Faster Convergence Under Data Sparsity	Khirirat et al. argued that data sparsity affects the range of admissible step-sizes and the convergence factors in the mini-batch gradient descent algorithm	Their model on mini-batch gradient descent can be adapted since convergence results yields faster results compared to classical approach
Liu et al.	2020	An Improved Analysis of Stochastic Gradient Descent with Momentum	Liu et. al argued that they can combine two algorithms in order to gain advantages to gain faster convergence. In the study they combine Stochastic Gradient Descent and Momentum. They also proved that their claim is correct with numerical experiments.	One of the main concerns of using stochastic gradient descent is having limited storage for data sets. This is why implementing their model in our study might help solve limited storage.

Multivariate Regression

The study of Susmita Ray briefly reviews various machine learning algorithms that are most frequently used. The difference between simple linear regressions is that there is a one-to-one relationship between the input and output variables. However, multiple linear regression has a many-to-one relationship between several independent variables and one dependent variable. But having more independent variables doesn't give you a better prediction, as it can result in over-fitting. Because this technique is achieved through multiple regression, tabulation techniques, and partial correlation, this models realistically complex real-world problems hence this can be used in quality control, process optimization, quality assurance, process control, etc [62].

The study of Rushdi M. et al. uses Multivariate machine learning to predict Airborne wind energy. In this study, a Kite system is used to collect experimental data that will be used to train machine learning regression models. The system is focused on predicting the generated tethered force, and they have collected input-output samples from their sets of experimental runs to be used as their training data for their machine learning. In this study they used multiple parameters to predict the tethered force, such as the position of the kite, orientation, and its moving speed. Multiple Multivariate regression models are used to compare and achieve the best and more accurate results. The study has successfully shown the potential of predicting the tether force with their results. Their study shows great promise in guiding new designs that promote optimal power generation [63].

Neural Knapsack

Knapsack is an algorithm that outputs an optimized value based on the Weight and Value of the items being differentiated. The algorithm works via giving a two integer arrays value [0…n-1] and weight [0…n-1]. Each value and weight are associated with items respectively. The key concept here is to find out the maximum value subset of value such that the weight of this subset is smaller than the knapsack capacity. There are three approaches on solving knapsack, these are the Recursion by Brute-Force Algorithm, Dynamic Programming based implementation, and Memoization Technique.

According to the data gathered by Mchmed, applying Neural networks to solve knapsack problems has been a huge success. They trained their model by generating 200k instances for training and 1k for model evaluation from each type of instances. They evaluate the neural network by using the greedy algorithm as the baseline. Memory Constructor is used with either Dense Layers, ID-Convolution (CNN) layers, or gated recurrent unit (GRU) layers. All instances were solved using CBC an LP branch-and-cut library based on CLP I solver. PuLP is used as a python interface to the CBC library. Adam optimizer was also used for training with default parameters and learning rate was set to 0.004, during learning the model was evaluated for each epoch. It was a great body of work on heuristic and metaheuristic algorithms. According to the author's note machine learning community should consider the benefit of using the Neural Knapsack problem when incorporating optimization problems [64].

Continuous Optimization Using A Dynamic Simplex Method

Simplex method is another form of Optimization algorithm using Linear Programming. But simplex methods need constraints in order to function properly.

In the work of Xiong and Jutan, they managed to create a dynamic simplex method for continuous optimization, which can be used by the proponents in their study since the biodigester will provide continuous data and using these data the pH level must be optimized to boost the production of Biogas. In their work they modified the Nelder-Mead Simplex method and extended to allow tracking of moving optima. According to them the Direct-Search methods are a good candidate for real time optimization and the use of simplex method makes the process simple to implement in evaluation of function. The researchers were also able to conduct a difference using their model via 2-D and 3-D tracking, the results yields that the 2-D tracking offers much better performance and more robustness compared to dynamic response of the surface method. According to them, Dynamic Simplex Method shows a great promise for continuous-dynamic optimization in processes for which it is difficult to obtain a good model and the measurements are costly and time consuming [65].

2.6 Internet of Things

The research of Lezzar, F., et al., implemented an Internet of Things (IoT) system for real-time water quality monitoring that allows data from electronic sensors to be monitored. The proponents used an Arduino microcontroller that has a set of sensors attached to it. The distance between the highest half of the water tower and the water level is calculated using an ultrasonic sensor, and the available volume of water is then calculated. Data will be obtained and transferred to the IoT Platform through the MQTT protocol, specifically to the Wiring module, which links the devices and user applications to the platform. The wiring module saves this information in a NoSQL database [66].

The main objective of Dieudonne, D., et al., in this study was to enhance present biogas digesters by demonstrating the efficiency of using IoT as a technology to optimize biogas digesters. To address this problem, the proponents projected the design and implementation of an integrated IoT system to connect and monitor the Biogas digester. Only two temperature sensors were used in the IoT prototype system: a waterproof temperature sensor and a temperature-humidity sensor. The system was set up in one of the biogas digesters in the area. The location site was Tumba College of Technology for research. The proponents visited this facility during the data collection process [67].

An IoT-based efficiency monitoring system for biogas facilities was proposed in this research of Acharya, V., et al. The proponents utilized an Arduino microcontroller system to monitor gas production and consumption. They implement an Android-based application that calculates the biogas usage and will notify through text message with an authentication code, and it serves as an SMS gateway. Knowing that the facility operator can monitor the parameters through a monitor that displays usage statistics [68].

The study of Abdurrahman, A. H., et al., developed an Internet of Things (IoT) biogas production volume monitoring system. The primary purpose of this research was to calculate the volume of the biogas produced. The daily biogas production was monitored using an IoT platform. The measurement data is transferred to the IoT platform, which allows it to be monitored remotely. The flowmeter sensor's measurement procedure will be received and processed by an Arduino Nano microcontroller. The proponents also included a GSM/GPRS communication module, specifically the SIM800L communication module, allowing the miniature cellular module to be integrated with Thingspeak as an IoT platform with a 15-minute delivery time. Because of this, the proponents concluded that the gas monitoring system has a sensor value of 94.84 percent and a volume reading accuracy value of 95.75% [69].

Author	**Year**	**Title**	**Relevant Findings**	**Significance to BIOPTIMIZE**
Lezzar, F., et al.	2020	IoT for Monitoring and Control of Water Quality Parameters	Data will be obtained and transferred to the IoT Platform through the MQTT protocol, specifically to the Wiring module, which links the devices and user applications to the platform.	They implemented an Internet of Things (IoT) system for real-time water quality monitoring that allows data from electronic sensors to be monitored.
Dieudonne, D., et al.	2018	Effectiveness of applying IoT to Improve Biogas digesters in Rwanda	They projected the design and implementation of an integrated IoT system to connect and monitor the Biogas digester.	The use of IoT as a technology to optimize biogas digesters
Acharya, V., et al.	2017	IoT (internet of things) based efficiency monitoring system for biogas plants.	The facility operator can monitor the parameters through a monitor that displays usage statistics.	They implement an Android-based application that calculates the biogas usage and will notify.
Abdurrahman, A. H., et al.	2020	Biogas Production Volume Measurement and Internet of Things based Monitoring System	The proponents concluded that the gas monitoring system has a sensor value of 94.84 percent and a volume reading accuracy value of 95.75%	The measurement data is transferred to the IoT platform, which allows it to be monitored remotely.

CHAPTER 3
METHODOLOGY

This chapter tackles the Research Design of the Study, the Research Process Flow, and the Research Design. The Project Workplan and the Statistical Analysis pertinent to this study were also presented in this chapter.

3.1 Research Design

In this study, Experimental, Correlational, Developmental, and Descriptive research designs will be used.

3.1.1 Experimental

The study will employ an experimental research design to investigate the effect of implementing a closed-loop system in a biodigester on biogas production. It will focus on comparing the biogas production between the closed-loop system and a traditional biodigester. The experimental setup will include two separate configurations: one with the closed-loop system and another with the conventional setup. By manipulating key parameters and controlling operating conditions, the researchers can observe the impact of the closed-loop system on biogas production. Data on biogas production, as well as temperature, pH levels, and feedstock characteristics, will be collected and statistically analyzed to determine the significance of the observed differences. This study aims to provide quantitative and qualitative evidence regarding the effectiveness and feasibility of implementing closed-loop systems to enhance biogas production in biodigesters.

3.1.2 Correlational

In this study, a correlational research design will be employed to investigate the relationship between temperature and its impact on the pH level within the system. The researchers will collect data sets consisting of temperature and corresponding pH values from the biodigester system. By analyzing and correlating these data, the study aims to identify any patterns or associations between temperature and pH levels.

The collected data will provide insights that can assist in optimizing the pH level based on the detected temperature. By understanding how temperature influences the pH level, the system can be adjusted to maintain an optimal pH range for efficient biogas production.

Furthermore, the study will also examine the correlation between pH levels and biogas production. By analyzing the relationship between pH levels and the efficiency of biogas production, the researchers aim to train the system to identify the optimum pH level that yields the highest biogas production for each temperature value.

By utilizing a correlational research design, this study seeks to establish a comprehensive understanding of the relationship between temperature, pH levels, and biogas production. The resulting data will contribute to the development of strategies for optimizing the system's performance by adjusting pH levels based on temperature variations. Ultimately, these findings aim to enhance the efficiency and effectiveness of biogas production by ensuring an optimal pH environment within the biodigester system.

3.1.3 Developmental

The proponents will innovate a traditional biodigester and apply a closed-loop control system that aims to increase the production of biogas utilizing a microcontroller motor and sensors (temperature, gas, pressure, pH) and machine learning technology to optimize the pH level and mixing. The biodigester will also include a mobile application for monitoring systems that applies Internet of Things technology.

3.1.4 Descriptive

The descriptive research design will be employed to evaluate the system and device according to the ISO standard. This design involves systematically describing and documenting their characteristics, features, and performance. The assessment will compare the system and device against specific ISO standard requirements, examining documentation and conducting performance testing. The findings will provide a comprehensive description of their adherence to the ISO standard, aiding stakeholders in decision-making, quality assurance, and compliance verification. This approach ensures a systematic and objective evaluation, promoting a thorough understanding of their alignment with established quality benchmarks.

3.1.5 Input-Process-Output

Table 2: Input Process Output

Input	Process	Output
Required Knowledge: – Python Programming – Machine Learning Required Hardware: - Raspberry Pi 4 microcontroller - Temperature sensor (DS18b20) - pH sensor (SEN0161-V2) - Pressure sensor (BMP180) - Gas sensor (MQ-9) - ½ HP Electric Induction Motor - Three-blade Propeller - Solar Panel - 370L Polyethylene Tank - Propane tank - Polyethylene tubes - Solenoid Valve - Metal Frames for support	Hardware Development: - Constructing the biodigester with closed-loop control system - Mixing system - IoT Network Monitoring System - Biogas storage Software Development: - Raspberry Pi programming - Machine learning algorithm for optimization programming - Mobile application development programming Testing: - Accuracy testing - Functionality testing - System evaluation	Bioptimize: A closed-loop biodigester system that utilizes machine learning for pH level optimization to increase biogas production, and IoT application for monitoring system

Table 2 shown above is the Input-Process Output (IPO) model of the system of the study. The input of the system will be the sensor's data such as temperature, pH, pressure, gas sensor, motor speed, and valve. This will be possible with the help of Raspberry Pi 4 as the microcontroller, different sensors for the data earlier, three-blade Propeller for mixing, solar panel as an energy source for the system, 300L polyethylene tank for the biodigester, polyethylene tubes and propane tank for the storage system. Then, a program will process the data via gradient descent algorithm to identify the appropriate pH level to boost the biogas production. The application will serve as the monitoring system for the system, data gathered as well as notification will show here. With this the proponents will be able to create a closed loop biodigester system that utilizes Gradient Descent for pH level optimization to increase biogas production, with integration of IoT application for monitoring.

3.2 Research Process Flow

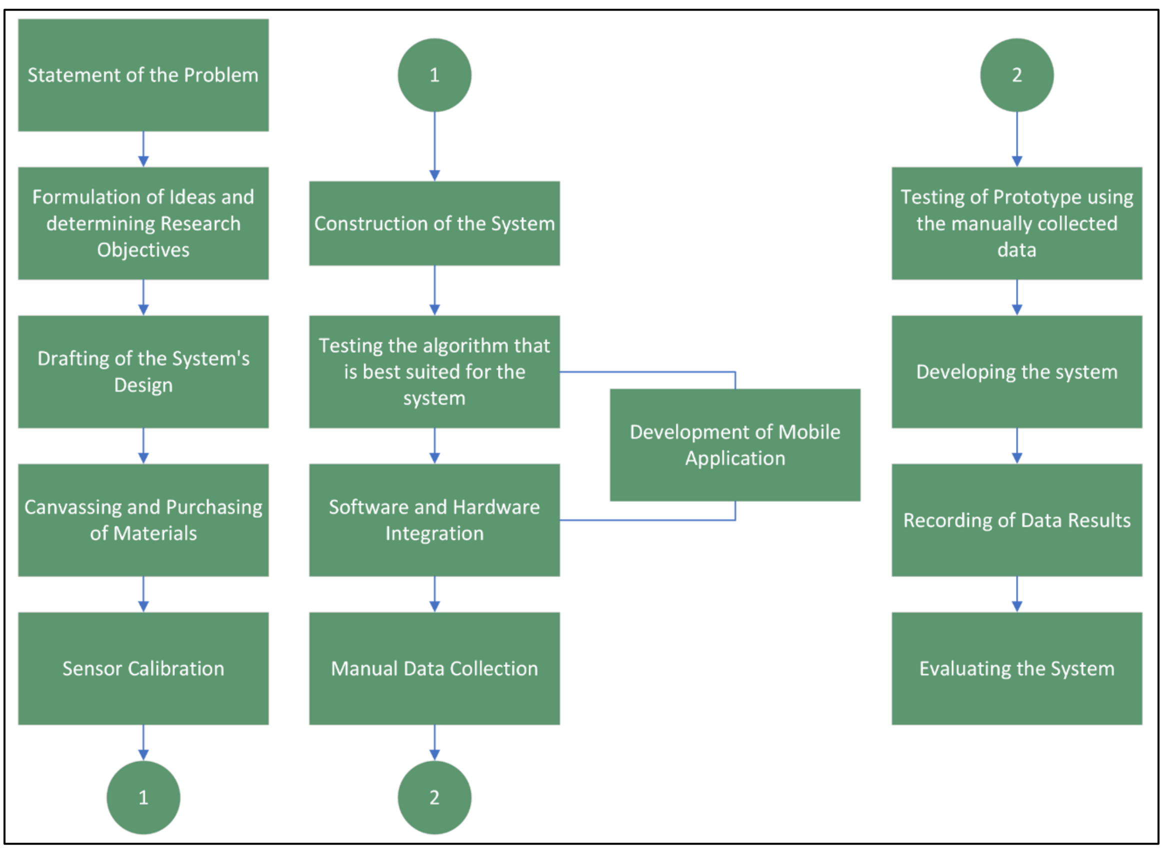


Figure 1. Research Process Flow

3.3 Designing and Construction of a Biodigester with a closed-loop system

This section discusses the design and building of a small-scale biodigester with a closed-loop system.

3.3.1 Materials and Equipment

Table 3. Biodigester System Components

PRODUCT	QTY.
370L Polyethylene Tank	1
PVC CLEAN OUT END CAP 4"	2
PVC CLEAN OUT END CAP 6"	2
½ HP Electric Induction Motor	1
Waterproof Temperature Sensor (DS18b20)	2
Gas Sensor (MQ-9)	1
Analog pH Sensor (SEN0161-V2)	1
Pressure Transducer Transmitter Sensor G1/4 Stainless Steel	1
Solar Panel	1
Solar Panel Regulator (controller)	1
Solar Inverter (power supply)	1
Solar Panel Battery CSL12V55	1
Raspberry Pi 4 (8Gb)	1
SD Card (64Gb)	1
Customized Metal Blade	1
12V Relay Module 1 Channel	4
Solenoid Valve	2
5 Water Container Gallon with Faucet	1
2.5 Water Container Gallon with Faucet	1
Gate Valve	2
2 x 6 Gi Nipple	2
1/2 x 2 Gi Nipple	6
Gi Elbow	4
Gi Coupling	4
60 Meters 22 AWG Wires	1

PRODUCT	QTY.
Jumper Wires - Male to Female	30
Jumper Wires - Female to Female	25

Table 4. Biogas Storage Components

PRODUCT	QTY.
Butyl Tire Truck 700 X 16	1
3 Way Tee Brass Y Ball Valve	1
Hose Clamps	3
LPG Rubber Hose	3
Small Ball Valve Outer	1

3.3.2 Sensor Calibration

The proponents will calibrate the sensors that will be used in the system in order to ensure accurate readings of parameters that are crucial for the closed-loop control system. The pH sensors will be calibrated using pH level calibration solution, the gas sensor will be calibrated using a gas tester kit. The temperature sensors will also be calibrated using a testing kit, the temperature sensor probe will be used in wet substances and the dht11 temperature sensor will be calibrated using dry materials. Lastly the pressure sensor will be calibrated using a calibration tool.

3.3.3 Biodigester Designing

The following figures shows the initial design of the Biodigester with a closed loop control system. In these figures, the dimensions, the parts and the sensor placements are shown. The propeller design was based on the study of Pannucharoenwong N. [52], but since the propeller type that produced the most biogas is not accessible by the proponents, they used a 3- pitched blade type which is easily accessible and anchored to the propeller type that produced the second-best result which is a 4-pitched blade propeller. Two propellers A and B were used to have an even mixing from the top of the volume and the bottom. With that, a requirement of filling the digester up to the second propeller is needed to maximize the energy used for mixing.

Figure 2. Front view of the Biodigester.

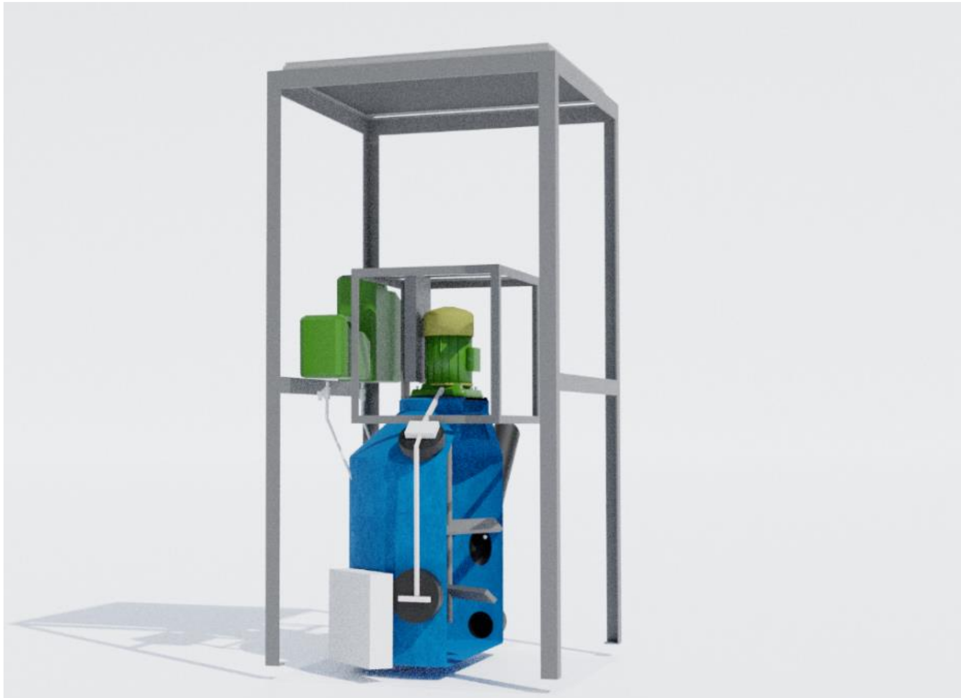


Figure 3. Left-side view of the Biodigester.

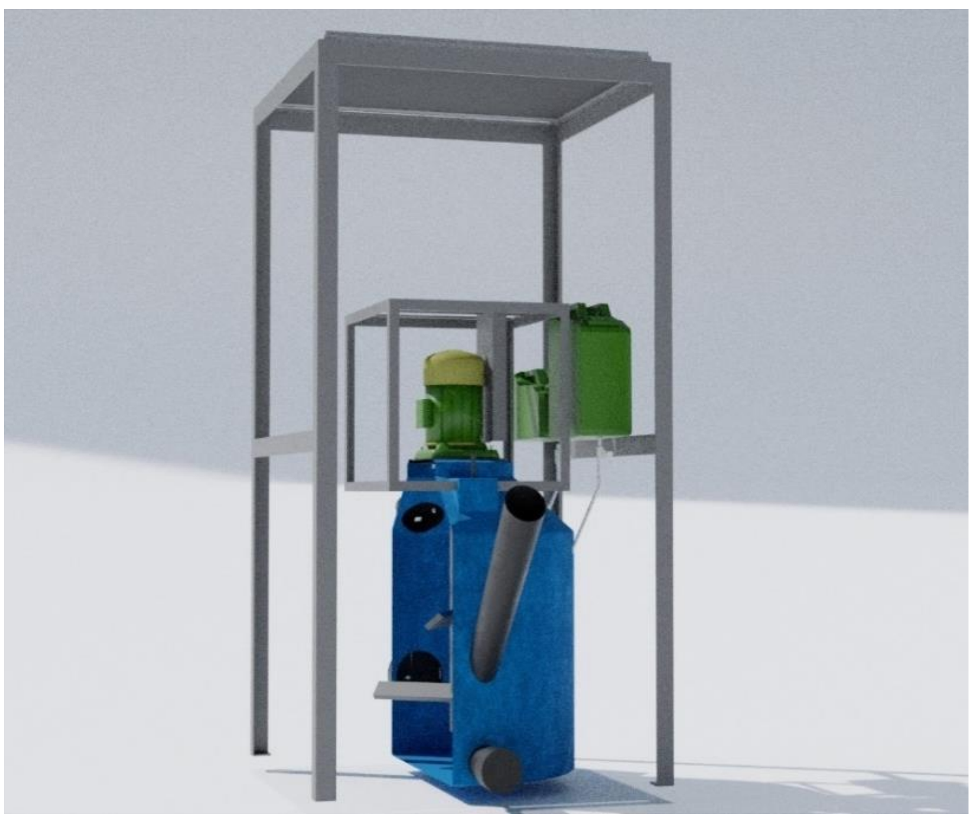


Figure 4. Right-side view of the Biodigester.

3.3.4 Block Diagram of the Closed-Loop Control System

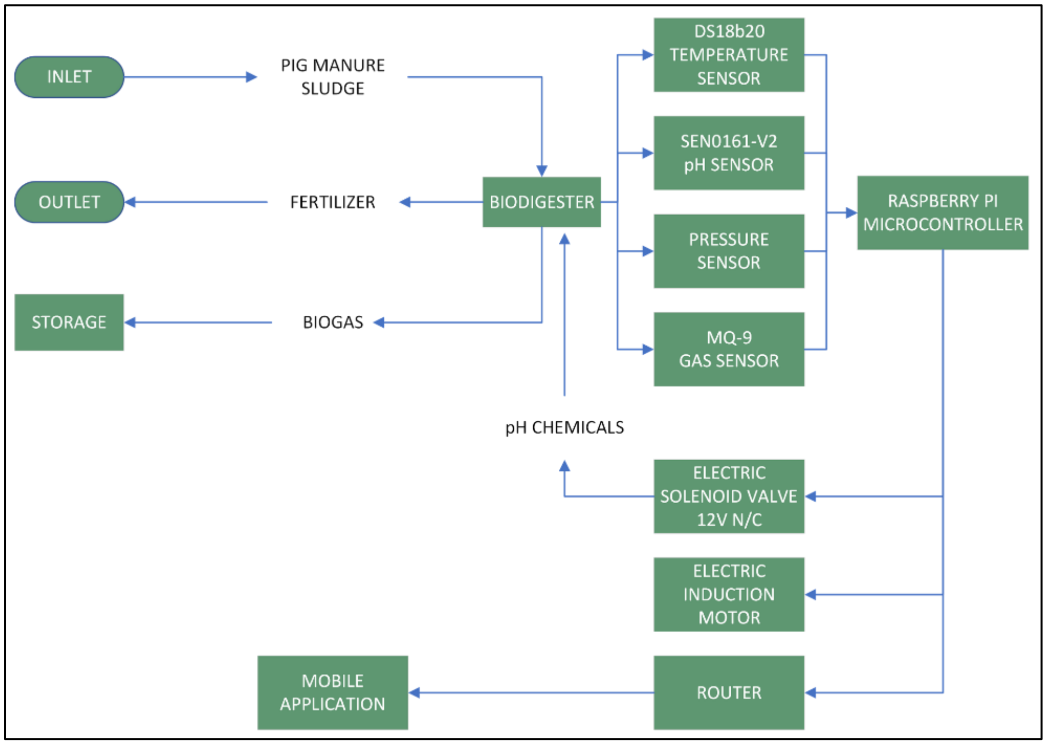


Figure 5. Block Diagram of the Closed-Loop Control System.

Figure 5 depicts the connection between the components such as sensors, microcontrollers, modules, and regulators inside the biodigester. The sensors such as temperature sensor (DS18b20) pH sensor (pH probe), gas sensor (MQ-214), and pressure sensor (LPS35HW) will record the current parameters in the biodigester. The data gathered by the sensors will be transmitted into raspberry pi which will run the optimization algorithm. Subsequently, the data gathered here can be accessed on the database through an IoT-based smart phone application. Then the algorithm will return a specific value of pH level in which the electronic solenoid valve will regulate the flow of pH according to its value. The solenoid valve for base will open if the pH level needs to go down, while the solenoid valve for acid will open if the pH level needs to go up. After a while the motor, which is controlled also by the Raspberry Pi, will mix and the cycle will repeat again. Once the system learns that there is no more gas produced it will notify the user to get the fertilizer and reload manure in the system. The stored biogas can be used as an input for generator or as a raw output for cooking, or any heat related activities.

3.4 Development of Appropriate Gradient Descent Algorithm

This section presents the various methodologies for developing appropriate Gradient Descent algorithms and the respective software that will be used to perform the testing.

3.4.1 Algorithm Testing

The proponents proposed using the Gradient Descent as an optimizer for the pH level in the biodigester. The algorithms that will be used are the Stochastic Gradient Descent, Batch Gradient Descent, and Mini-Batch Gradient Descent. The proponents will test these three most used algorithms on which is the most applicable to be used as an optimizer for the biodigester to increase production. Stochastic Gradient Descent was chosen because it can be updated continuously online. Which the proponents believe would be relevant to the system they would build. Batch Gradient Descent or Vanilla gradient descent is picked since the retention time of the data will determine, or when the sludge does not produce any significant gas in a given time. Batch gradient descent disadvantage is that it does not allow the programmer to update the model online resulting into slow and intractable for datasets that do not fit in the memory. At the same time, Mini-Batch Gradient Descent is used for sparse data. Mini Batch Gradient Descent offers faster navigation than Stochastic Gradient Descent but offers much more complex code, resulting in more consumed memory. The proponents will test these algorithms and choose the most suitable algorithm to perform faster and reduce error.

As recommended to the proponents, the algorithm that will be used will no longer be Gradient Descent as it is not applicable to the study. The proponents will now be using different machine learning algorithms that fit their study. The three machine learning algorithms are Multivariate Regression, Knapsack algorithm and Simplex method algorithm. The new algorithms are to be tested to the system and their results will be compared to choose which will be the most applicable and best optimization algorithm for the system.

3.4.2 Software

The software that the proponents plan to use is Python. The proponents plan to implement TensorFlow as one of the libraries for optimization. The sensors will record their data every five mins. Then the data gathered by the sensor (Biogas Produced) will be recorded and saved in the csv file. Then the function gradient descent code will read the csv file and process the code. The code is expected to have an output of pH level. After a day, the sensor will again record the biogas and deduct it from the previous reading to determine the overall amount of biogas generated. The procedure will then repeat.

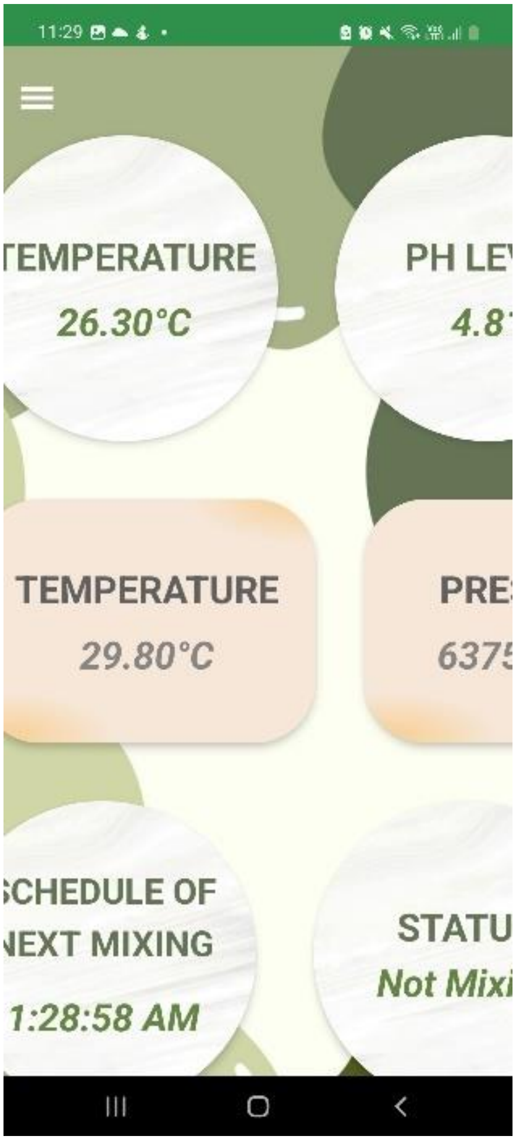
3.5 Development of a IoT Application for Monitoring of the System

This section will present the various methodologies for developing the website that will show the needed information for monitoring the biodigester.

3.5.1 IoT Mobile Application

Figure 6. Main Page **Figure 7.** Login Page of Bioptimize App

The proponents will develop a mobile application as an IoT platform through Kodular, a Python cross-platform framework developed to aid in efficient software development. Kodular utilizes cutting-edge user interfaces, such as multi-touch applications. Users prefer native looks in most apps, however UI designs that stand out might be effective design decisions that help users utilize your program on several devices without any problems. Kodular employs a bridge technique to compile the code, therefore creating apps in it takes a little longer. Flutter improves the development of applications and facilitates testing by compiling to native code that runs on the Dart VM [70] The mobile application will display the following features: Biogas Produced, Storage Pressure for the condition of the storage and to maintain safety, Temperature of the Manure and gas inside the Biodigester, pH level, Amount of Acid and Base. The relationship between the Gas Production and Consumption of Biogas. The application will also generate graphs illustrating the relationship between Gas Production and Consumption of Biogas, Electricity Produced vs. Consumption of Biogas, and Capacity of Manure vs. Total Capacity of the Biodigester. The IoT mobile application will monitor the following parameters: temperature, pH level, electricity produced, pressure and gas volume. Additional features such as a notification system for high pressure inside the biodigester for safety.



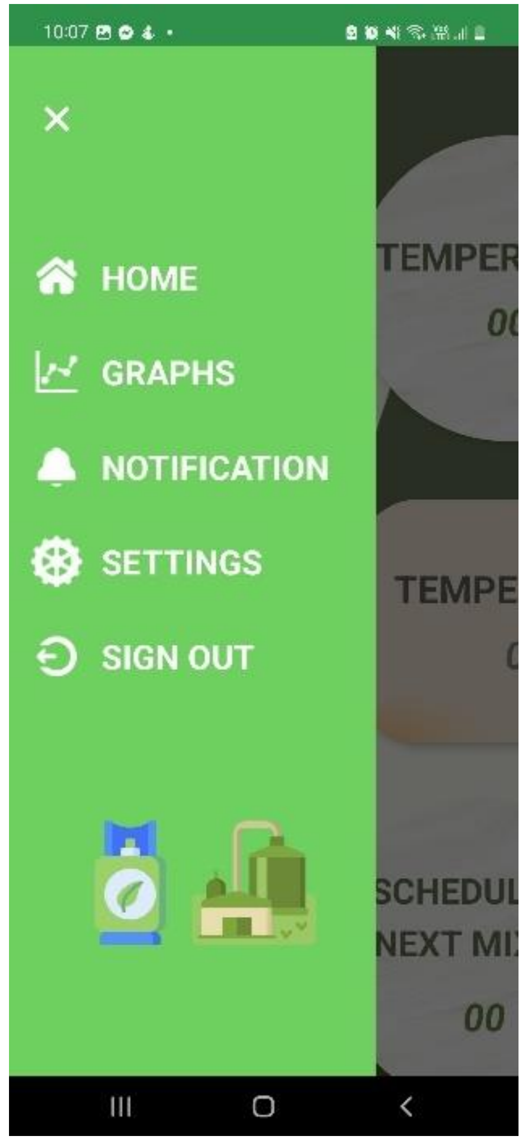


Figure 8. The Parameters **Figure 9.** Main Menu of Bioptimize App

The proponents were introduced to MIT inventor app that was recommended by the experts. They suggested that to create an app development in significantly less time than the abovementioned programming environment, the proponents are advised to use the said platform. This platform offers a blocks-based tool that makes creating complicated structures easier and takes less time and effort. For that reason, the abovementioned cross-platform of python framework for GUI apps are neglected by the proponents to create a mobile application. Nevertheless, the proponents continued to utilize the Python programming language and were able to integrate and create an efficient and working mobile application. The mobile application will display the following features: Biogas Produced, Storage Pressure for the condition of the storage and to maintain safety, Sludge and Gas Temperature, pH level for the amount of acid and base, and the motor status.

Figure 10. Settings Menu

The application will also generate graphs illustrating the relationship between the measured pH level vs biogas produced and the biogas produced per day. A notification system for high pressure inside the biodigester, a kill button to turn the system off if necessary, and options for more information are additional features to ensure safety. In response to the panelist's request, the researchers have successfully incorporated comprehensive harvesting and safety manuals into their system, ensuring that users have access to detailed instructions and guidelines for harvesting practices and maintaining safety standards while utilizing the technology. These manuals provide valuable resources for users, empowering them with the knowledge and guidance necessary to operate the system effectively and safely.

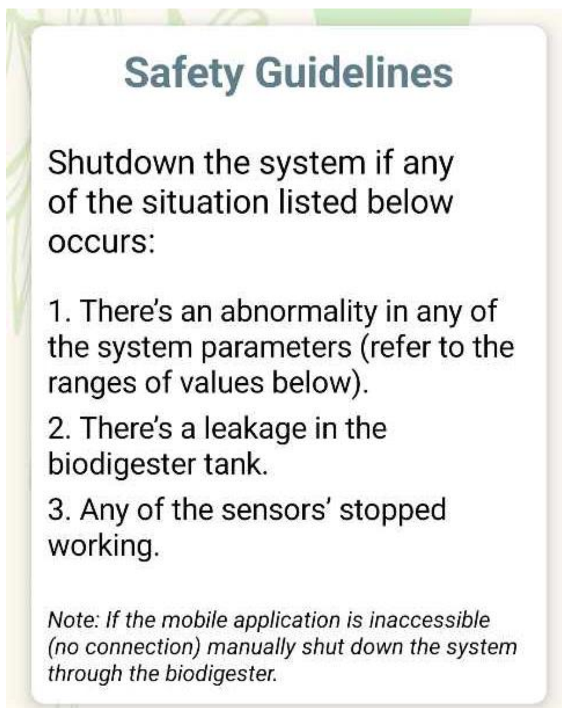


Figure 11. Safety Guidelines in the Bioptimize App

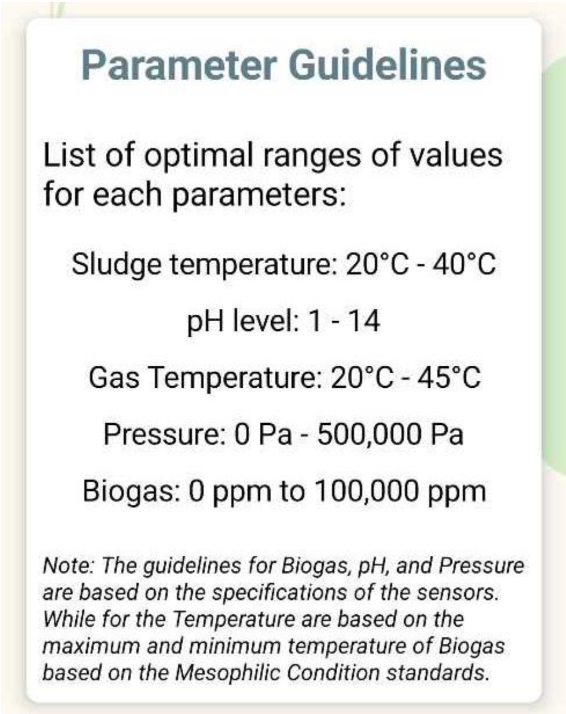


Figure 12. Parameter Guidelines in the Bioptimize App

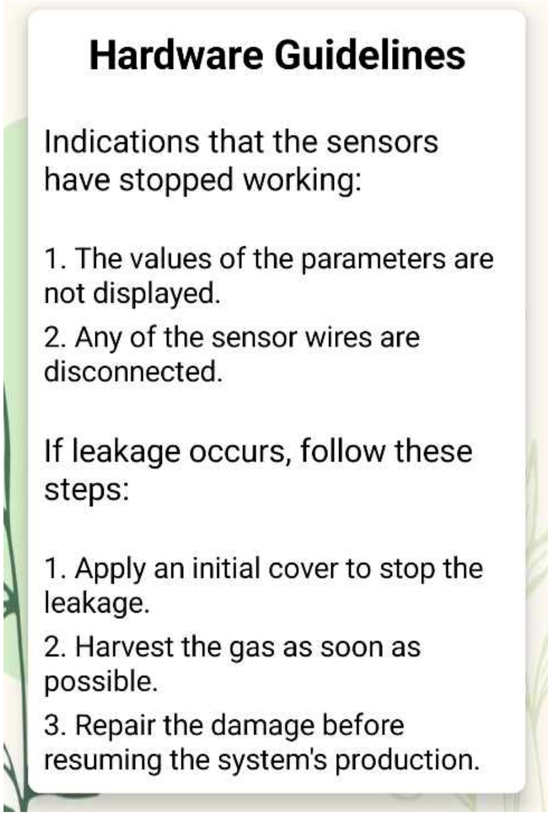


Figure 13. Hardware Guidelines in the Bioptimize App

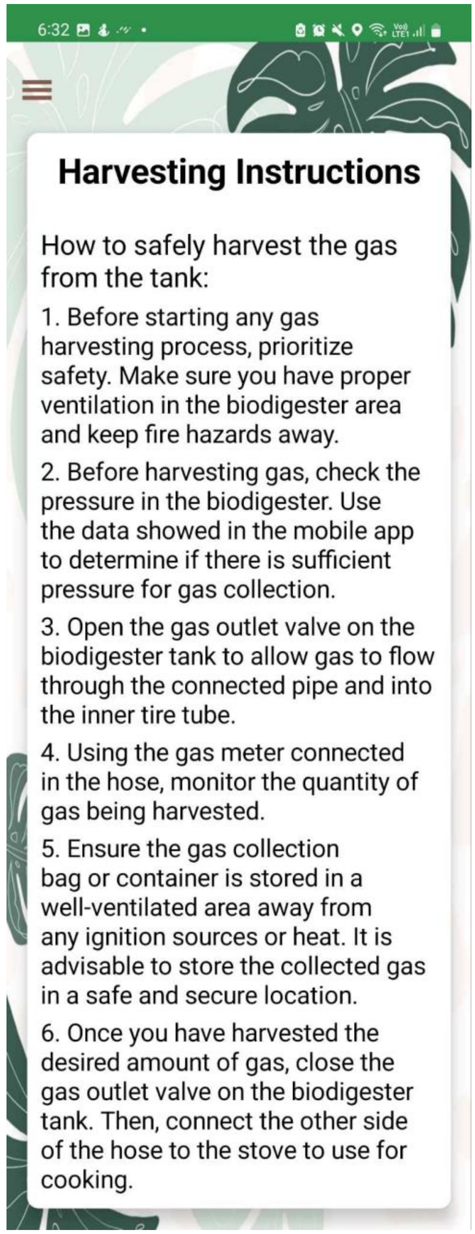


Figure 14. Harvesting Instructions in the Bioptimize App

The pages dedicated to guidelines and safety in the biodigester application provide essential information for users to ensure proper operation and minimize potential risks. These guidelines cover various aspects, including installation, start-up procedures, feedstock handling, and maintenance protocols. They emphasize the importance of following safety precautions, such as wearing appropriate protective gear, ensuring proper ventilation, and adhering to electrical and fire safety measures. Additionally, the guidelines outline best practices for monitoring and controlling parameters within the biodigester, such as temperature, pH levels, and gas pressure, to ensure optimal performance and prevent potential hazards. By providing clear and comprehensive instructions, the application promotes the safe and efficient use of biodigesters, minimizing risks to both the users and the environment.

3.5.2 Program Flowchart

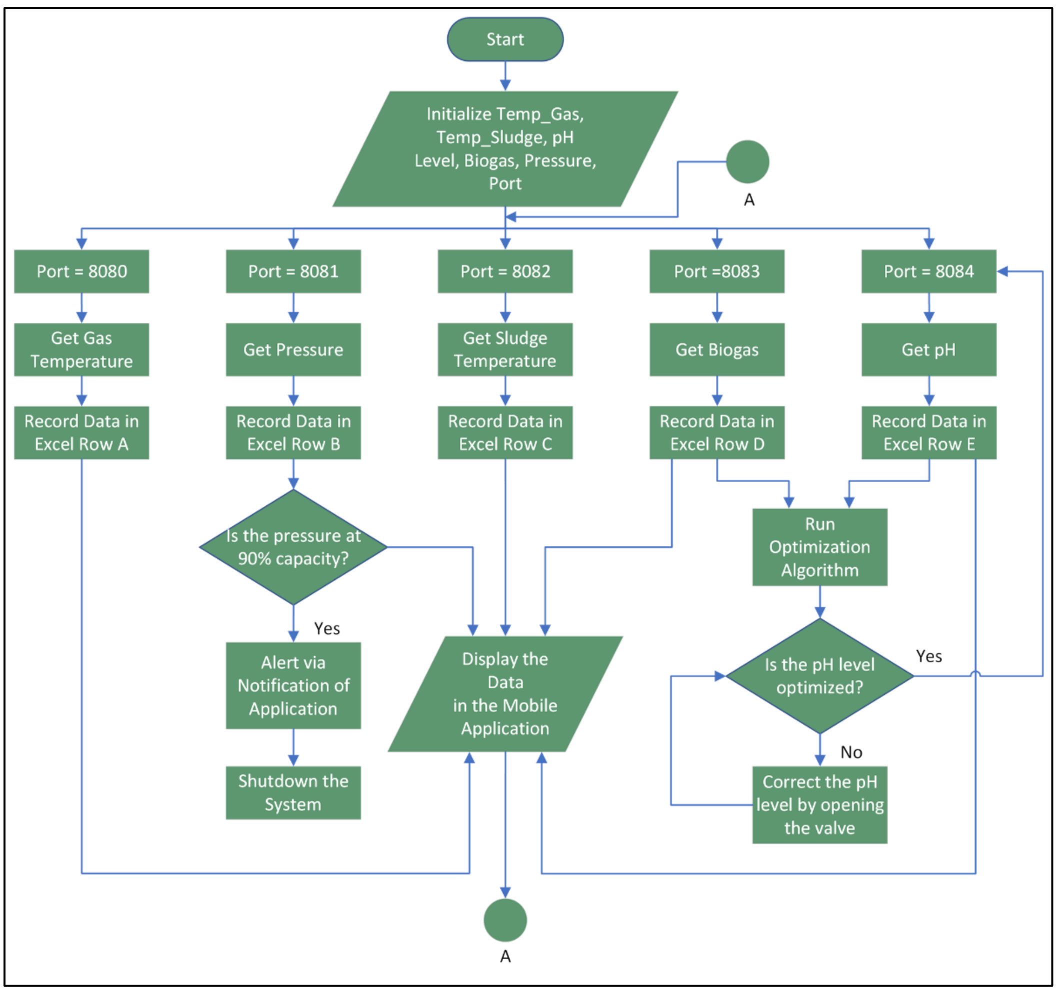


Figure 15: System Flowchart

Figure 15 depicts how the system operates and does the process of the biogas production. First, the proponents will initialize all sensors as well as the data set gathered from the manual testing. The proponents will do this in order to have a startup value that will correct the biodigester in its first run. After correcting the system, the pH level of the valve will open as feedback to correct the current pH level of the sludge. Limewater will be used to decrease the pH level, while alkaline water will be used to increase the pH level. At the same time, the propeller will mix for a n minute and wait for 1 hour for the pH level to take effect. After 1 hour the system will get the data from the pressure, and gas production to run as a system check. It will first check if the biodigester has a large amount of pressure. If it has the system will notify the user that storage is needed to empty the gas in the biodigester chamber. If the biodigester is not full it will also run a test check for the sludge if the system does not see any huge factor of biogas production, it will notify the user that the sludge in the system is now ready to be used as a fertilizer. These data will be inputted in the IoT/Website. If there is a significant change in the gas production the pH level will now be optimized using gradient descent algorithm. In the algorithm it will look for the best suitable pH level in the present condition of the biodigester such as temperature, and gas production. The calculated amount of pH level, temperature, and gas produced will be recorded in the database. Then the sensor will collect the new data of sensors e.g. temperature and pH level.

3.6 User and Expert-Acceptance of the Software and Field Testing of the Biodigester

This section provides the planned methodologies for consultation of experts and testing of the prototype and system implemented in a backyard farm setup.

3.6.1 Data Collection

The researchers will manually collect data on temperature, pH level, and biogas output while maintaining manure inside the digester in order to determine the initial value for the optimization approach. The data will also be used to determine the mixing time and the retention time of the manure.

3.6.2 Prototype Testing

Following data collection, the system will be trained using the initial values until stable positive feedback is established. Once established, it indicates that the prototype is self-learning; the proponents will begin collecting data every day with the determined retention time. With the collected data, the proponents will be able to track the progress of biogas production as well as its learning rate. Lastly, the proponents will check if the IoT-based monitoring system displays the acquired data accurately.

3.6.3 Calculating and Comparison of Results

Using the selected test, the production results will be compared to the initial values representing the traditional biodigester.

3.6.4 Validation - ISO STANDARD

To determine the prototype's functionality and application, the proponents will gather feedback on the performance of Bioptimize: A closed loop biodigester system that utilizes Gradient Descent for pH level optimization to increase biogas production, and monitoring system through IoT application. The evaluation will be based on several characteristics in accordance with ISO 25010 to establish the software's quality and a technical evaluation, as well as ISO 20675 to demonstrate the study's contribution to the development, application, and production of biogas.

Table 5. Expert-Professional Survey Form based on ISO 25010

Introduction: The students involved in the completion of this study must conduct a questionnaire to assess various factors and parameters, entitled *"Bioptimize: A closed-loop biodigester system that utilizes an algorithm for pH level optimization to increase biogas production, and monitoring system through IoT application"*					
Instruction: Please rate each criterion and choose one answer if your assessment meets this rating. Select one best answer from the following options. **1** – Strongly Disagree, **2** – Disagree, **3** – Neutral, **4** – Agree, **5** – Strongly Agree.					
Survey statements	**Rating**				
	1	**2**	**3**	**4**	**5**
Functionality and Efficiency					
1. The closed-loop biodigester is more efficient than the traditional method.					
2. Optimizing pH level increases biogas production					
3. The biodigester provided energy and cooking fuel for the user.					
4. The production of biogas reduced the polluting tendencies of animal manure.					
5. The information in the application's interface for monitoring is clearly displayed and in real-time.					
Usability and Aesthetics					
6. The whole system including the application is easy to navigate and learn.					
7. The whole system requires minimum supervision during the entire operation.					
8. The whole system is easy to operate.					
9. The biodigester is pleasing to the eye of the user.					
Mobility and Maintainability					
10. The biodigester does not require special handling during the operation.					
11. The system's instructions are straightforward and easy to follow.					
12. Maintenance of the biodigester and its system does not require so much effort.					
Safety and Reliability					
13. The device does not have health safety risk or physical risk in entire operation.					
14. The inlets, outlets and connection of wires are properly placed.					
15. The biodigester did not cause any explosion or fire incident.					

This assessment form is based on ISO 25010, titled "Systems and software engineering – Systems and software Quality Requirements and Evaluation (SQuaRE) – System and software quality models", which will determine the quality and technical evaluation of the software. This will be answered by both user and the professional. It also includes functionality, efficiency, usability and aesthetics, mobility, and maintainability, as well as safety and dependability, which will help the proponents in gathering user feedback.

For the user's assessment, we prepared a questionnaire that includes different factors and parameters of the system and the mobile application.

Table 6. User Survey Form based on ISO 25010

Introduction: The students involved in the completion of this study must conduct a questionnaire to assess various factors and parameters, entitled *"Bioptimize: A closed-loop biodigester system that utilizes an algorithm for pH level optimization to increase biogas production, and monitoring system through IoT application"*					
Instruction: Please rate each criterion and choose one answer if your assessment meets this rating. Select one best answer from the following options. **1** – Strongly Disagree, **2** – Disagree, **3** – Neutral, **4** – Agree, **5** – Strongly Agree.					
Survey statements	**Rating**				
	1	**2**	**3**	**4**	**5**
Functionality and Efficiency					
1. Bioptimize is more efficient than the traditional biodigester.					
2. The product minimized your electricity bill.					
3. The product helped the user lessen the use of LPG.					
4. The by-product provided an alternative organic fertilizer.					
5. The mobile app helped the user track the parameters in real time.					
Usability and Aesthetics					
6. The mobile app is user-friendly.					
7. The interface of the mobile app is pleasing in the eyes.					
8. The user was able to operate the system on their own.					
Maintainability					
9. The user was able to handle the maintenance of the biodigester on their own.					
10. Did the user experience issues in the biodigester quite often?					
Safety and Reliability					
11. There are safety guidelines provided.					
12. The user was able to shut down the system through the mobile app.					
13. The mobile app was able to notify the user about the biodigester's current capacity.					
14. Did the user experience any kind of issues such as:					
- Leaks					
- Biodigester inflation					
- Sensor malfunction					
15. The fertilizer didn't cause soil degradation.					
16. The fertilizer didn't cause ammonia toxicity.					

3.7 Volume of Methane Emitted from Tank

Since the tank is deployed for a short period of time, small amounts of gas were produced to be able to be used and tested conveniently. With this, the proponents measured the methane output emitted from the hose of the biodigester system. The proponents utilized the fluid dynamics principles. By measuring the flow rate, the proponents will be able to determine the total volume of Biogas emitted by the biodigester.

By concept the formula for the volume flow rate is Q = V/t where Q is the Volume flow rate of the Gas; V is the Volume of the hose; and t is the time on how long the flame burns. Since the proponents would like to know the total volume of biogas emitted by the biodigester. The computation for the theoretical Volume of Gas emitted by the biodigester is the following:

$$Q = \frac{V}{t}$$

$$V = Qt$$

$$V = Avt$$

$$V = \pi r^2 (\frac{d}{t}) t$$

$$V = \pi r^2 d$$

Where:

$$Q = Volume\ flow\ rate$$

$$d = Width\ of\ the\ portion\ of\ the\ fluid$$

$$v = Speed\ of\ the\ fluid$$

$$A = Cross\ sectional\ area\ of\ the\ fluid$$

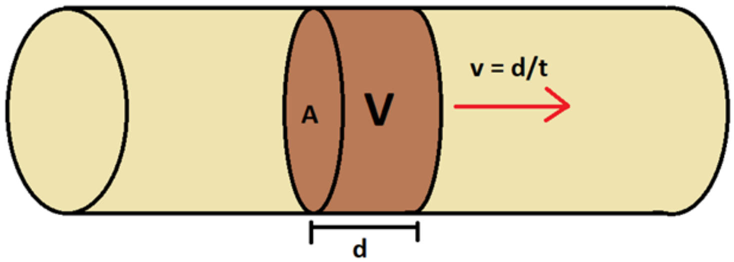


Figure 16: Glass Flow Rate Diagram

3.8 Statistical Analysis

The data gathered was thoroughly documented in tables, examined statistically, and interpreted depending on the outcome of the statistical analysis. In this research, the authors analyzed the data using a single sample t-test.

One sample T-test. A single group's mean is compared to a specified mean.

The formula applied was:

$t = (x1 - x2) / (\sigma / \sqrt{n1} + \sigma / \sqrt{n2})$,

Where:

x1 represents the data prior to establishing the closed-loop control system.

x2 represents the data after the implementation of the closed-loop control system.

Now that the results of the functionality test have been obtained, the data will be compared. From there, the influence of the closed-loop control system on biogas output may be assessed.

3.9 Project Work Plan

Upon developing the system, the proponents observed the Gantt chart as its time frame in creating the whole system.

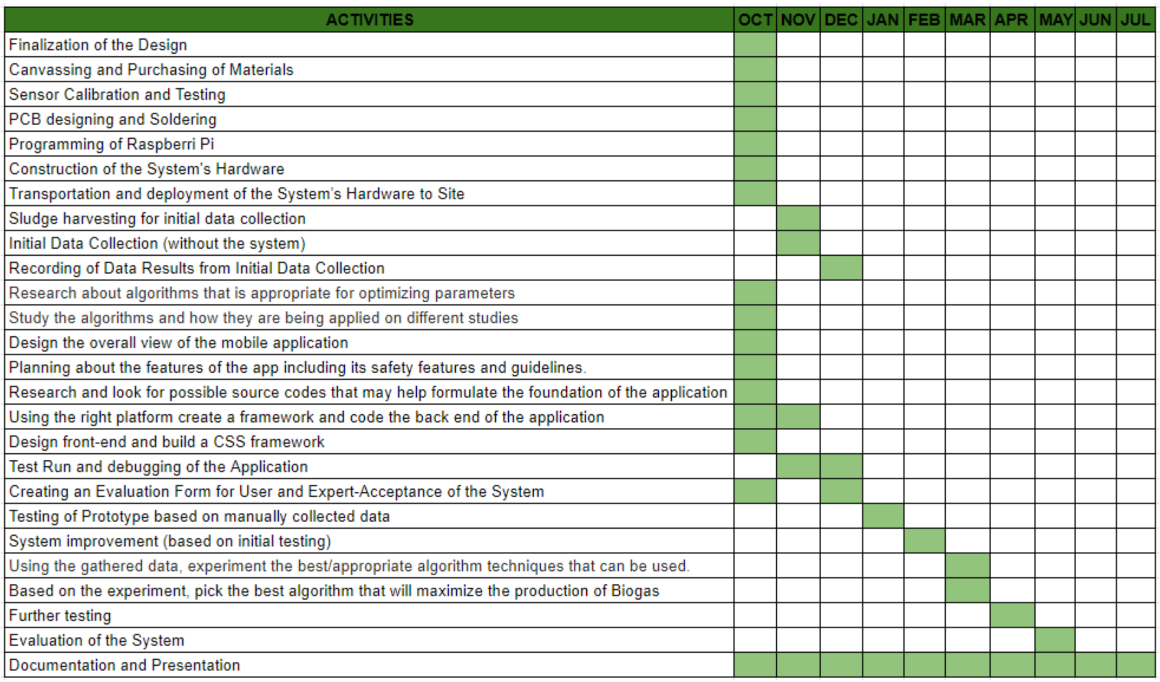


Figure 17. Gantt Chart

CHAPTER 4

RESULTS AND DISCUSSION

This chapter interprets the acquired data and analyzes the outcomes depending on the tests conducted and performed.

4.1. Project Technical Description

The study Bioptimize: A closed-loop biodigester system that utilizes machine learning for pH level optimization to increase biogas production, and IoT application for monitoring system, utilizes a Raspberry pi 4 model B that acts as its microcontroller. In this study, a microcontroller is programmed with Python programming to collect data from various sensors that measure the parameters needed for the study. A mobile application that will be used for IoT monitoring will be developed using C sharp programming and MIT App Inventor to provide users with a visual representation of the data.

A total of two sensors are used, one for gas and one for sludge. Using Machine Learning, the microcontroller will optimize the necessary base and acid chemicals to keep the sludge at a pH level that is optimal for its production by recording data and sending it to the microcontroller. An electronic valve, controlled by the microcontroller, will be used to control the pH chemicals.

Data from the sensors will be sent to the mobile application remotely through the internet in order to monitor the values and gas production within the system. Additionally, the mobile application contains convenient functions for the user, including the history of values, a visual representation of the data in graphs, a notification system, and a switch that can be used to turn off and on the system. Furthermore, the mobile app has a login function that protects the system from unauthorized users, since it can cause problems for both the system and the users.

4.2. Project Structural Organizational

4.2.1 Parts of the System

The system consists of a Raspberry Pi 4 microcontroller, a smartphone, sensors, a single-phase induction motor, a propeller, a solar panel, a polyethylene tank, solenoid valves, and an internet modem. The Raspberry Pi 4 serves as the software system's microcontroller. Meanwhile, the smartphone serves as both a monitoring and notification device for users. The aforementioned devices are networked together by an internet modem for a wireless and long-distance connection.

The sensors are for temperature (DS18b20), pH (SEN0161-V2), pressure (BMP 180), and gas (MQ-9). The sensors are separated into two readings: the BMP180 and MQ-9 read the biodigester tank's gas, while the DS18b20 and SEN0161-V2 detect the temperature and pH level of the sludge. The single-phase induction motor has 1/2 horsepower and is devised as the mechanism that would actuate the propeller. The propeller has two three-blade fans mounted on a polyethylene tube designed to mix the sludge inside the biodigester tank. To power the entire system, the solar panel set includes a 100W photovoltaic module with a 55-ah battery, a 12V-30A solar charge controller, a 12V DC to 230 AC inverter, MC-4 connectors, and a fuse.

Lastly, the biodigester tank is made up of polyethylene material, which is best suited for a biodigester function. The solenoid valves are also utilized to maintain the pH level of the sludge by constantly dropping natural chemicals.

4.2.2 Backyard Pig Farm

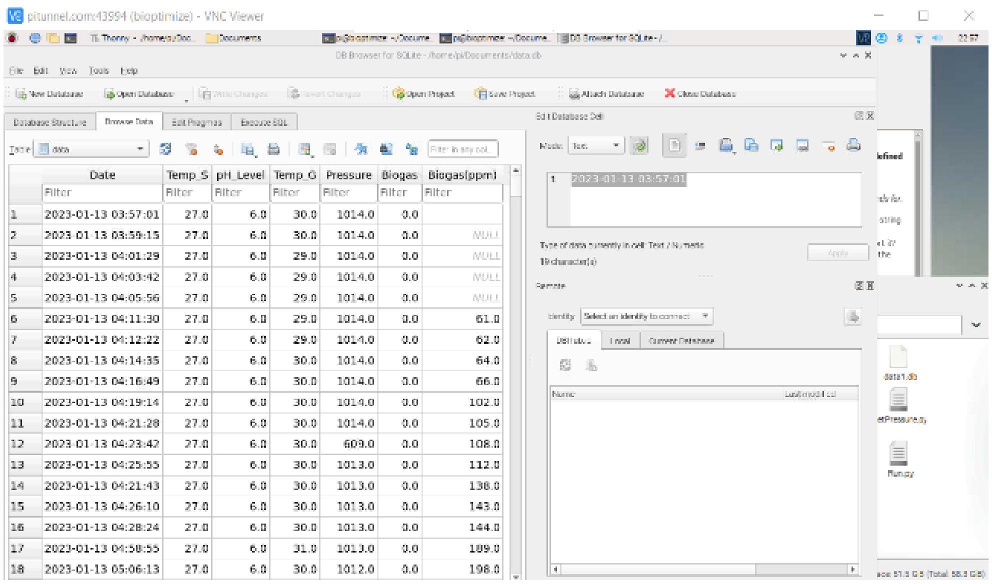
The deployment site is located at Purok Uno, Sampaga, San Antonio Quezon. A privately owned backyard piggery farm that has 100-150 pigs. The farm's lot area is approximately 500 square meters, which includes a few pigpens and houses for a residential area for its caretakers. The figure shown below is the actual backyard pig farm.

Figure 18: Actual Backyard Pig farm.

4.3 Experimental Results and Data Analysis

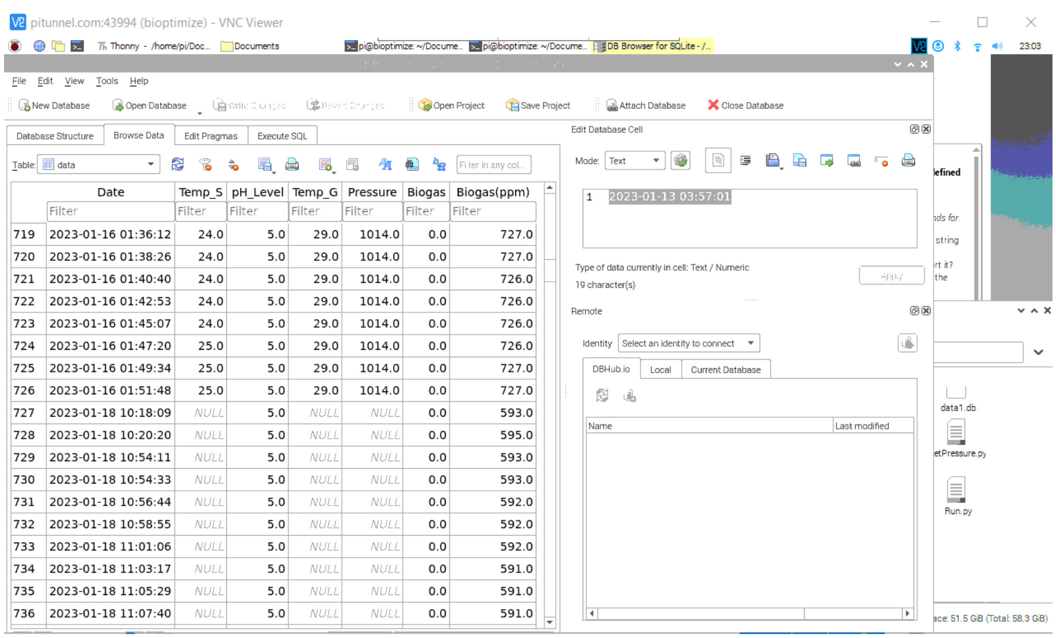
4.3.1 Database Results from Mobile Application

For the first database, 4396 data sets have been generated, and for the second database, 1213 data sets have been generated. It is estimated that the proponents have collected at least 5500 datasets as of January 31, 2023. However, they encountered a problem with one of their sensors during data collection. As shown in Figure 18, biogas production has drastically decreased as a result of an accident that occurred within the site where the wire was chipped by the guard dog. (See Figure 18). For the full view of the csv file see the link here (shorturl.at/nVY17)



	Date	Temp_S	pH_Level	Temp_G	Pressure	Biogas	Biogas(ppm)
1	2023-01-13 03:57:01	27.0	6.0	30.0	1014.0	0.0	
2	2023-01-13 03:59:15	27.0	6.0	30.0	1014.0	0.0	NULL
3	2023-01-13 04:01:29	27.0	6.0	29.0	1014.0	0.0	NULL
4	2023-01-13 04:03:42	27.0	6.0	29.0	1014.0	0.0	NULL
5	2023-01-13 04:05:56	27.0	6.0	29.0	1014.0	0.0	NULL
6	2023-01-13 04:11:30	27.0	6.0	29.0	1014.0	0.0	61.0
7	2023-01-13 04:12:22	27.0	6.0	29.0	1014.0	0.0	62.0
8	2023-01-13 04:14:35	27.0	6.0	30.0	1014.0	0.0	64.0
9	2023-01-13 04:16:49	27.0	6.0	30.0	1014.0	0.0	66.0
10	2023-01-13 04:19:14	27.0	6.0	30.0	1014.0	0.0	102.0
11	2023-01-13 04:21:28	27.0	6.0	30.0	1014.0	0.0	105.0
12	2023-01-13 04:23:42	27.0	6.0	30.0	609.0	0.0	108.0
13	2023-01-13 04:25:55	27.0	6.0	30.0	1013.0	0.0	112.0
14	2023-01-13 04:21:43	27.0	6.0	30.0	1013.0	0.0	138.0
15	2023-01-13 04:26:10	27.0	6.0	30.0	1013.0	0.0	143.0
16	2023-01-13 04:28:24	27.0	6.0	30.0	1013.0	0.0	144.0
17	2023-01-13 04:58:55	27.0	6.0	31.0	1013.0	0.0	189.0
18	2023-01-13 05:06:13	27.0	6.0	30.0	1012.0	0.0	198.0

Figure 19: Screenshot of First Database Readings



	Date	Temp_S	pH_Level	Temp_G	Pressure	Biogas	Biogas(ppm)
719	2023-01-16 01:36:12	24.0	5.0	29.0	1014.0	0.0	727.0
720	2023-01-16 01:38:26	24.0	5.0	29.0	1014.0	0.0	727.0
721	2023-01-16 01:40:40	24.0	5.0	29.0	1014.0	0.0	726.0
722	2023-01-16 01:42:53	24.0	5.0	29.0	1014.0	0.0	726.0
723	2023-01-16 01:45:07	24.0	5.0	29.0	1014.0	0.0	726.0
724	2023-01-16 01:47:20	25.0	5.0	29.0	1014.0	0.0	726.0
725	2023-01-16 01:49:34	25.0	5.0	29.0	1014.0	0.0	727.0
726	2023-01-16 01:51:48	25.0	5.0	29.0	1014.0	0.0	727.0
727	2023-01-18 10:18:09	NULL	5.0	NULL	NULL	0.0	593.0
728	2023-01-18 10:20:20	NULL	5.0	NULL	NULL	0.0	595.0
729	2023-01-18 10:54:11	NULL	5.0	NULL	NULL	0.0	593.0
730	2023-01-18 10:54:33	NULL	5.0	NULL	NULL	0.0	593.0
731	2023-01-18 10:56:44	NULL	5.0	NULL	NULL	0.0	592.0
732	2023-01-18 10:58:55	NULL	5.0	NULL	NULL	0.0	592.0
733	2023-01-18 11:01:06	NULL	5.0	NULL	NULL	0.0	592.0
734	2023-01-18 11:03:17	NULL	5.0	NULL	NULL	0.0	591.0
735	2023-01-18 11:05:29	NULL	5.0	NULL	NULL	0.0	591.0
736	2023-01-18 11:07:40	NULL	5.0	NULL	NULL	0.0	591.0

Figure 20: Database Upon Accident

Consequently, the proponents created another database that is more durable and continues even if the sensor does not function correctly by returning NULL. Furthermore, the proponents upgraded the casing and rewired the circuit to prevent future damage to the wire. (See Figure 20)

Figure 21: New Casing of the Raspberry Pi and Wires

4.3.2 Machine Learning Algorithm

In this study, three machine learning optimization algorithms were tested in order to choose the best option for our system, namely Multivariate Regression, Knapsack, and Simplex algorithm. With our initial testing, the data were used to test the algorithms. Using pandas that will read the .db file on the SQLite database, the initial optimized value of pH level per temperature level was determined using the three algorithms. As a result, the mean square error, root mean square error and r squared were the basis of choosing the best algorithm for the system.

```
1/1 [==============================] - 0s 15ms/
1/1 [==============================] - 0s 16ms/
1/1 [==============================] - 0s 15ms/
1/1 [==============================] - 0s 16ms/
Best pH for maximum gas output: 3.3
Mean squared error: 0.12
Root mean squared error: 0.34
R-squared: 0.84
```

Figure 22: Multivariate via Neural Network

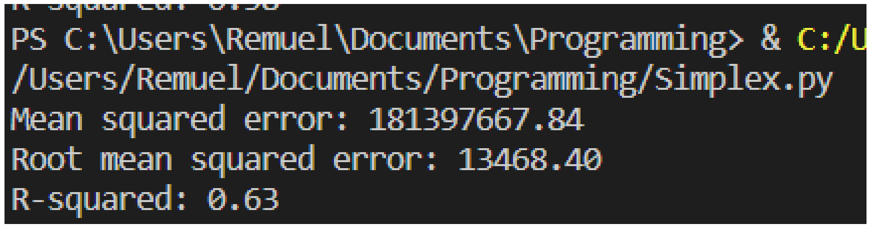

```
PS C:\Users\Remuel\Documents\Programming> & C:/U
/Users/Remuel/Documents/Programming/Simplex.py
Mean squared error: 181397667.84
Root mean squared error: 13468.40
R-squared: 0.63
```

Figure 23: Simplex

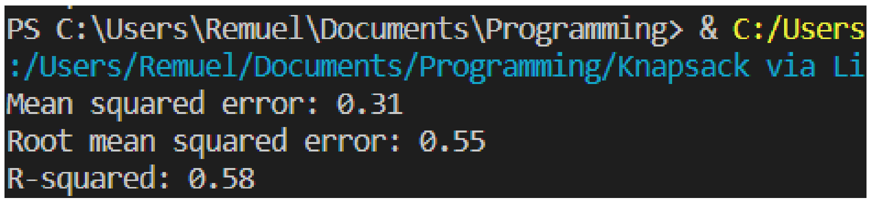

```
PS C:\Users\Remuel\Documents\Programming> & C:/Users
:/Users/Remuel/Documents/Programming/Knapsack via Li
Mean squared error: 0.31
Root mean squared error: 0.55
R-squared: 0.58
```

Figure 24: Knapsack via Linear Regression

Based on the obtained findings, the researchers have reached a conclusion that the multivariate regression algorithm outperforms the other two algorithms. The utilization of multivariate regression resulted in the lowest values for both the Mean Squared Error and the Root Mean Squared Error. Conversely, the remaining two algorithms exhibited considerably higher error values, rendering them unsuitable for integration into the system.

4.3.3 Findings from Initial Testing

According to our database, the proponents were able to see that the data had not yet experienced significant changes every two minutes. Therefore, the proponents believe that the delay should be increased from 2 minutes to 5 minutes when the data is recorded in the database. Additionally, the pressure sensor BMP180 does not fit as a sensor in a gas tank due to its failure within three days of installation. Possibly, this is due to the black particles that lead to rust in the gas, which interfere with the sensor's functionality (see Figure 24). As a result, it was determined that a new sensor would be required.

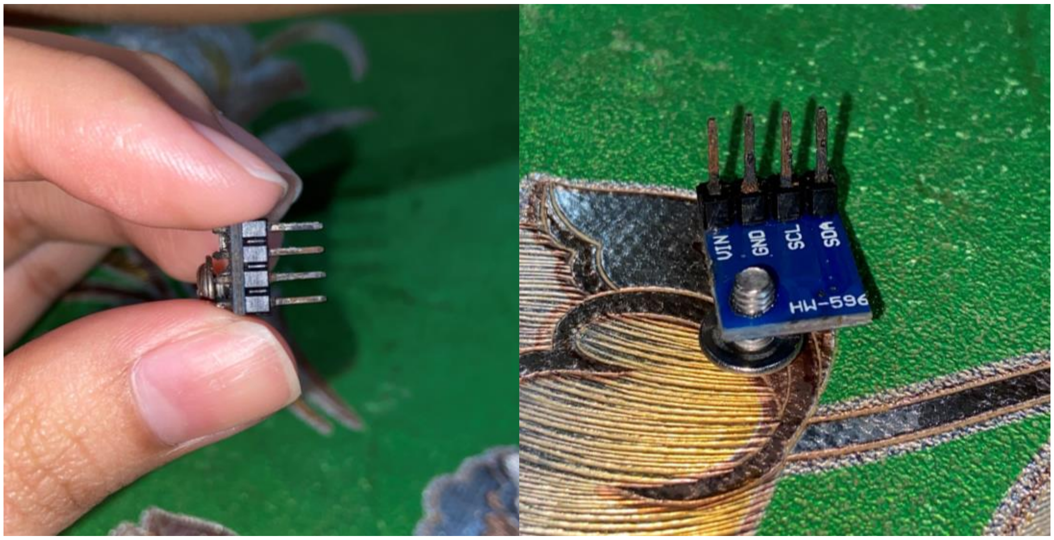


Figure 25: Black Particles from the Sensor BMP180

With the following adjustments, a complete data result for the biogas was obtained shown in figure 26. This result was gathered using the traditional biodigester procedure and was deployed within 11 days.

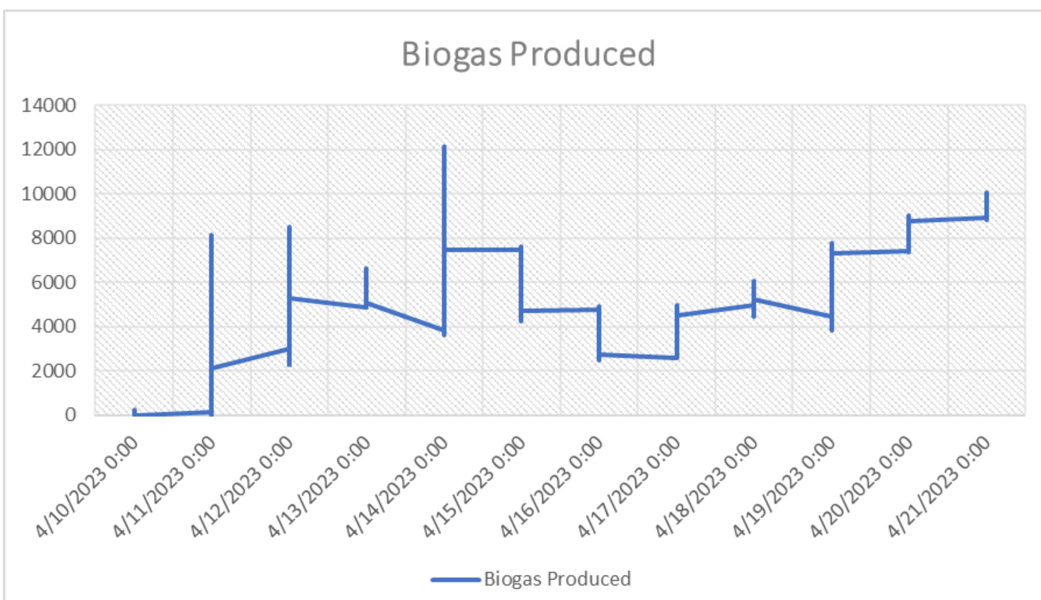


Figure 26: Biogas Produced without the System

The chart provided shows the total amount of biogas produced over an 11-day period. It is worth noting that there is a very small increase in the readings from the MQ-9 Gas Sensor between April 10 and April 11. This slight change is because the researchers allowed the sensor to settle and provide accurate readings for at least two days. Additionally, the researchers noticed occasional spikes in the sensor readings, which could be caused by factors such as temperature and pH levels that are controlled inside the tank to optimize the biogas production process.

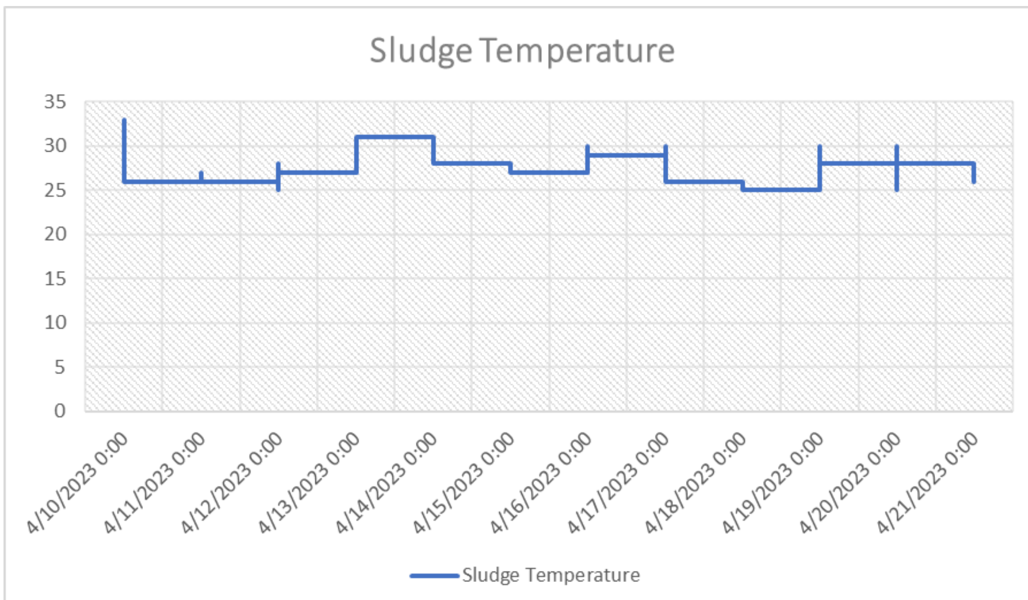


Figure 27: Sludge Temperature without the System

The presented chart depicts the temperature measurements of the sludge inside the biodigester. The researchers have observed that, despite the biodigester's gas tank being temperature resistant, the surrounding environment significantly influences the overall temperature inside the biodigester. This finding emphasizes that external factors can still have a notable impact on the temperature conditions within the biodigester, affecting the biogas production process.

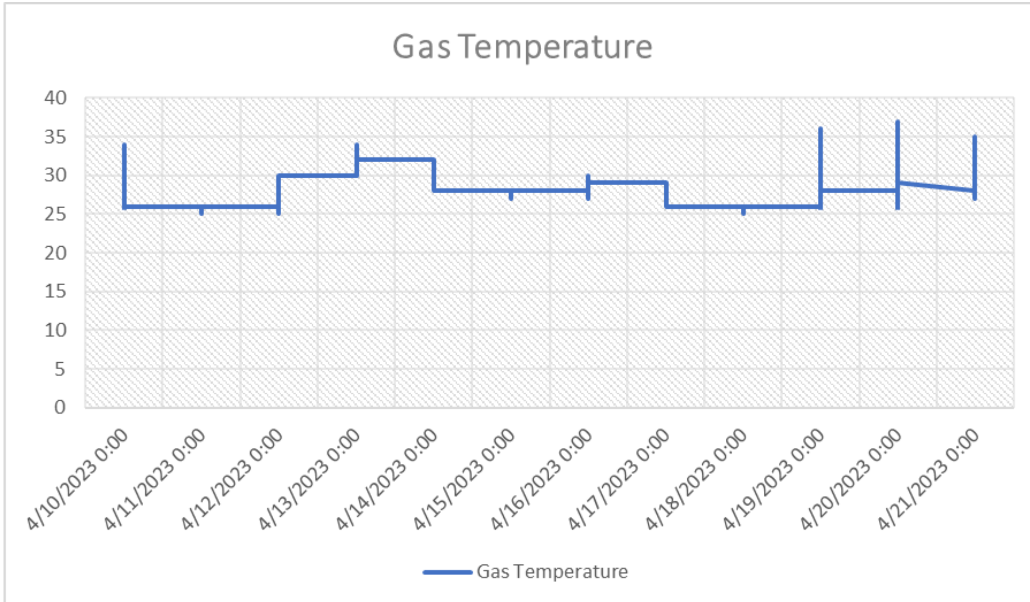


Figure 28: Gas Temperature without the System

The provided chart presents the collected data from the temperature sensor for gas in the biodigester. The researchers have made an interesting observation regarding the correlation between the temperature of the gas and the temperature of the sludge within the system. Notably, there is a strong similarity between the two, as the data reveals that an increase in gas temperature corresponds to a corresponding increase in the sludge temperature. This finding suggests a significant correlation between the thermal dynamics of the gas and the sludge, indicating that changes in gas temperature have a direct impact on the temperature of the sludge. Consequently, the gathered data may be considered redundant due to the consistent relationship observed between these two variables.

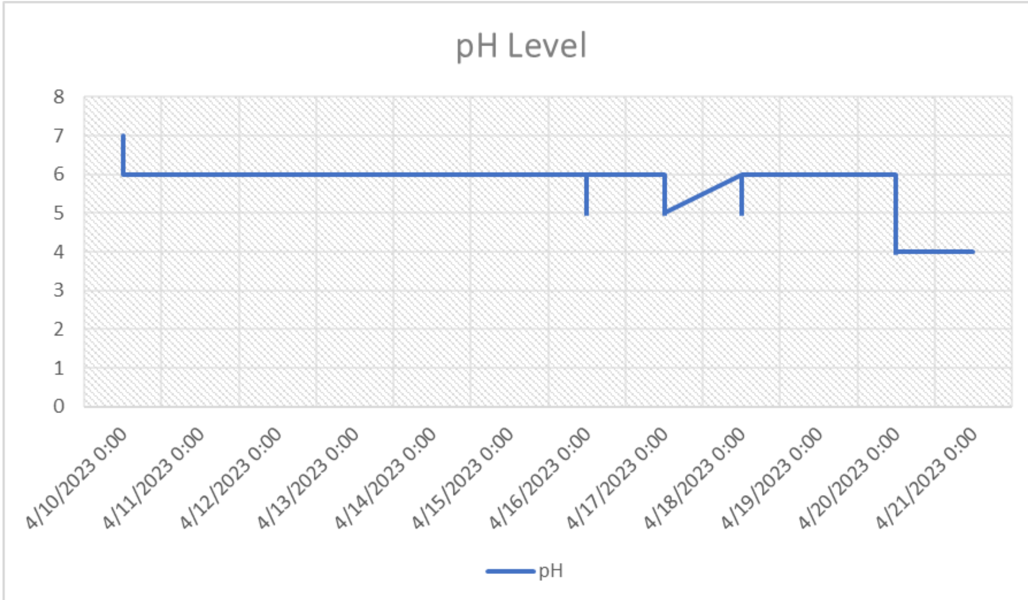


Figure 29: pH Level without the System

The presented chart focuses on the pH level of the sludge with a 1:1 concentration ratio. The researchers noted that the initial pH level of the manure was 7, as water was added to it during the experimental setup. Over time, the pH level gradually decreased to 4. However, it is important to note that the local database CSV (Comma-Separated Values) used for recording the data only accepts integer values. As a result, the decimal values of the pH readings were automatically rounded to the nearest whole number, resulting in an averaged representation of the pH level in the chart. Despite this limitation, the data still provides valuable insights into the overall trend of pH level degradation in the sludge during the experimental period.

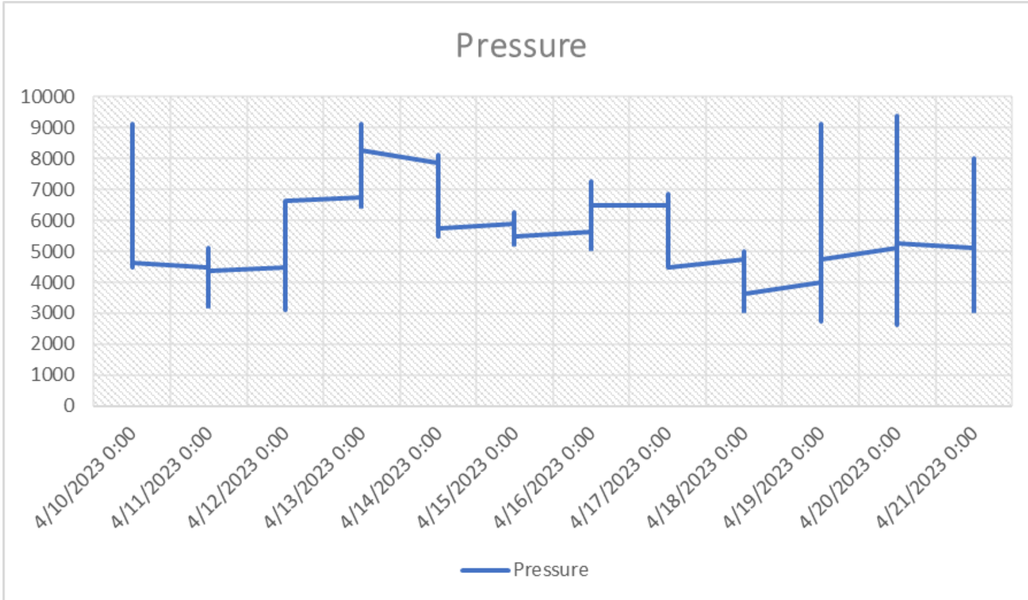


Figure 30: Pressure without the System

The presented chart illustrates the readings obtained from the pressure sensor located inside the tank. The researchers made an observation regarding the behavior of pressure inside the tank, noting that it follows Gay Lussac's Law. According to this law, when the volume of gas is kept constant, the pressure is directly proportional to the temperature. This finding implies that as the temperature increases, the pressure inside the tank also increases, demonstrating the relationship between these two variables. By recognizing the application of Gay Lussac's Law in this context, the researchers provide valuable insights into the understanding of the pressure dynamics within the tank and its dependence on temperature.

4.3.4 Findings from Final Testing

After the initial testing, with similar steps and procedure, the final testing which utilizes the process where the control system is implemented was started.

The final testing was also deployed in the same backyard pig farm with identical time allotment of 11 days. The final testing results are shown in Figure 31.

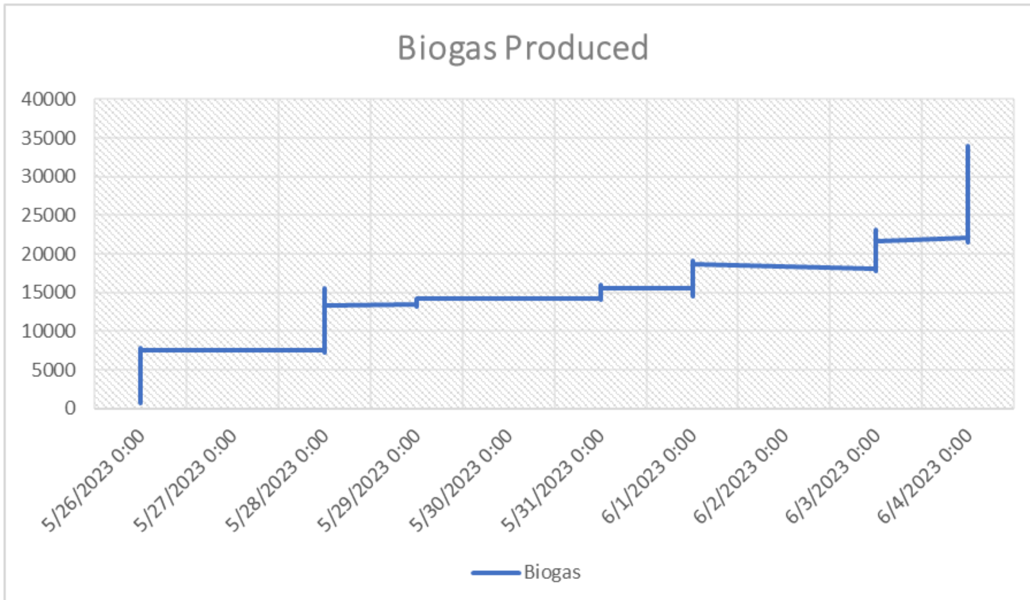


Figure 31: Biogas Production with System

The provided chart focuses on the biogas production of a biodigester equipped with an automatic pH level optimizer. According to the observations made by the researchers, there was a significant increase in biogas production over the course of 11 days. This notable improvement can be attributed to the optimization of the pH level inside the biodigester. The researchers also noted a decrease in the occurrence of spikes in the sensor readings. This can be attributed to the successful optimization of the pH level, which has resulted in a steady and controlled increase in the pH level over time. The optimized pH level has positively impacted the overall biogas production process, leading to a more efficient and consistent generation of biogas.

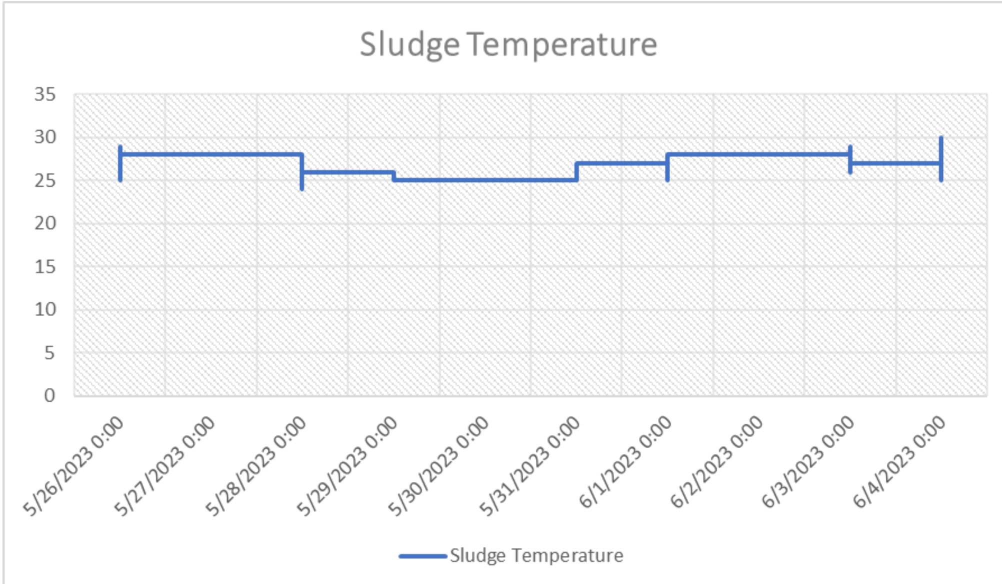


Figure 32: Sludge Temperature with System

Based on the presented chart, it is evident that the temperature of the sludge consistently remains within the range of 25 to 30 degrees Celsius. It can be observed that the temperature ranges of the initial and final tests exhibit notable similarity, primarily due to the deployment of these tests in comparable environments.

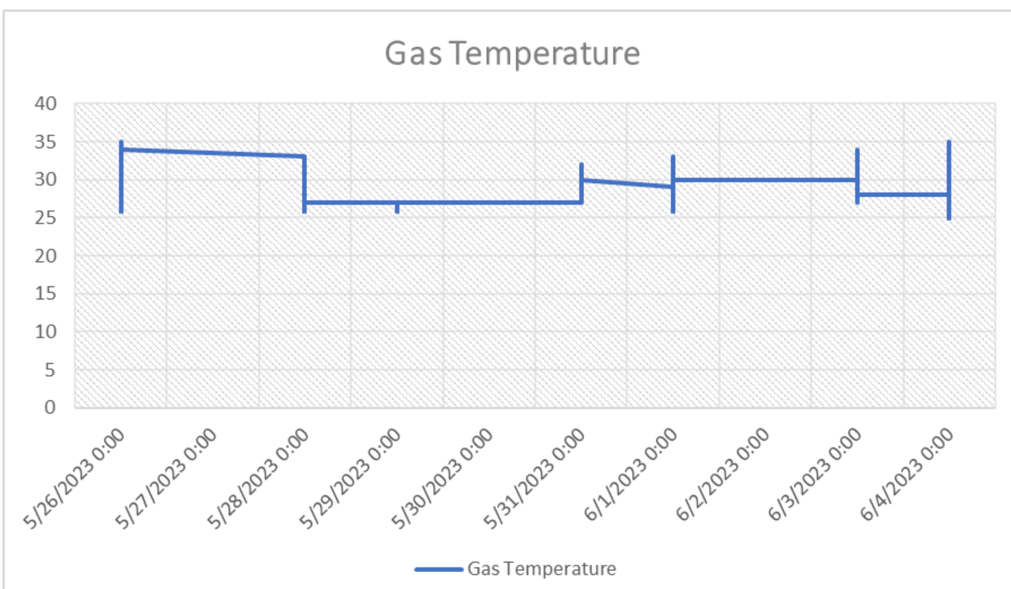


Figure 33: Gas Temperature with System

Similar to the Sludge temperature, the gas temperature was also within a range of temperature, from 25 to 35 degrees Celsius. It is also observed that the outside environment serves as a huge factor to the temperature of the Gas as well as the Sludge. Comparing the charts shows a notable similarity of adjustments. It is visible that both charts share the same movement of values which is a good indication that they have a direct correlation.

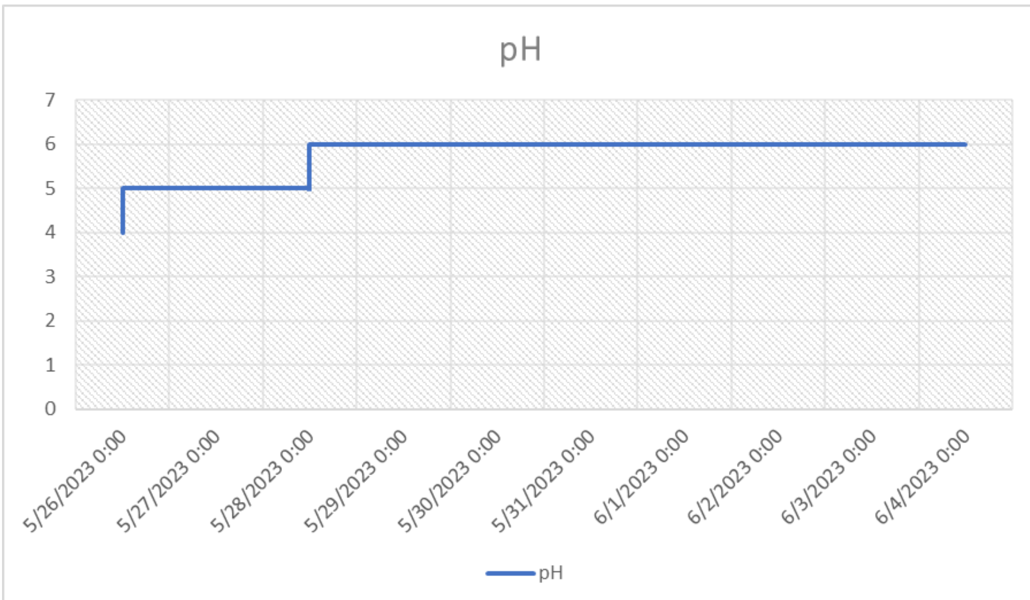


Figure 34: pH Level with System

Comparing both charts, it is evident that there is a noticeable difference in the pH levels between the initial and final testing. Normally, the pH level of the sludge decreases gradually over time. However, in the final test of this study, the pH level was deliberately controlled and optimized, resulting in an increase. The algorithm used in the study determined an average optimized value of 7.9 for every temperature level. Unfortunately, due to a lack of sufficient chemicals to reach the target pH level, it couldn't be achieved. Nevertheless, the overall results still indicate that as the pH value gets closer to the target, the gas production increases.

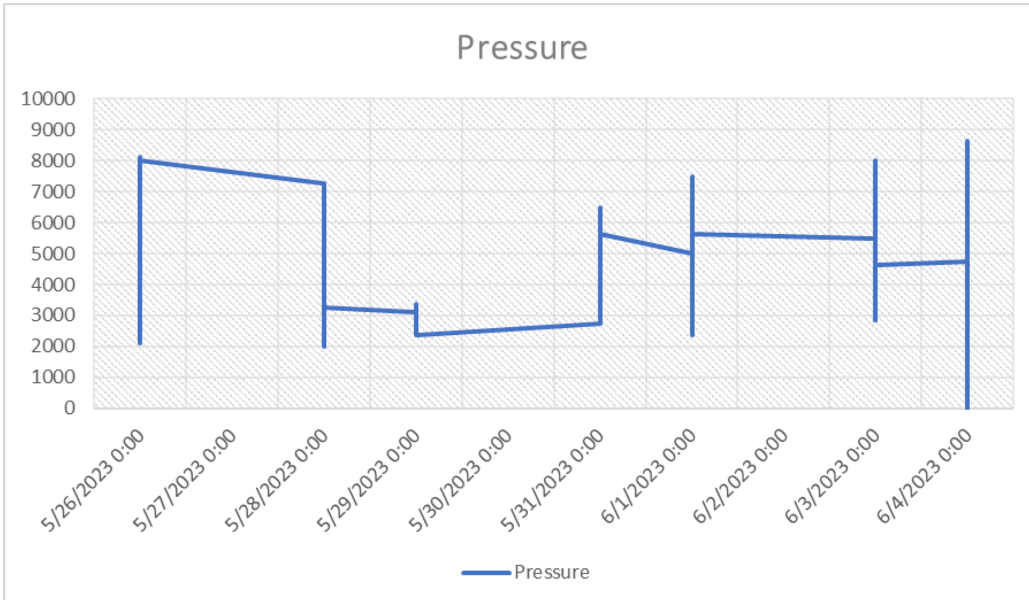


Figure 35: Pressure Level with System

Just like in the initial testing, the pressure inside the tank exhibits a pattern that closely resembles the temperature, indicating a direct proportionality between the two variables, as governed by Gay Lussac's law. By recognizing the application of Gay Lussac's Law in this particular context, the researchers offer valuable insights into comprehending the dynamics of pressure within the tank and its relationship with temperature.

4.3.5 Analysis of Results

Both initial and final testing were deployed with similar steps and procedures, having a 1:1 ratio of sludge (mixture of water and manure) from the same backyard pig farm. The data gathered over an observation period of approximately 11 days reveals that the biodigester system outperforms the non-enhanced system in terms of biogas production. Comparatively, the system without enhancements exhibits a slow increase in biogas or methane concentrations inside the tank, reaching a modest level of 8000 ppm. In contrast, when the system is equipped with enhancements, the biogas production demonstrates a significant improvement.

4.3.6 Volume of Methane Emitted from Tank

During the experimental procedure aimed at determining the volume of methane emitted from the tank, the gas output was ignited briefly. The proponents then calculate the total volume of methane in the biodigester where:

$$r = 0.1925\, inch$$

$$d = 1.5\, meters = 59.9551\, inch$$

$$V = \pi(0.1925\, inch)^2(59.9551\, inch)$$

$$V = 6.9797\ \ inch^3\ of\ methane$$

Therefore, the biodigester produced only $47.089\, inch^3$, this is from the record where in the biogas sensors registered a methane concentration of approximately 30,000 parts per million (ppm), while the combustion lasted for a duration of less than one second. There could be several factors contributing to the low production of methane based on proponents' observations:

- By-Batch feeding process - the process used in this study is by-batch feeding process, and not continuous feeding, it is more fitted to the study since it will focus on the comparison of the traditional way to the one with the system.

- Low pressure - another reason observed is that there is not enough pressure in order to emit a lot of gas out of the tank, also related to the third reason.
- Time of digestion - In this study, the time taken per batch of digestion is 10-15 days. It is observed that the time is insufficient in order to produce a lot of gas since it is a by-batch process which takes more time than continuous process, and that the time is also insufficient to produce the amount of gas that will also increase the pressure in the tank.

Therefore, the proponents suggest a continuous feeding of the manure inside the biodigester. Since microorganisms inside the biodigester needs a feedstock in order to produce more methane. These feedstocks may be in the form of other waste materials such as corn, food waste, or even pig manure itself. The proponents also suggest using air compressor for harvesting and storage of the biogas before making it more usable since biogas are comprised of methane about 50%-75%, carbon dioxide about 25%-50%, and nitrogen about (2%-8%) and traces of other gasses such as ammonia, and hydrogen.

4.3.7 Notification Alerts

In regard to the notification system of the device, there are two ways to communicate with the users. The first is through the application, where if the parameters exceed their limits while using the application, a notification will be displayed. Should the client not be able to be contacted via the internet, the second notification alert will be sent by SMS. It will be possible for these notifications to contact the user and remind them to take precautionary measures to protect the system and the client.

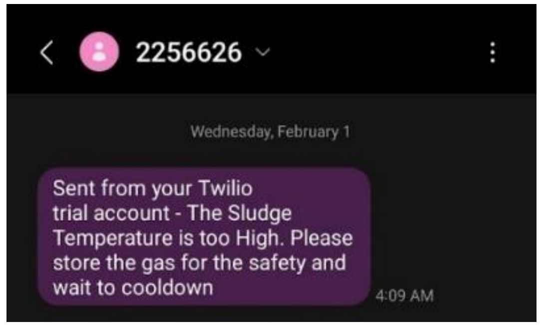


Figure 36: Notification Alert in SMS

Figure 37: Notification Alert in Bioptimize App

4.4 Project Evaluation

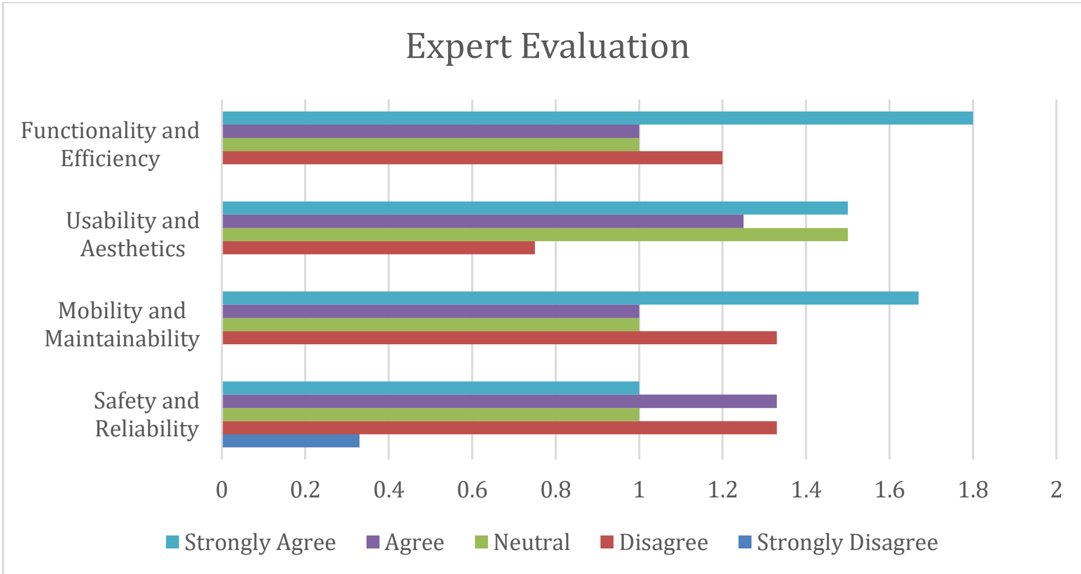


Figure 38. Summary of Expert Evaluation of Bioptimize System

Table 7. Interpretation of Expert Evaluation of Bioptimize System

Criteria	$\frac{Total\ (N=5)}{mean}$	Interpretation
Functionality and Efficiency	3.85	Agree
Usability and Aesthetics	3.94	Agree
Mobility and Maintainability	3.75	Agree
Safety and Reliability	3.33	Neither Agree nor Disagree

The Expert Evaluation Form was completed by four respondents representing diverse fields of expertise, who provided their feedback on the Bioptimize system through questionnaires. The evaluation encompassed multiple aspects, including functionality and efficiency, usability and aesthetics, mobility and maintainability, as well as safety and reliability. Here is a breakdown of the responses received for each aspect:

In terms of functionality and efficiency, the form produced a response of 3.85, which is interpreted as agreement. These figures suggest an overall favorable perception of the performance and effectiveness of the Bioptimize system.

Moving on to the realm of usability and aesthetics, the data collected from expert responses indicates an average rating of 3.94, denoting agreement. These findings emphasize a positive inclination towards the user-friendliness and visual attractiveness of the system.

As for the mobility and maintainability aspect, the survey gathered responses from participants, with 3.75 indicating agreement. These findings imply that the respondents widely recognized the system's convenient portability and its potential for effortless maintenance.

Lastly, in terms of safety and reliability, an average rating of 3.33 was obtained, indicating a neutral stance. Although the majority of respondents expressed confidence in the system's safety and reliability, there was one respondent who strongly disagreed, suggesting the necessity for further scrutiny and potential improvements in this domain.

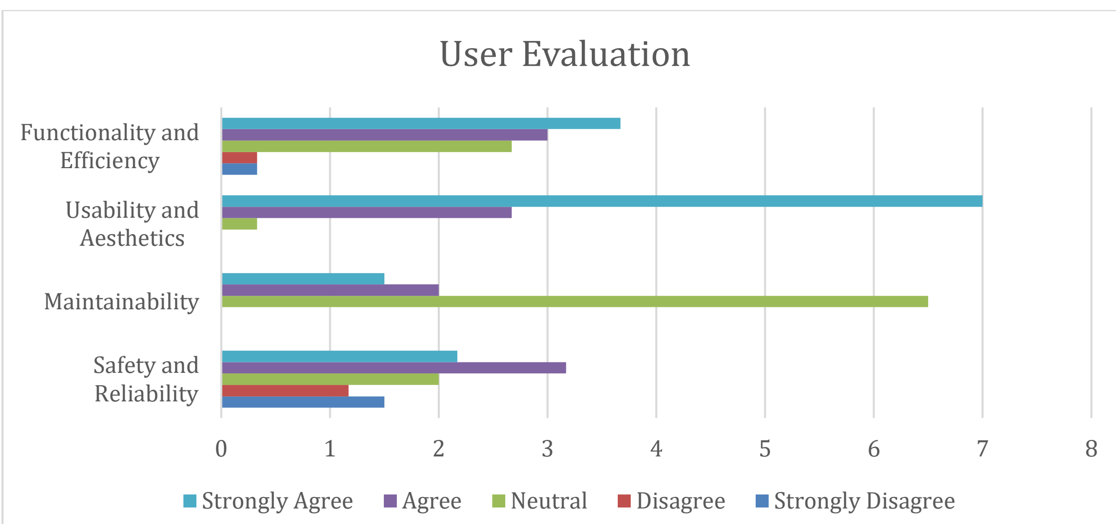


Figure 39. Interpretation of User Evaluation of Bioptimize System

Table 8. Interpretation of User Evaluation of Bioptimize System

Criteria	$\frac{\boldsymbol{Total}\ (\boldsymbol{N} = \mathbf{5})}{\boldsymbol{mean}}$	Interpretation
Functionality and Efficiency	3.93	Agree
Usability and Aesthetics	4.67	Strongly Agree
Maintainability	3.5	Agree
Safety and Reliability	3.33	Neither Agree nor Disagree

The User Evaluation Form was completed by 10 respondents, representing users from the Sampaga community in San Antonio Quezon. They shared their valuable feedback on the Bioptimize system through questionnaires, covering various aspects including functionality and efficiency, usability and aesthetics, mobility and maintainability, as well as safety and reliability. Here is a breakdown of the responses received for each aspect:

In terms of the functionality and efficiency aspect, the survey obtained an average rating of 3.93, which is interpreted as agreement. These responses reflect a generally optimistic perception of the Bioptimize system's ability to meet user requirements and effectively perform its intended tasks.

Moving on to the realm of usability and aesthetics, the survey data reveals an average rating of 4.67, indicating a strong consensus that is interpreted as "Strongly Agree." This robust agreement among users provides substantial evidence supporting the system's high level of user-friendliness and visually appealing design.

In terms of the maintainability aspect, the survey recorded an average rating of 3.5, indicating agreement. However, the majority of respondents expressed a neutral stance, indicating the need for further deliberation to enhance the system's maintainability and ensure its long-term sustainability.

Lastly, in terms of safety and reliability, the survey data obtained a score of 3.33, which is interpreted as a neutral stance between agreement and disagreement. Although the overall sentiment leans towards positivity, the presence of a significant number of disagree and strongly disagree responses highlights concerns regarding the system's safety and reliability. Addressing these concerns becomes imperative to cultivate trust and confidence among users.

Table 9. Implementation of a 5-Point Likert Scale to the Evaluation Results

Statements	1		2		3		4		5		Total Score	Mean Score	Rating
	x	%	x	%	x	%	x	%	x	%			
Functionality	1	5	0	0	4	20	7	35	8	40	81	4.05	Strongly Agree
Reliability	0	0	0	0	13	52	5	20	7	28	94	3.76	Agree
Usability	0	0	0	0	0	0	6	30	14	70	94	4.7	Strongly Agree
Maintainability	1	1.70	6	10.17	11	18.64	20	33.9	21	35.593	231	3.915	Agree
Efficiency	0	0	1	11.11	0	0	1	11.11	7	77.78	41	4.556	Strongly Agree
Overall Mean Score												**4.196**	Strongly Agree

0.01 – 1 (Strongly Disagree), 1.01-2.00 (Disagree), 2.01-3.00 (Neutral), 3.01-4.00 (Agree), 4.01-5 (Strongly Agree)

The Table 9 shows the results that were analyzed using a 5-point Likert scale, revealing an overall mean score of 4.1962. The system received positive feedback in terms of functionality (mean score: 4.05), usability (mean score: 4.7), and efficiency (mean score: 4.556), indicating that it effectively meets user needs and is user-friendly and efficient. However, there is room for improvement in reliability (mean score: 3.76) and maintainability (mean score: 3.915), suggesting the need to address potential issues and provide better support for system maintenance. Overall, the findings highlight the system's strengths while identifying areas for enhancement to ensure a more reliable and easily maintainable user experience.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This chapter presents the conclusions drawn from the findings and offers valuable recommendations to enhance the study further.

5.1 Conclusion

Based on the study's findings and results, the proponents have derived the following conclusions:

1. The system incorporates essential components such as sensors for monitoring gas, pressure, temperature, and pH, as well as a motor, solenoid valve, microcontrollers, and storage for pH control substances. However, it is worth noting that the researchers encountered challenges in ensuring a thorough enclosure of the biodigester system, which required additional time and effort. Nonetheless, the successful creation of the closed-loop biodigester system sets the stage for enhanced waste management and sustainable biogas production. Further refinements in the enclosure will contribute to the system's overall efficiency and reliability.
2. Through a thorough evaluation of different machine learning algorithms, we have determined that the Multivariate via Neural Network algorithm is best suited for our system. This algorithm offers superior performance in optimizing the pH level, ensuring optimal conditions for efficient biogas production. By implementing the Multivariate via Neural Network algorithm, we can enhance the overall

functionality and effectiveness of our biodigester system, leading to improved sustainability and renewable energy generation.

3. Using the Kodular platform, we have developed a user-friendly software application that enables users to monitor various parameters, receive instructions, and access a notification system. This mobile application enhances the convenience and accessibility of monitoring the biodigester system, empowering users to effectively manage and maintain optimal conditions for biogas production. The integration of IoT technology and mobile application contributes to efficient and streamlined monitoring, promoting sustainable waste management and renewable energy production.
4. The Expert Evaluation Form and the User Evaluation Form have provided valuable insights into the perceptions and experiences of stakeholders regarding the Bioptimize system. The expert evaluation indicates positive feedback across multiple dimensions, highlighting the system's functionality, usability, mobility, and maintainability. However, it is essential to address potential issues related to safety and reliability. The user evaluation demonstrates positive feedback in functionality, usability, and maintainability, emphasizing the system's strengths. Nevertheless, attention should be directed towards resolving concerns regarding safety and reliability to improve the user experience and enhance overall system performance.

5.2 Recommendation

The implementation of the project was accomplished successfully; nevertheless, the proponents would like to propose the following recommendations in order to enhance the project further:

1. Enhance the biodigester tank by improving the sealing of its inlet and outlets, making them more secure and easily attachable, and detachable;
2. Utilize higher quality grade sensors for enhanced performance;
3. Explore alternative methods to efficiently extract biogas from the tank, studying approaches that are more effective in the process; and
4. Consider reducing the size of the biodigester tank to facilitate more effective data testing and improvement.

References:

[1] B. Susantono and R. Guild, Eds., Creating Livable Asian cities. Oakland: *O BOOKS SUN &amp*; MOON, 2021.

[2] “Philippines Energy Market", *International Trade Administration | Trade.gov*, 2022. https://www.trade.gov/market-intelligence/philippines-energy-market.

[3] ”Renewable Energy: The Clean Facts", *NRDC*, 2022. https://www.nrdc.org/stories/renewable-energy-clean-facts.

[4] "Renewables Best Way to Power Philippine Development", *Wwf.org.ph*, 2022. https://wwf.org.ph/what-we-do/climate/renewables/renewables-to-power-ph-dev/.

[5] "How Reliant is the Philippines on Renewable Energy?", *Dost.gov.ph*, 2022. https://www.dost.gov.ph/knowledge-resources/news/56-infographics/infographics-2018/1487-how-reliant-is-the-philippines-on-renewable-energy.html.

[6] “Biogas definition - what is biogas production? is it sustainable?,” Youmatter, 13-Feb-2020. https://youmatter.world/en/definition/definitions-biogas-definition-what-is-biogas/.

[7] "Backyard Biogas Production from Animal Manure: Process and Utilization", *UNL Water*, 2022. https://water.unl.edu/article/animal-manure-management/backyard-biogas-production-animal-manure-process-and-utilization.

[8] "Philippine Statistics Authority | Republic of the Philippines", *Psa.gov.ph*, 2022. https://psa.gov.ph/livestock-poultry-iprs/swine/inventory.

[9] "Pig Farming In The Philippines, How To Start | Agri Farming", *Agri Farming*, 2022.https://www.agrifarming.in/pig-farming-in-the-philippines-how-to-start.

[10] “Biogas: An alternative energy source,” POWER Magazine, 01-Mar-2013. https://www.powermag.com/biogas-an-alternative-energysource/#:~:text=Rendering%20biogas%20to%20be%20at,most%20efficient%20alternative%20energy%20sources.

[11] Q. P. Peneyra, “Biogas technology: Fuelling the future of Agricultural Development,” Agriculture Monthly, 27-Oct-2020. https://www.agriculture.com.ph/2018/03/19/biogas-technology-fuelling-the-future-of-agricultural-development/.

[12] Oh, J.-I., Lee, J., Lin, K.-Y. A., Kwon, E. E., & Fai Tsang, Y. (2018). Biogas production from food waste via anaerobic digestion with wood chips. *Energy & Environment, 29(8),* 1365–1372. https://doi.org/10.1177/0958305X18777234

[13] M. Uddin et al., "Prospects of Bioenergy Production From Organic Waste Using Anaerobic Digestion Technology: A Mini Review", *Frontiers in Energy Research*, vol. 9, 2021. 10.3389/fenrg.2021.627093

[14] Prasad, Shiv & Rathore, Dheeraj & Singh, Anoop. (2017). Recent Advances in Biogas Production. *Chemical Engineering & Process Techniques. 3. 1038*.

[15] Setyobudi, R. H., Yandri, E., Mousa Atoum, M. F., Nur, S. M., Zekker, I., Idroes, R., ... & Zahriah, Z. (2021). Healthy-Smart Concept as Standard Design of Kitchen Waste Biogas Digester for Urban Households. *Jordan Journal of Biological Sciences, 14(3).*

[16] Canales-Gutiérrez, Á., Quispe-Aucca, B. J., Romero-Loaiza, R., Villafuerte-Prudencio, N., Ramos Pineda, J. R., Aguilar, J. M., & Canqui-Flores, B. (2021). Design of an anaerobic biodigester model as an alternative for methane generation. *Journal of the Selva Andina Biosphere*, *9*(2), 81-91.

[17] Acharya, V., Hegde, V. V., Anjan, K., & Kumar, M. (2017, December). IoT (Internet of Things) based efficiency monitoring system for bio-gas plants. In *2017 2nd International Conference on Computational Systems and Information Technology for Sustainable Solution (CSITSS)* (pp. 1-5). IEEE.

[18] Parralejo, A. I., Royano, L., González, J., & González, J. F. (2019). Small scale biogas production with animal excrement and agricultural residues. *Industrial Crops and Products*, *131*, 307-314.

[19] Yoshida, K., & Shimizu, N. (2020). Biogas production management systems with model predictive control of anaerobic digestion processes. *Bioprocess and biosystems engineering*, *43*(12), 2189-2200.

[20]Renewable Energy Agency, I. (2016). *Measuring small-scale biogas capacity and production*. www.irena.org

[21] *Biogas Energy - Tasneem Abbasi, S.M. Tauseef, S.A. Abbasi - Google Books*. (n.d.). Retrieved June 9, 2022, from https://books.google.com.ph/books?hl=en&lr=&id=hWprsOiNyfEC&oi=fnd&pg=PR3&dq=biogas&ots=fG8Sa2bsWT&sig=SCfTdPHy9_7m_PtFmhvVx4tP-uQ&redir_esc=y#v=onepage&q=biogas&f=false

[22] Peter, E., Rollo, F., Pabilona, L. L., Sami, A.-A., Magomnang, M., Villanueva, E. P., Mae, D., & Rollo, E. P. F. (2017). Analysis of Biogas Production from Cow, Chicken and Swine Manure. In */ Mindanao Journal of Science and Technology* (Vol. 15).

[23] Deng, L., Liu, Y., & Wang, W. (2020). Biogas technology. In *Biogas Technology*. Springer Singapore. https://doi.org/10.1007/978-981-15-4940-3

[24] Schnürer, A., & Jarvis, Å. (2010). *Microbiological Handbook for Biogas Plants Swedish Waste Management U2009:03 Swedish Gas Centre Report 207*. www.avfallsverige.se

[25] Tabatabaei, M., Valijanian, E., Aghbashlo, M., Ghanavati, H., Sulaiman, A., & Wakisaka, M. (2018). *Prominent Parameters in Biogas Production Systems* (pp. 135–161). https://doi.org/10.1007/978-3-319-77335-3_6

[26]Isaksson, S. (2018). *Biogas production at high ammonia levels The importance of temperature and trace element supplementation on microbial communities*. http://www.teknat.uu.se/student

[27]Deng, L., Liu, Y., & Wang, W. (2020). Biogas technology. In *Biogas Technology*. Springer Singapore. https://doi.org/10.1007/978-981-15-4940-3

[28] Kalamaras, S. D., Vitoulis, G., Christou, M. L., Sfetsas, T., Tziakas, S., Fragos, V., Samaras, P., & Kotsopoulos, T. A. (2021). The effect of ammonia toxicity on methane production of a full-scale biogas plant—an estimation method. *Energies*, *14*(16). https://doi.org/10.3390/en14165031

[29] Tira, H. S., Padang, Y. A., & Supriadi. (2019, June). Effect of acidity level of substrate by lime water and acetic acid addition on biogas production. In AIP Conference Proceedings (Vol. 2114, No. 1, p. 060006). AIP Publishing LLC.

[30] Schiraldi, C., & de Rosa, M. (2014). Mesophilic Organisms. In *Encyclopedia of Membranes* (pp. 1–2). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-40872-4_1610-2

[31] Jaimes-Estévez, J., Zafra, G., Martí-Herrero, J., Pelaz, G., Morán, A., Puentes, A., Gomez, C., Castro, L. D. P., & Hernández, H. E. (2021). Psychrophilic full scale tubular digester operating over eight years: Complete performance evaluation and microbiological population. *Energies*, *14*(1). https://doi.org/10.3390/en14010151

[32] Moyer, C. L., Eric Collins, R., & Morita, R. Y. (2017). Psychrophiles and Psychrotrophs. In *Reference Module in Life Sciences*. Elsevier. https://doi.org/10.1016/b978-0-12-809633-8.02282-2

[33] Sarker, S., Lamb, J. J., Hjelme, D. R., & Lien, K. M. (2019). A review of the role of critical parameters in the design and operation of biogas production plants. *Applied Sciences*, *9*(9), 1915.

[34] Singh, B., Szamosi, Z., & Siménfalvi, Z. (2020). Impact of mixing intensity and duration on biogas production in an anaerobic digester: a review. *Critical reviews in biotechnology*, *40*(4), 508-521.

[35] Stollenwerk, D., Rieke, C., Dahmen, M., & Pieper, M. (2016, March). Biogas Production Modelling: A Control System Engineering Approach. In *IOP Conference Series: Earth and Environmental Science* (Vol. 32, No. 1, p. 012008). IOP Publishing.

[36] Menacho, W. A., Mazid, A. M., & Das, N. (2022). Modelling and analysis for biogas production process simulation of food waste using Aspen Plus. *Fuel*, *309*, 122058.

[37] Chávez-Fuentes, J. J., Capobianco, A., Barbušová, J., & Hutňan, M. (2017). Manure from our agricultural animals: A quantitative and qualitative analysis focused on biogas production. *Waste and Biomass Valorization*, *8*(5), 1749-1757.

[38] Peter, E., Rollo, F., Pabilona, L. L., Sami, A.-A., Magomnang, M., Villanueva, E. P., Mae, D., & Rollo, E. P. F. (2017). Analysis of Biogas Production from Cow, Chicken and Swine Manure. In */ Mindanao Journal of Science and Technology* (Vol. 15).

[39] Sajaruddin, Kalsum, L., & Muchtar, Z. (2020). The Analysis Of Biogas Fermentation Time From Cow Manure On Fixed Dome Biodigester Batch Systems. *Journal of Physics: Conference Series*, *1500*(1), 012043. https://doi.org/10.1088/1742-6596/1500/1/012043

[40] Service on Appropriate Technology, A. (n.d.). *Biogas Digest Volume II Biogas-Application and Product Development Information and Advisory Service on Appropriate Technology*.

[41] Deng, L., Liu, Y., & Wang, W. (2020). Biogas technology. In *Biogas Technology*. Springer Singapore. https://doi.org/10.1007/978-981-15-4940-3

[42] Ghiandelli, M. (n.d.). *Development and implementation of small-scale biogas balloon biodigester in Bali, Indonesia*.

[43] Canales-Gutiérrez, Á., Quispe-Aucca, B. J., Romero-Loaiza, R., Villafuerte-Prudencio, N., Ramos Pineda, J. R., Aguilar, J. M., & Canqui-Flores, B. (2021). Design of an anaerobic biodigester model as an alternative for methane generation. *Journal of the Selva Andina Biosphere*, *9*(2), 81–91. https://doi.org/10.36610/j.jsab.2021.090200081x

[44] "What is a Raspberry Pi?", *Opensource.com*, 2022.https://opensource.com/resources/raspberry-pi.

[45] "What is the Raspberry Pi 4? Everything you need to know about the tiny, low-cost computer", *ZDNet*, 2022. [Online]. Available: https://www.zdnet.com/article/what-is-the-raspberry-pi-4-everything-you-need-to-know-about-the-tiny-low-cost-computer/. [Accessed: 26- Jun- 2022].

[46] Nvs, B., & Saranya, P. L. (2020). Water pollutants monitoring based on Internet of Things. In *Inorganic Pollutants in Water* (pp. 371-397). Elsevier.

[47] Karastogianni, S., Girousi, S., & Sotiropoulos, S. (2016). pH: principles and measurement. *Encyclopedia of Food and Health*, *4*, 333-338.

[48] Caballero, B., Trugo, L. C., & Finglas, P. M. (2003).*Encyclopedia of food sciences and nutrition*. (pp. 4501-4507). Academic.

[49] Gianchandani, Y. B., Tabata, O., & Zappe, H. P. (Eds.). (2008). *Comprehensive microsystems* (Vol. 1, pp. 375-432). Amsterdam: Elsevier.

[50] W. Bolton, "Control systems", *Control Systems*, pp. 1-36, 2002. 10.1016/b978-075065461-6/50001-5

[51] Vasudev, A., & Bhansali, S. (2013). Microelectromechanical systems (MEMS) for in vivo applications. In *Implantable Sensor Systems for Medical Applications* (pp. 331-358). Woodhead Publishing.

[52] Pannucharoenwong, N. (2018). Effect of Agitator Type on Co-digestion of Pig Manure and Vegetable Waste for Biogas Production. In *International Journal of Applied Engineering Research* (Vol. 13, Issue 5). http://www.ripublication.com

[53] Kulkarni, I., Zang, J. W., Leandro, W. M., Parikh, P., Adler, I., Da Fonseca-Zang, W. A., & Campos, L. C. (2021). Closed-Loop Biodigesters on Small-Scale Farms in Low-and Middle-Income Countries: A Review. *Water*, *13*(19), 2744.

[54] Fawzy, S., Saeed, M., Eladl, A., & El-Saadawi, M. (2020). Adaptive Control System for Biogas Power Plant Using Model Predictive Control. *Journal of Modern Power Systems and Clean Energy*, *9*(5), 1193-1204.

[55] Digesters. *Chemical Engineering Transactions*, *65*, 433-438.

[56] Tabatabaei, M., Aghbashlo, M., Valijanian, E., Panahi, H. K. S., Nizami, A. S., Ghanavati, H., ... & Karimi, K. (2020). A comprehensive review on recent biological innovations to improve biogas production, part 1: upstream strategies. *Renewable Energy*, *146*, 1204-1220.

[57] R. Sebastian, “An overview of gradient descent optimization algorithms,” *arXiv*, 2016.

[58] A. Mustapha, L. Mohamed, and K. Ali, “An overview of gradient descent algorithm optimization in Machine Learning: Application in the ophthalmology field,” *Communications in Computer and Information Science*, vol. 1207, pp. 349–359, Jun. 2020.

[59] Khirirat, Sarit; Feyzmahdavian, Hamid Reza; Johansson, Mikael (2017). *[IEEE 2017 IEEE 56th Annual Conference on Decision and Control (CDC) - Melbourne, Australia (2017.12.12-2017.12.15)] 2017 IEEE 56th Annual Conference on Decision and Control (CDC) - Mini-batch gradient descent: Faster convergence under data sparsity. , (), 2880–2887.* doi:10.1109/CDC.2017.8264077

[60] Liu, Yanli, Yuan Gao, and Wotao Yin. " ." *Advances in Neural Information Processing Systems* 33 (2020): 18261-18271.

[61] Lezzar, F., Benmerzoug, D., & Kitouni, I. (2020). IoT for monitoring and control of water quality parameters.

[62] Ray, S. (2019). A Quick Review of Machine Learning Algorithms. 2019 International Conference on Machine Learning, Big Data, Cloud and Parallel Computing (COMITCon)

[63] Rushdi, M. A., Rushdi, A. A., Dief, T. N., Halawa, A. M., Yoshida, S., & Schmehl, R. (2020). Power Prediction of Airborne Wind Energy Systems Using Multivariate Machine Learning. Energies, 13(9), 2367. doi:10.3390/en13092367

[64] Nomer, H. A. A., Alnowibet, K. A., Elsayed, A., & Mohamed, A. W. (2020). Neural Knapsack: A Neural Network Based Solver for the Knapsack Problem. IEEE Access, 8, 224200–224210. doi:10.1109/access.2020.3044005

[65] Xiong, Q., & Jutan, A. (2003). Continuous optimization using a dynamic simplex method. Chemical Engineering Science, 58(16), 3817–3828. doi:10.1016/s0009-2509(03)00236-7

[66] Lezzar, Fouzi & Benmerzoug, Djamel & Kitouni, Ilham. (2020). IoT for Monitoring and Control of Water Quality Parameters. International Journal of Interactive Mobile Technologies (iJIM).

[67] Dieudonne, D., & Shima, H. (2018, April). Effectiveness of applying IoT to improve biogas digesters in Rwanda. In *2018 IEEE International Conference on Applied System Invention (ICASI)* (pp. 441-444). IEEE.

[68] Acharya, V., Hegde, V. V., Anjan, K., & Kumar, M. (2017, December). IoT (Internet of Things) based efficiency monitoring system for bio-gas plants. In *2017 2nd International Conference on Computational Systems and Information Technology for Sustainable Solution (CSITSS)* (pp. 1-5). IEEE.

[69] Abdurrahman, A. H., Kirom, M. R., & Suhendi, A. (2020, December). Biogas Production Volume Measurement and Internet of Things based Monitoring System. In *2020 IEEE International Conference on Communication, Networks and Satellite (Comnetsat)* (pp. 213-217). IEEE.

[70] "Build an Android application with Kivy Python framework - LogRocket Blog", *LogRocket Blog*, 2022. https://blog.logrocket.com/build-android-application-kivy-python-framework/.

ANNEX I:
BILL OF MATERIALS

BILL OF MATERIALS

Item	Unit	Item Description	Qty.	Unit Cost	Total Cost
1	pc	370L Polyethylene Tank	1	₱13,000.00	₱13,000.00
2	pc	PVC CLEAN OUT END CAP 6"	2	₱880.00	₱1,760.00
3	pc	PVC CLEAN OUT END CAP 4"	2	₱180.00	₱360.00
4	pc	Raspberry Pi 4 (8GB)	1	₱8,475.00	₱8,475.00
5	pc	SD Card (64Gb)	1	₱308.00	₱308.00
6	pc	Raspberry Pi Shield	1	₱600.00	₱600.00
7	pc	Gas Sensor (MQ-9)	1	₱100.00	₱100.00
8	pc	Analog pH Sensor (SEN0161-V2)	1	₱2,500.00	₱2,500.00
9	pc	Waterproof Temperature Sensor (DS18b20)	2	₱100.00	₱200.00
10	pc	Pressure Transducer Transmitter Sensor Stainless Steel	1	₱700.00	₱700.00
11	pc	Electrical Enclosure Square Junction Box	1	₱593.00	₱593.00
12	pc	Solar Panel 100W	1	₱1,945.00	₱1,945.00
13	pc	Solar Panel Regulator (controller)	1	₱230.00	₱230.00
14	pc	Solar Inverter (12V to 220V)	1	₱458.00	₱458.00
15	pc	Solar Panel Battery CSL12V55	1	₱2,850.00	₱2,850.00
16	m	Wire with MC4 Connector	1	₱430.00	₱430.00
17	pc	Solenoid Valve	2	₱250.00	₱500.00
18	pc	12V Relay Module 1 Channel	4	₱70.00	₱280.00
19	L	Phosphorus Based pH pH DOWN	2	₱410.00	₱820.00
20	L	Phosphorus Based pH UP	8	₱410.00	₱2,870.00
21	gal	Water Container Gallon with Faucet	5	₱200.00	₱200.00
22	gal	Water Container Gallon with Faucet	2.5	₱100.00	₱100.00
23	pc	Gate Valve	2	₱240.00	₱480.00
24	pc	2 x 6 GI Nipple	2	₱40.00	₱80.00
25	pc	1/2 x 2 GI Nipple	6	₱20.00	₱120.00
26	pc	GI Elbow	4	₱35.00	₱140.00
27	pc	GI Coupling	4	₱35.00	₱140.00
28	pc	Wireless Router	1	₱1,020.00	₱1,020.00
29	pc	Extension	2	₱200.00	₱400.00

30	m	Ethernet Cable LAN Cable	50	₱280.00	₱280.00
31	pc	Butyl Tire Truck 700 X 16	1	₱529.00	₱529.00
32	pc	3 Way Tee Brass Y Ball Valve	1	₱90.00	₱90.00
33	pc	Hose Clamp	3	₱10.00	₱30.00
34	pc	Small Ball Valve Outer	1	₱45.00	₱45.00
35	pc	LPG Rubber Hose	3	₱250.00	₱750.00
36	pc	Motor	1	₱2,800.00	₱2,800.00
37	pc	Metal Blade	1	₱400.00	₱400.00
38	m	Flat Bars	6	₱220.00	₱1,320.00
39	m	Angle bar	4	₱320.00	₱1,280.00
40	kg	Welding Rad	1	₱100.00	₱100.00
41	pc	Bering	3	₱90.00	₱270.00
42	pc	Teflon	8	₱24.00	₱192.00
43	m	22 AWG Wires	60	₱10.00	₱600.00
44	set	Jumper Wires - Male to Female	1	₱45.00	₱45.00
45	set	Jumper Wires - Female to Female	1	₱45.00	₱45.00
46	pc	Screw	50	₱100.00	₱100.00
47	pc	Bolt & Screw	10	₱12.00	₱120.00
48	pc	Cutting Disk	4	₱35.00	₱140.00
49	pc	Liha #100	3	₱10.00	₱30.00
50	pc	Spray Paint	6	₱100.00	₱600.00
51	pc	Roll Electrical Tape	6	₱30.00	₱180.00
52	set	Heat Shrinks	1	₱199.00	₱199.00
53	pc	Soldering Iron	1	₱135.00	₱135.00
54	pc	Soldering Lead in Tube	2	₱40.00	₱80.00
55	set	Pioneer Epoxy A & B	1	₱135.00	₱135.00
56	pc	Folder with Clipboard	8	₱90.00	₱720.00
57	ream	A4 Bond Paper	6	₱200.00	₱1,200.00
				TOTAL	**₱54,074.00**

ANNEX II:
SURVEY FORMS

QUESTIONNAIRE

Name: Princess Nicole L. Roxas

Signature:

Occupation: student

Introduction: The students involved in the completion of this study must conduct a questionnaire to assess various factors and parameters, entitled ***"Bioptimize: A closed-loop biodigester system that utilizes machine learning for pH level optimization to increase biogas production, and IoT application for monitoring system"***
Instruction: Please rate each criterion and choose one answer if your assessment meets this rating. Select one best answer from the following options. **1** – Strongly Disagree, **2** – Disagree, **3** – Neutral, **4** – Agree, **5** – Strongly Agree.

Survey statements	**Rating**				
	1	2	3	4	5
Functionality and Efficiency					
1. Bioptimize is more efficient than the traditional biodigester.		✓			
2. The by-product provided an alternative organic fertilizer.			✓		
3. The mobile app helped the user track the parameters in real time.				✓	
Usability and Aesthetics					
4. The mobile app is user-friendly.				✓	
5. The interface of the mobile app is pleasing in the eyes.				✓	
6. The user was able to operate the system on their own.			✓		
Maintainability					
7. The user was able to handle the maintenance of the biodigester on their own.				✓	
8. Did the user experience issues in the biodigester quite often?			✓		
Safety and Reliability					
9. There are safety guidelines provided.					✓
10. The user was able to shut down the system through the mobile app.				✓	
11. The mobile app was able to notify the user about the biodigester's current capacity.			✓		
12. Did the user experience any kind of issues such as:					
- Leaks			✓		
- Biodigester inflation			✓		
- Sensor malfunction			✓		

What are your suggestions and recommendations for the improvement of the said project?

QUESTIONNAIRE

Name: Ramil Lubigan
Occupation: Farmer

Signature:

Introduction: The students involved in the completion of this study must conduct a questionnaire to assess various factors and parameters, entitled ***"Bioptimize: A closed-loop biodigester system that utilizes machine learning for pH level optimization to increase biogas production, and IoT application for monitoring system"***					
Instruction: Please rate each criterion and choose one answer if your assessment meets this rating. Select one best answer from the following options. **1** – Strongly Disagree, **2** – Disagree, **3** – Neutral, **4** – Agree, **5** – Strongly Agree.					
Survey statements	**Rating**				
	1	2	3	4	5
Functionality and Efficiency					
1. Bioptimize is more efficient than the traditional biodigester.					✓
2. The by-product provided an alternative organic fertilizer.			✓		
3. The mobile app helped the user track the parameters in real time.					✓
Usability and Aesthetics					
4. The mobile app is user-friendly.					✓
5. The interface of the mobile app is pleasing in the eyes.					✓
6. The user was able to operate the system on their own.					✓
Maintainability					
7. The user was able to handle the maintenance of the biodigester on their own.			✓		
8. Did the user experience issues in the biodigester quite often?			✓		
Safety and Reliability					
9. There are safety guidelines provided.					✓
10. The user was able to shut down the system through the mobile app.		✓			
11. The mobile app was able to notify the user about the biodigester's current capacity.		✓			
12. Did the user experience any kind of issues such as:					
- Leaks				✓	
- Biodigester inflation	✓				
- Sensor malfunction				✓	

What are your suggestions and recommendations for the improvement of the said project?

QUESTIONNAIRE

Name: Arnold Balaye

Occupation: Farm helper

Signature: Arnold Balaye

Introduction: The students involved in the completion of this study must conduct a questionnaire to assess various factors and parameters, entitled ***"Bioptimize: A closed-loop biodigester system that utilizes machine learning for pH level optimization to increase biogas production, and IoT application for monitoring system"***
Instruction: Please rate each criterion and choose one answer if your assessment meets this rating. Select one best answer from the following options. **1** – Strongly Disagree, **2** – Disagree, **3** – Neutral, **4** – Agree, **5** – Strongly Agree.

Survey statements	**Rating**				
	1	2	3	4	5
Functionality and Efficiency					
1. Bioptimize is more efficient than the traditional biodigester.					✓
2. The by-product provided an alternative organic fertilizer.			✓		
3. The mobile app helped the user track the parameters in real time.					✓
Usability and Aesthetics					
4. The mobile app is user-friendly.					✓
5. The interface of the mobile app is pleasing in the eyes.					✓
6. The user was able to operate the system on their own.					✓
Maintainability					
7. The user was able to handle the maintenance of the biodigester on their own.			✓		
8. Did the user experience issues in the biodigester quite often?			✓		
Safety and Reliability					
9. There are safety guidelines provided.					✓
10. The user was able to shut down the system through the mobile app.			✓		
11. The mobile app was able to notify the user about the biodigester's current capacity.				✓	
12. Did the user experience any kind of issues such as:					
- Leaks				✓	
- Biodigester inflation	✓				
- Sensor malfunction				✓	

What are your suggestions and recommendations for the improvement of the said project?

QUESTIONNAIRE

Name: Jefferson Balaye

Occupation: Farm helper

Signature: [signature]

Introduction: The students involved in the completion of this study must conduct a questionnaire to assess various factors and parameters, entitled ***"Bioptimize: A closed-loop biodigester system that utilizes machine learning for pH level optimization to increase biogas production, and IoT application for monitoring system"***
Instruction: Please rate each criterion and choose one answer if your assessment meets this rating. Select one best answer from the following options. **1** – Strongly Disagree, **2** – Disagree, **3** – Neutral, **4** – Agree, **5** – Strongly Agree.

Survey statements	**Rating**				
	1	2	3	4	5
Functionality and Efficiency					
1. Bioptimize is more efficient than the traditional biodigester.					✓
2. The by-product provided an alternative organic fertilizer.			✓		
3. The mobile app helped the user track the parameters in real time.					✓
Usability and Aesthetics					
4. The mobile app is user-friendly.					✓
5. The interface of the mobile app is pleasing in the eyes.					✓
6. The user was able to operate the system on their own.					✓
Maintainability					
7. The user was able to handle the maintenance of the biodigester on their own.			✓		
8. Did the user experience issues in the biodigester quite often?			✓		
Safety and Reliability					
9. There are safety guidelines provided.					✓
10. The user was able to shut down the system through the mobile app.		✓			
11. The mobile app was able to notify the user about the biodigester's current capacity.				✓	
12. Did the user experience any kind of issues such as:					
- Leaks				✓	
- Biodigester inflation	✓				
- Sensor malfunction				✓	

What are your suggestions and recommendations for the improvement of the said project?

QUESTIONNAIRE

Name: Leomar Mendoza
Occupation: Farm Helper

Signature: [signature]

Introduction: The students involved in the completion of this study must conduct a questionnaire to assess various factors and parameters, entitled ***"Bioptimize: A closed-loop biodigester system that utilizes machine learning for pH level optimization to increase biogas production, and IoT application for monitoring system"***

Instruction: Please rate each criterion and choose one answer if your assessment meets this rating. Select one best answer from the following options. **1** – Strongly Disagree, **2** – Disagree, **3** – Neutral, **4** – Agree, **5** – Strongly Agree.

Survey statements	Rating				
	1	2	3	4	5
Functionality and Efficiency					
1. Bioptimize is more efficient than the traditional biodigester.					✓
2. The by-product provided an alternative organic fertilizer.				✓	
3. The mobile app helped the user track the parameters in real time.					✓
Usability and Aesthetics					
4. The mobile app is user-friendly.					✓
5. The interface of the mobile app is pleasing in the eyes.					✓
6. The user was able to operate the system on their own.					✓
Maintainability					
7. The user was able to handle the maintenance of the biodigester on their own.				✓	
8. Did the user experience issues in the biodigester quite often?			✓		
Safety and Reliability					
9. There are safety guidelines provided.					✓
10. The user was able to shut down the system through the mobile app.		✓			
11. The mobile app was able to notify the user about the biodigester's current capacity.			✓		
12. Did the user experience any kind of issues such as:					
- Leaks			✓		
- Biodigester inflation	✓				
- Sensor malfunction			✓		

What are your suggestions and recommendations for the improvement of the said project?

QUESTIONNAIRE

Name: Nicolas Z. Roxas
Occupation: Farm Owner

Signature:

Introduction: The students involved in the completion of this study must conduct a questionnaire to assess various factors and parameters, entitled ***"Bioptimize: A closed-loop biodigester system that utilizes machine learning for pH level optimization to increase biogas production, and IoT application for monitoring system"***

Instruction: Please rate each criterion and choose one answer if your assessment meets this rating. Select one best answer from the following options. **1** – Strongly Disagree, **2** – Disagree, **3** – Neutral, **4** – Agree, **5** – Strongly Agree.

Survey statements	Rating				
	1	2	3	4	5
Functionality and Efficiency					
1. Bioptimize is more efficient than the traditional biodigester.					✓
2. The by-product provided an alternative organic fertilizer.			✓		
3. The mobile app helped the user track the parameters in real time.				✓	
Usability and Aesthetics					
4. The mobile app is user-friendly.					✓
5. The interface of the mobile app is pleasing in the eyes.					✓
6. The user was able to operate the system on their own.					✓
Maintainability					
7. The user was able to handle the maintenance of the biodigester on their own.			✓		
8. Did the user experience issues in the biodigester quite often?					✓
Safety and Reliability					
9. There are safety guidelines provided.					✓
10. The user was able to shut down the system through the mobile app.			✓		
11. The mobile app was able to notify the user about the biodigester's current capacity.					✓
12. Did the user experience any kind of issues such as:					
- Leaks				✓	
- Biodigester inflation	✓				
- Sensor malfunction				✓	

What are your suggestions and recommendations for the improvement of the said project?

more study

QUESTIONNAIRE

Name: Riza Roxas		Signature: [signature]
Occupation: Housewife

Introduction: The students involved in the completion of this study must conduct a questionnaire to assess various factors and parameters, entitled ***"Bioptimize: A closed-loop biodigester system that utilizes machine learning for pH level optimization to increase biogas production, and IoT application for monitoring system"***
Instruction: Please rate each criterion and choose one answer if your assessment meets this rating. Select one best answer from the following options. **1** – Strongly Disagree, **2** – Disagree, **3** – Neutral, **4** – Agree, **5** – Strongly Agree.

Survey statements	Rating				
	1	2	3	4	5
Functionality and Efficiency					
1. Bioptimize is more efficient than the traditional biodigester.					✓
2. The by-product provided an alternative organic fertilizer.			✓		
3. The mobile app helped the user track the parameters in real time.				✓	
Usability and Aesthetics					
4. The mobile app is user-friendly.					✓
5. The interface of the mobile app is pleasing in the eyes.					✓
6. The user was able to operate the system on their own.					✓
Maintainability					
7. The user was able to handle the maintenance of the biodigester on their own.			✓		
8. Did the user experience issues in the biodigester quite often?					✓
Safety and Reliability					
9. There are safety guidelines provided.					✓
10. The user was able to shut down the system through the mobile app.			✓		
11. The mobile app was able to notify the user about the biodigester's current capacity.					✓
12. Did the user experience any kind of issues such as:					
- Leaks				✓	
- Biodigester inflation	✓				
- Sensor malfunction				✓	

What are your suggestions and recommendations for the improvement of the said project?

conduct more research.

QUESTIONNAIRE

Name: Rowena Conde Signature: Nenle

Occupation: HOUSE keeper

Introduction: The students involved in the completion of this study must conduct a questionnaire to assess various factors and parameters, entitled ***"Bioptimize: A closed-loop biodigester system that utilizes machine learning for pH level optimization to increase biogas production, and IoT application for monitoring system"***

Instruction: Please rate each criterion and choose one answer if your assessment meets this rating. Select one best answer from the following options. **1** – Strongly Disagree, **2** – Disagree, **3** – Neutral, **4** – Agree, **5** – Strongly Agree.

Survey statements	Rating				
	1	2	3	4	5
Functionality and Efficiency					
1. Bioptimize is more efficient than the traditional biodigester.					✓
2. The by-product provided an alternative organic fertilizer.			✓		
3. The mobile app helped the user track the parameters in real time.				✓	
Usability and Aesthetics					
4. The mobile app is user-friendly.					✓
5. The interface of the mobile app is pleasing in the eyes.					✓
6. The user was able to operate the system on their own.				✓	
Maintainability					
7. The user was able to handle the maintenance of the biodigester on their own.			✓		
8. Did the user experience issues in the biodigester quite often?				✓	
Safety and Reliability					
9. There are safety guidelines provided.					✓
10. The user was able to shut down the system through the mobile app.			✓		
11. The mobile app was able to notify the user about the biodigester's current capacity.					✓
12. Did the user experience any kind of issues such as:					
- Leaks	✓				
- Biodigester inflation					
- Sensor malfunction					

What are your suggestions and recommendations for the improvement of the said project?

QUESTIONNAIRE

Name: GRACE ASUNCION
Occupation: House Keeper

Signature:

Introduction: The students involved in the completion of this study must conduct a questionnaire to assess various factors and parameters, entitled ***"Bioptimize: A closed-loop biodigester system that utilizes machine learning for pH level optimization to increase biogas production, and IoT application for monitoring system"***

Instruction: Please rate each criterion and choose one answer if your assessment meets this rating. Select one best answer from the following options. **1** – Strongly Disagree, **2** – Disagree, **3** – Neutral, **4** – Agree, **5** – Strongly Agree.

Survey statements	Rating				
	1	2	3	4	5
Functionality and Efficiency					
1. Bioptimize is more efficient than the traditional biodigester.			✓		
2. The by-product provided an alternative organic fertilizer.				✓	
3. The mobile app helped the user track the parameters in real time.	✓				
Usability and Aesthetics					
4. The mobile app is user-friendly.				✓	
5. The interface of the mobile app is pleasing in the eyes.				✓	
6. The user was able to operate the system on their own.					✓
Maintainability					
7. The user was able to handle the maintenance of the biodigester on their own.					✓
8. Did the user experience issues in the biodigester quite often?			✓		
Safety and Reliability					
9. There are safety guidelines provided.					✓
10. The user was able to shut down the system through the mobile app.			✓		
11. The mobile app was able to notify the user about the biodigester's current capacity.					✓
12. Did the user experience any kind of issues such as:					
- Leaks	✓				
- Biodigester inflation	✓				
- Sensor malfunction				✓	

What are your suggestions and recommendations for the improvement of the said project?

QUESTIONNAIRE

Name: angeline Roxas   Signature:
Occupation:

Introduction: The students involved in the completion of this study must conduct a questionnaire to assess various factors and parameters, entitled ***"Bioptimize: A closed-loop biodigester system that utilizes machine learning for pH level optimization to increase biogas production, and IoT application for monitoring system"***
Instruction: Please rate each criterion and choose one answer if your assessment meets this rating. Select one best answer from the following options. **1** – Strongly Disagree, **2** – Disagree, **3** – Neutral, **4** – Agree, **5** – Strongly Agree.

Survey statements	**Rating**				
	1	**2**	**3**	**4**	**5**
Functionality and Efficiency					
1. Bioptimize is more efficient than the traditional biodigester.				✓	
2. The by-product provided an alternative organic fertilizer.				✓	
3. The mobile app helped the user track the parameters in real time.				✓	
Usability and Aesthetics					
4. The mobile app is user-friendly.				✓	
5. The interface of the mobile app is pleasing in the eyes.				✓	
6. The user was able to operate the system on their own.				✓	
Maintainability					
7. The user was able to handle the maintenance of the biodigester on their own.				✓	
8. Did the user experience issues in the biodigester quite often?			✓		
Safety and Reliability					
9. There are safety guidelines provided.				✓	
10. The user was able to shut down the system through the mobile app.				✓	
11. The mobile app was able to notify the user about the biodigester's current capacity.				✓	
12. Did the user experience any kind of issues such as:					
- Leaks		✓			
- Biodigester inflation		✓			
- Sensor malfunction		✓			

What are your suggestions and recommendations for the improvement of the said project?

Users' Evaluation Responses (Processed/Treated and Interpreted)

Functionality and Efficiency				Usability and Aesthetics			
4.4 Strongly Agree	3.3 Neither Agree nor Disagree	4.1 Agree	**3.93 Agree**	4.7 Strongly Agree	4.7 Strongly Agree	4.6 Strongly Agree	**4.67 Strongly Agree**

Maintability			Safety and Reliability						
3.5 Agree	3.5 Agree	**3.5 Agree**	4.9 Strongly Agree	2.9 Neither Agree nor Disagree	4 Agree	3.3 Neither Agree nor Disagree	1.3 Strongly Disagree	3.6 Agree	**3.33 Neither Agree nor Disagree**

Professionals' Evaluation Responses (Processed/Treated and Interpreted)

Name (Last Name, FN, M.I.)	Position/Designation (e.g. Faculty, Mechanical Engineer, Electrical Engineer)	The closed-loop biodigester is more efficient than the traditional method.	Optimizing pH level increases biogas production.	The biodigester provided energy and cooking fuel for the user.	The production of biogas reduced the polluting tendencies of animal manure	The information in the application's interface for monitoring is clearly displayed and in real-tim	The whole system including the application is easy to navigate and learn.	The whole system requires minimum supervision during the entire operation.	The whole system is easy to operate.	The biodigester is pleasing to the eye of the user.	The biodigester does not require special handling during the operation.	The system's instructions are straightforward and easy to follow.	Maintenance of the biodigester and its system does not require so much effort.	The device does note have health safety risk or physical risk in entire operation.	The inlets, outlets and connection of wires are properly placed.	The biodigester did not cause any explosion or fire incident
Oroyan, Mark Topher, G	Mechanical Engineer	4	4	5	4	4	4	4	4	5	5	4	3	3	4	4
Tataro, Ilona Rosario T.	Automation Development Lead	2	3	2	2	2	2	2	3	3	2	2	2	2	2	2
Pablo, John Fil A.	Mechanical Engineer	4	3	5	5	3	4	4	5	3	4	5	3	3	4	1
Maguad, Glenn M.	Chemical Engineer	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5

Functionality and Efficiency						Usability and Aesthetics				
3.75 Agree	3.75 Agree	4.25 Strongly Agree	4 Strongly Agree	3.5 Agree	**3.85 Agree**	3.75 Agree	3.75 Agree	4.25 Strongly Agree	4 Agree	**3.94 Agree**

Mobility and Maintability				Safety and Reliability			
4 Agree	4 Agree	3.25 Neither Agree nor Disagree	**3.75 Agree**	3.25 Neither Agree nor Disagree	3.75 Agree	3 Neither Agree nor Disagree	**3.33 Neither Agree nor Disagree**

The interpretation followed the given legend:

1.00 – 1.79	*Strongly Disagree*
1.80 – 2.59	*Disagree*
2.60 – 3.39	*Neither Agree nor Disagree*
3.40 – 4.19	*Agree*
4.20 – 5.00	*Strongly Agree*

ANNEX III:
Bioptimize Application Codes

Python Code

```
#Imports
import RPi.GPIO as GPIO
import time
import os
import sys
import glob
import sqlite3
import math
import pandas as pd
import numpy as np

from sklearn.preprocessing import MinMaxScaler
from sklearn.model_selection import train_test_split
from sklearn.metrics import mean_squared_error, r2_score
from tflite_runtime.interpreter import Interpreter

from urllib.request import urlopen
from twilio.rest import Client

#Sensors

def Sludge_Temperature():
    os.system('modprobe w1-gpio')
    os.system('modproble w1-therm')
    base_dir = '/sys/bus/w1/devices/'
    device_folder = glob.glob(base_dir +'28*')[0]
    device_file = device_folder + '/w1_slave'
    f = open(device_file,'r')
    lines = f.readlines()
    f.close
    while lines[0].strip()[-3:] != 'YES':
        time.sleep(0.2)
        f = open(device_file,'r')
        lines = f.readlines()
        f.close
    equals_pos = lines[1].find('t=')
    if equals_pos != 1:
        temp_string = lines[1][equals_pos+2:]
        Celcius = float(temp_string)/1000
        Celcius = round(Celcius,1)
        return Celcius

def Gas_Temperature():
```

```
    os.system('modprobe w1-gpio')
    os.system('modproble w1-therm')
    base_dir = '/sys/bus/w1/devices/'
    device_folder = glob.glob(base_dir +'28*')[1]
    device_file = device_folder + '/w1_slave'
    f = open(device_file,'r')
    lines = f.readlines()
    f.close
    while lines[0].strip()[-3:] != 'YES':
        time.sleep(0.2)
        f = open(device_file,'r')
        lines = f.readlines()
        f.close
    equals_pos = lines[1].find('t=')
    if equals_pos != 1:
        temp_string = lines[1][equals_pos+2:]
        Celcius = float(temp_string)/1000
        Celcius = round(Celcius,1)
        return Celcius

def AnalogConverter():
    sys.path.append('../')
    from DFRobot_ADS1115 import ADS1115
    ADS1115_REG_CONFIG_PGA_6_144V        = 0x00
    ads1115 = ADS1115()

    ads1115.set_addr_ADS1115(0x49)
    ads1115.set_gain(ADS1115_REG_CONFIG_PGA_6_144V)
    adc0 = ads1115.read_voltage(0)
    time.sleep(0.2)
    adc1 = ads1115.read_voltage(1)
    time.sleep(0.2)
    adc2 = ads1115.read_voltage(2)
    time.sleep(0.2)
    adc3 = ads1115.read_voltage(3)
    time.sleep(0.2)
    sys.path.remove('../')
    return adc0, adc1, adc2, adc3

def pH_level():
    adc = AnalogConverter()
    analog1 = adc[1]['r']
    _temperature      = 25.0
    _acidVoltage      = 3154.00
    _neutralVoltage   = 2540.0
```

```
    slope     = (7.0-4.0)/((_neutralVoltage-1500.0)/3.0 -
(_acidVoltage-1500.0)/3.0)
    intercept = 7.0 - slope*(_neutralVoltage-1500.0)/3.0
    _phValue  = slope*(int(analog1)-1500.0)/3.0+intercept
    _phValue = round(_phValue,2)
    return _phValue

def Gas():
    adc = AnalogConverter()
    analog2 = adc[2]['r']
    analog2 = int(analog2)/1000
    ratio = ((3.3/analog2)-1)*(996/850)
    ppm = 703*(ratio**-2.24)
    per = ppm
    return per

def Pressure():
    adc = AnalogConverter()
    analog3 = adc[3]['r']
    analog3 = float(analog3/1000)
    analog3 = (125000*analog3)-62500
    return analog3

#Application (IoT)

def ThingSpeak_DB():
    sludge_temp = Sludge_Temperature()
    pH = pH_level()
    gas = Gas()
    gas_temp = Gas_Temperature()
    pressure = Pressure()
    WRITE_API = "HCT3P98R9ZKIZZBJ"
    BASE_URL =
"https://api.thingspeak.com/update?api_key={}".format(WRITE_API)
    thingspeakHttp = BASE_URL +
"&field1={:.2f}&field2={:.2f}&field3={:.2f}&field4={:.2f}&field5=
{:.2f}".format(sludge_tedge_temp,gas_temp,pH,pressure,gas)
    print(thingspeakHttp)
    conn = urlopen(thingspeakHttp)
    print("Response: {}".format(conn.read()))
    conn.close()

def Notification():
    TWILIO_ACCOUNT_SID = "ACbbf744344db402a896a2bbb250e2b3c4"
    TWILIO_AUTH_TOKEN = "39312212549d6195c049939d2286f8b4"
```

```
    TWILIO_PHONE_SENDER = "+12079622866"
    TWILIO_PHONE_RECIPIENT = "+639292182842"
    if pH >= 50:
        time.sleep(5)
        Temp_S = TS.read_temp()
        if Temp_S >= 50:
            client = Client(TWILIO_ACCOUNT_SID,
TWILIO_AUTH_TOKEN)
            message = client.messages.create(
            to=TWILIO_PHONE_RECIPIENT,
            from_=TWILIO_PHONE_SENDER,
            body="The Sludge Temperature is too High. Please
store the gas for the safety and wait to cooldown"
            print(message.sid)
        else:
            print("Normal")
    elif BiogasA >= 90000:
        time.sleep(5)
        BiogasA = MS.Analog2a()
        if BiogasA >= 90000:
            client = Client(TWILIO_ACCOUNT_SID,
TWILIO_AUTH_TOKEN)
            message = client.messages.create(
            to=TWILIO_PHONE_RECIPIENT,
            from_=TWILIO_PHONE_SENDER,
            body="The Biogas Tank is almost Full. Please store
the gas for the safety and wait to cooldown"
            print(message.sid)
        else:
            print("Normal")

def local_database():
    conn = sqlite3.connect('database_optimize.db')
    sludge_temp = Sludge_Temperature()
    pH = pH_level()
    gas = Gas()
    gas_temp = Gas_Temperature()
    pressure = Pressure()
    c = conn.cursor()
    c.execute("INSERT INTO database VALUES
(datetime('now','localtime'),%d,%d,%d,%d,%d)"%(sludge_temp,gas_te
mp,pH,gas,pre>
    conn.commit()
    conn.close()
    print("Succesfully recorded in the local database")
```

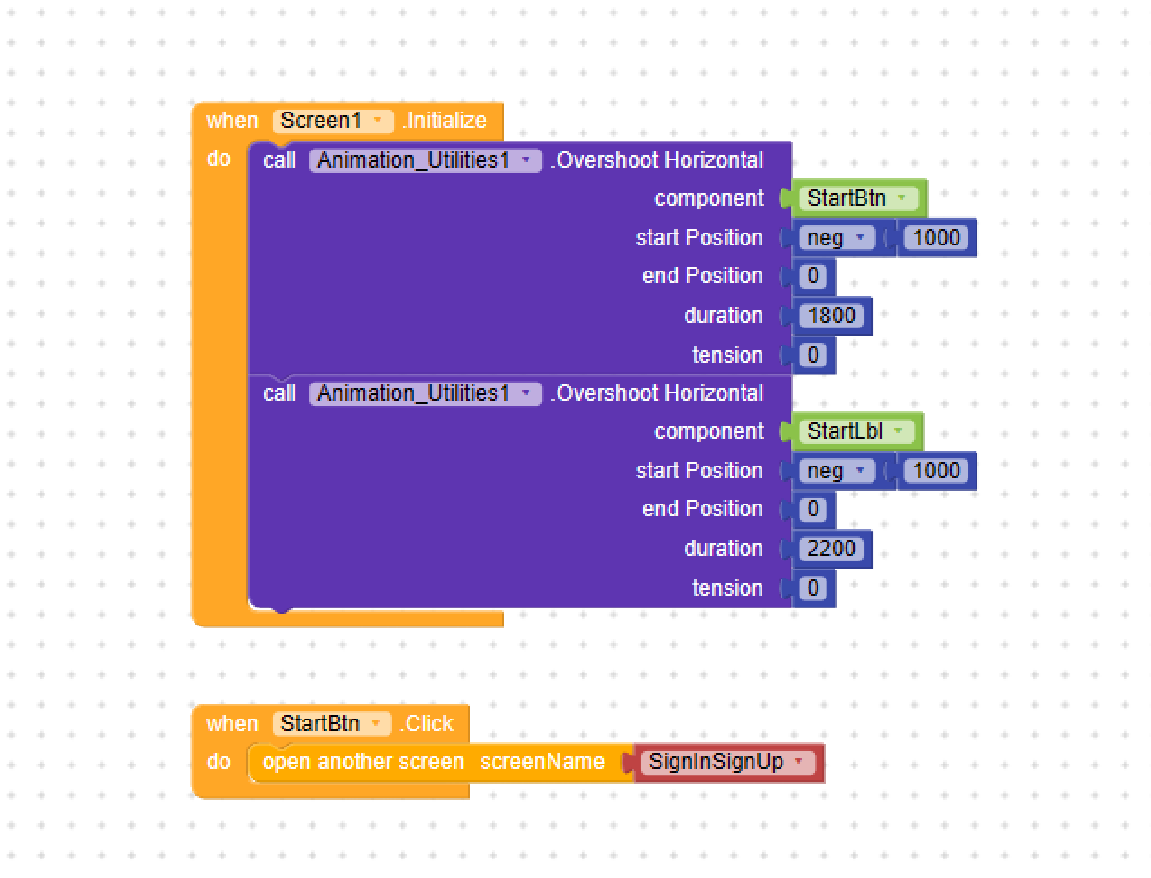
```
#Algorithms

def LinearRegression():
    # load the TFLite model
    interpreter = Interpreter('model.tflite')
    interpreter.allocate_tensors()
    input_details = interpreter.get_input_details()
    output_details = interpreter.get_output_details()

    # load the dataset
    df = pd.read_csv('database_0430.1.csv')

    # split the dataset into training and testing sets
    X = df.iloc[:, :-1].values # select all columns except the
last one
    y = df.iloc[:, -1].values # select the last column
    X_train, X_test, y_train, y_test = train_test_split(X, y,
test_size=0.2, random_state=0)

    # scale the data
    scaler = MinMaxScaler()
    X_train_scaled = scaler.fit_transform(X_train)
    X_test_scaled = scaler.transform(X_test)
    y_train_scaled = scaler.fit_transform(y_train.reshape(-1, 1))
    y_test_scaled = scaler.transform(y_test.reshape(-1, 1))

    # define a function to predict using the TFLite model
    def predict_tflite(input_data):
        interpreter.set_tensor(input_details[0]['index'],
input_data)
        interpreter.invoke()
        output_data =
interpreter.get_tensor(output_details[0]['index'])
        return output_data

    # make predictions on the testing set
    X_test_scaled = X_test_scaled.astype(np.float32)
    y_pred_scaled = np.array([predict_tflite(x.reshape(1, -
1)).flatten() for x in     X_test_scaled])
    y_pred = scaler.inverse_transform(y_pred_scaled).flatten()

    # evaluate the performance of the model
    mse = mean_squared_error(y_test, y_pred)
    rmse = np.sqrt(mse)
```

```
    r2 = r2_score(y_test, y_pred)

    sludge_temp = 50 # set the sludge temperature
    pH_range = np.arange(3, 8, 0.1) # set the pH range to test
    gas_output = []
    for pH in pH_range:
        X1_new = np.array([[pH]])
        X1_new_2d = X1_new.reshape(1, -1)
        X2_new = np.array([sludge_temp])
        X2_new_2d = X2_new.reshape(1, -1)
        X1_new_scaled = scaler.transform(X1_new_2d)
        X2_new_scaled = scaler.transform(X2_new_2d)
        X_new_scaled = np.concatenate((X1_new_scaled,
X2_new_scaled), axis=1).astype(np.float32)
        y_new_pred_scaled = predict_tflite(X_new_scaled)[0][0]
        y_new_pred =
scaler.inverse_transform(y_new_pred_scaled.reshape(-1,
1)).flatten()
        gas_output.append(y_new_pred[0])
    best_pH = pH_range[np.argmax(gas_output)]
    print('Best pH for maximum gas output:
{:.1f}'.format(best_pH))
    print('Mean squared error: {:.2f}'.format(mse))
    print('Root mean squared error: {:.2f}'.format(rmse))
    print('R-squared: {:.2f}'.format(r2))
    return best_pH

#Automation (aka Control System)

def add_pH():
    GPIO.setmode(GPIO.BCM)
    RELAY_1_GPIO = 23 #Pin 11
    GPIO.setup(RELAY_1_GPIO, GPIO.OUT) # GPIO Assign mode
    GPIO.output(RELAY_1_GPIO, GPIO.LOW) # out
    GPIO.output(RELAY_1_GPIO, GPIO.HIGH) # on
    time.sleep(10)
    GPIO.output(RELAY_1_GPIO, GPIO.LOW) # out
    GPIO.cleanup()

def subtract_pH():
    GPIO.setmode(GPIO.BCM)
    RELAY_2_GPIO = 24 #Pin 13
    GPIO.setup(RELAY_2_GPIO, GPIO.OUT) # GPIO Assign mode
    GPIO.output(RELAY_2_GPIO, GPIO.LOW) # out
    GPIO.output(RELAY_2_GPIO, GPIO.HIGH) # on
```

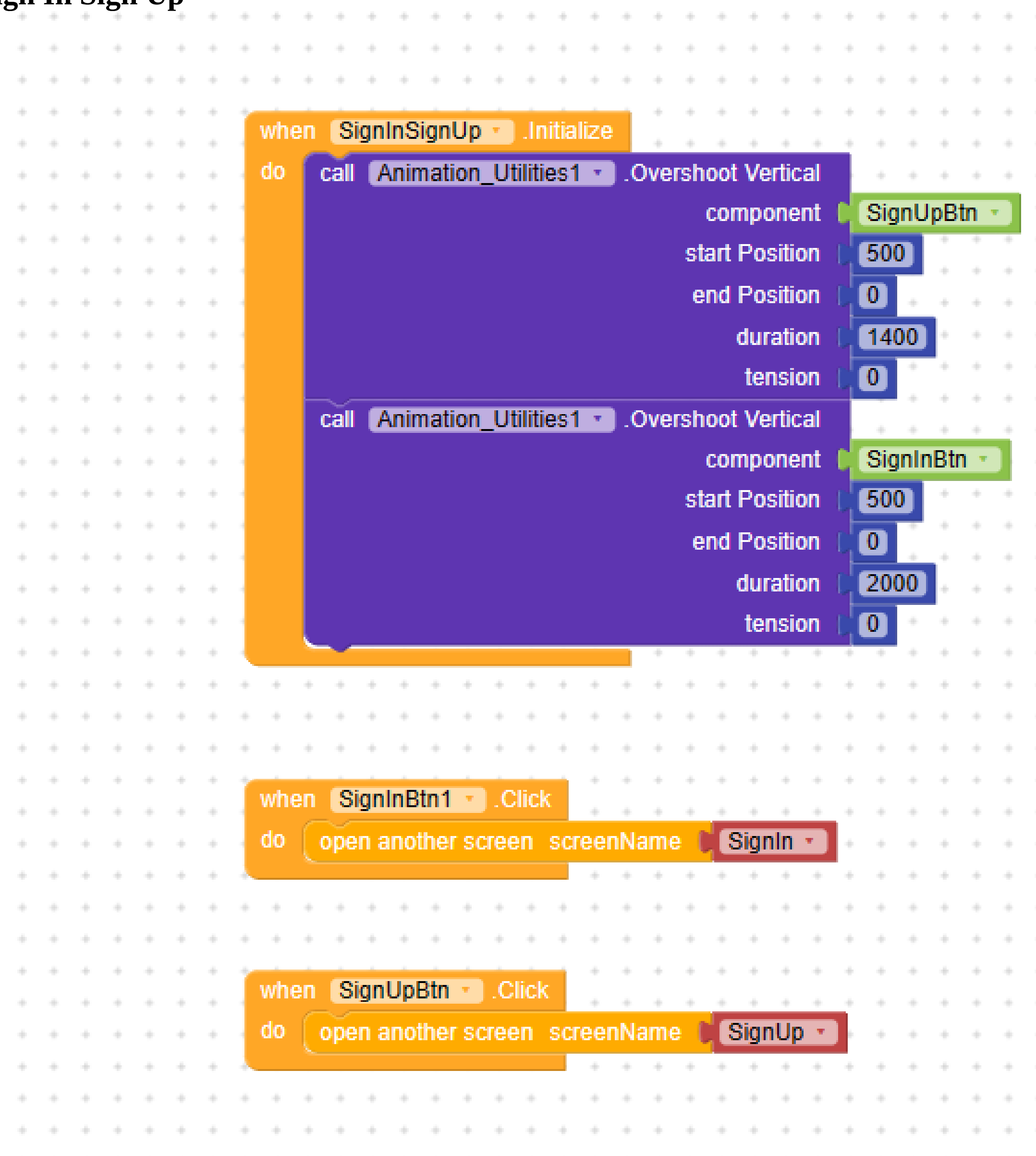
```
    time.sleep(150)
    GPIO.output(RELAY_2_GPIO, GPIO.LOW) # out
    GPIO.cleanup()

def Motor():
    GPIO.setmode(GPIO.BCM)
    RELAY_3_GPIO = 8 #Pin 13
    GPIO.setup(RELAY_3_GPIO, GPIO.OUT) # GPIO Assign mode
    GPIO.output(RELAY_3_GPIO, GPIO.LOW) # out
    GPIO.output(RELAY_3_GPIO, GPIO.HIGH) # on
    time.sleep(15)
    GPIO.output(RELAY_3_GPIO, GPIO.LOW) # out
    GPIO.cleanup()


#Process
def main():
    pH = pH_level()
    pH_optimized = LinearRegression()
    cycle = 0
    while cycle < 14:
        if cycle % 3 == 0:
            if pH > pH_optimized:
                subtract_pH()
                print("Optimizing pH level(-)")
                cycle = cycle +1
            elif pH < pH_optimized:
                add_pH()
                print("Optimizing pH level(+)")
                cycle = cycle + 1
        else:
            ThingSpeak_DB()
            Notification()
            local_database()
            cycle = cycle +1
            time.sleep(500)
    Motor()
    python = sys.executable
    os.execl(python, python, *sys.argv)

try:
    main()
except:
    python = sys.executable
    os.execl(python. python, *sys.argv)
```

Kodular Code (Mobile App)

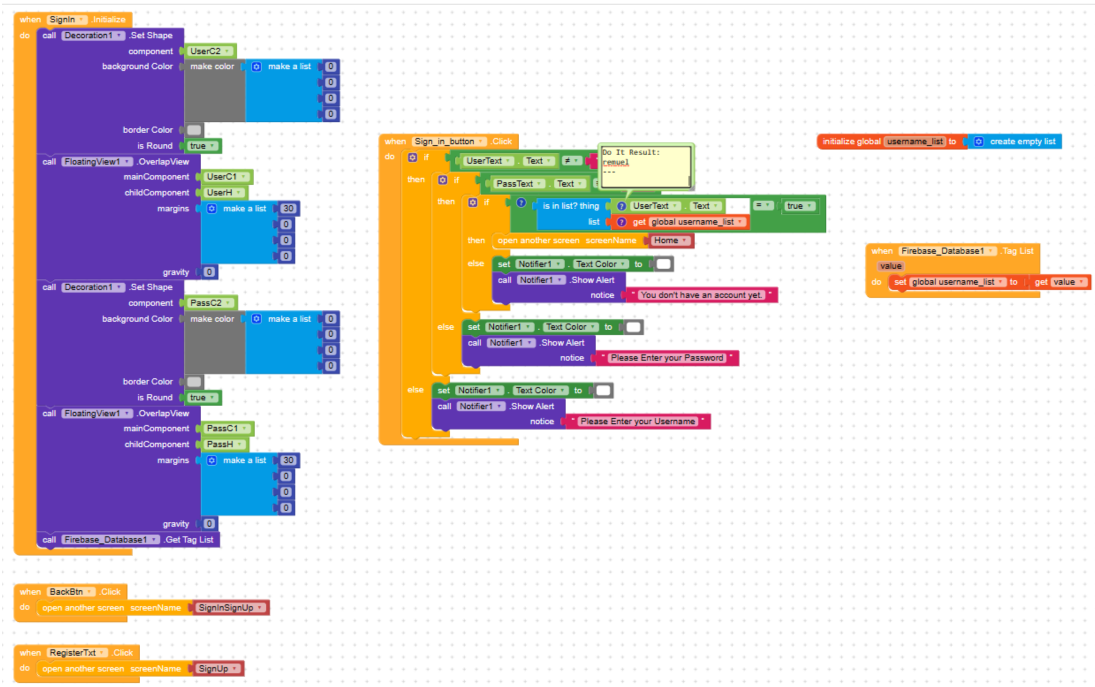
Screen 1 (Main Screen)



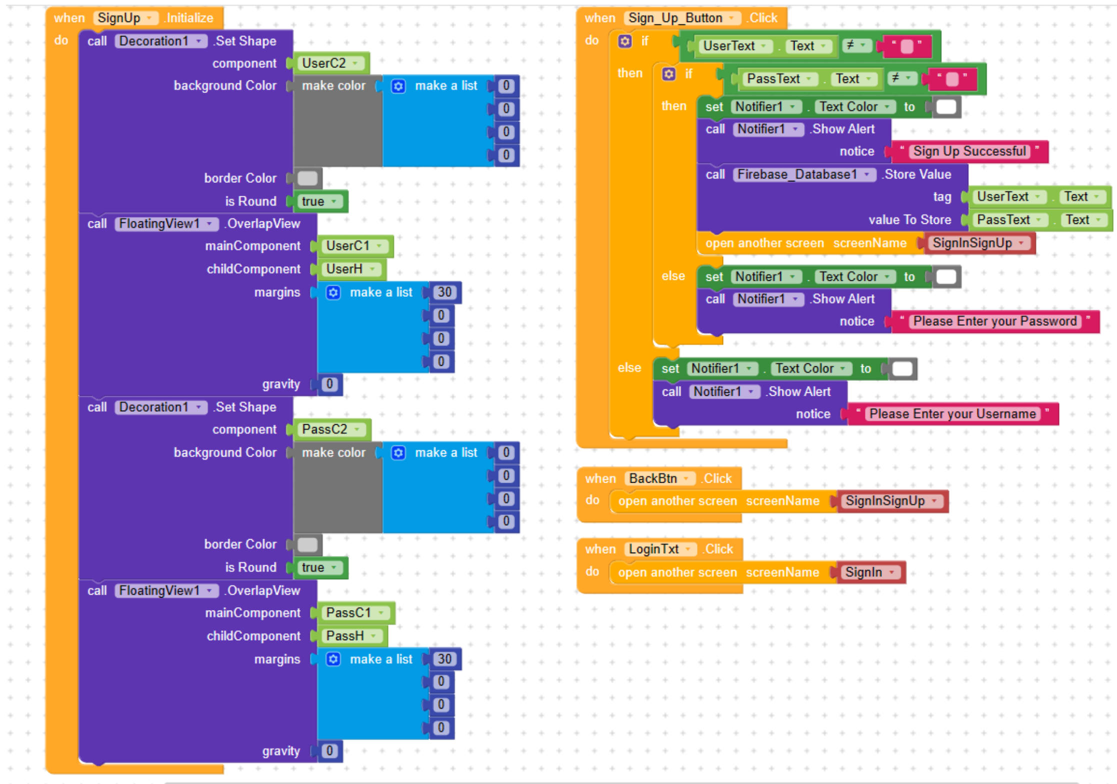
Sign In Sign Up



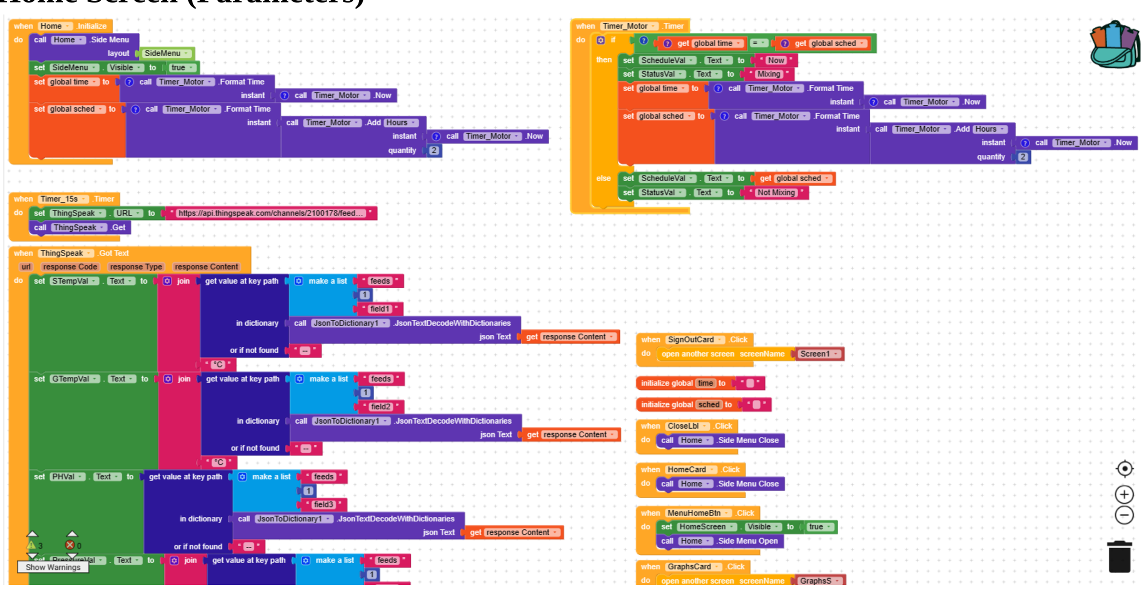
Sign In

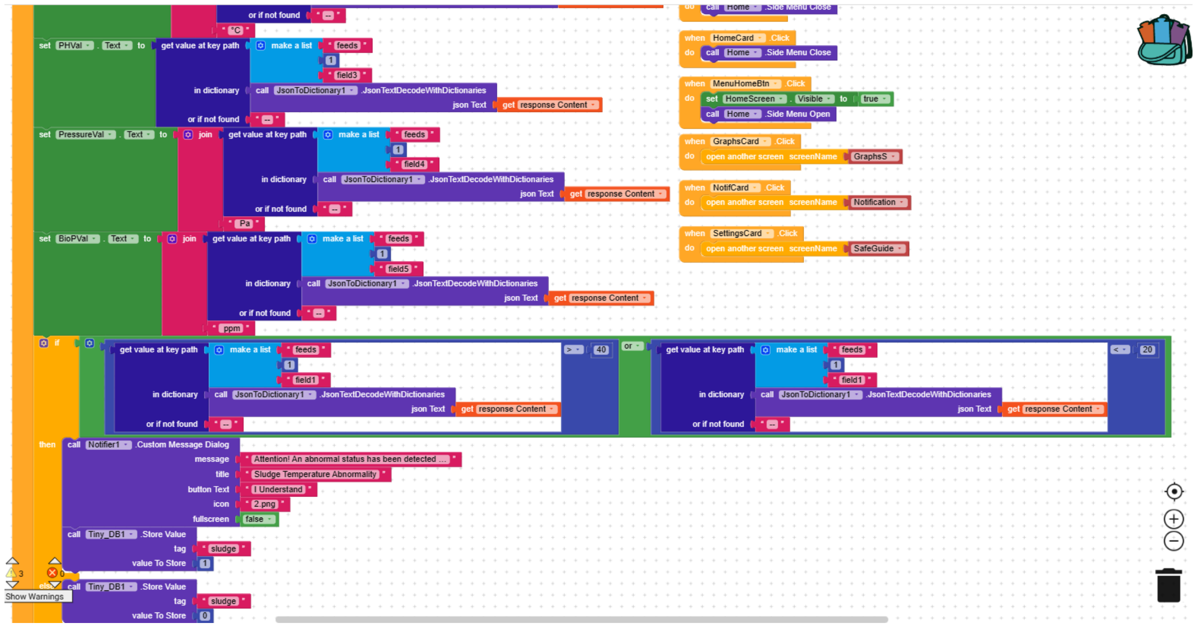


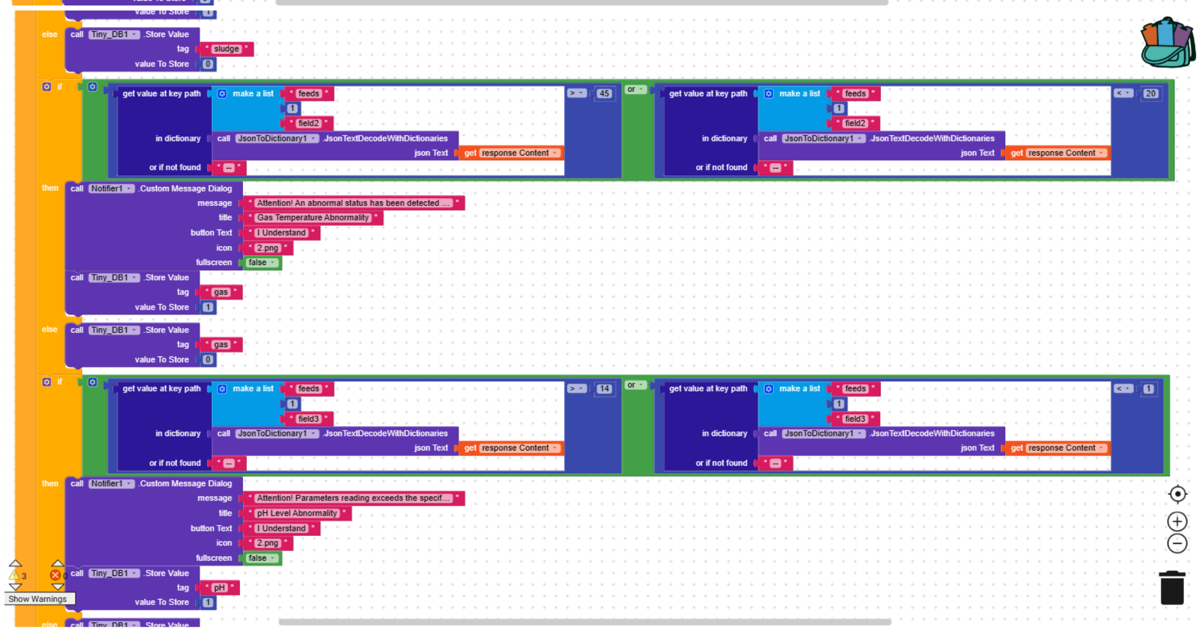
Sign Up

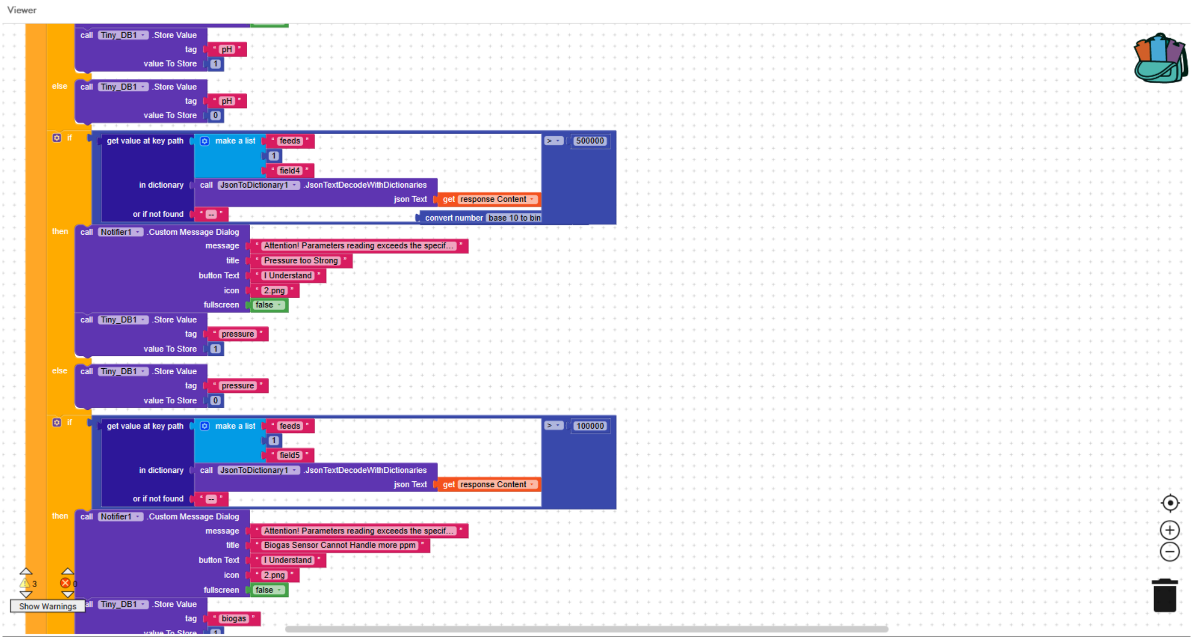


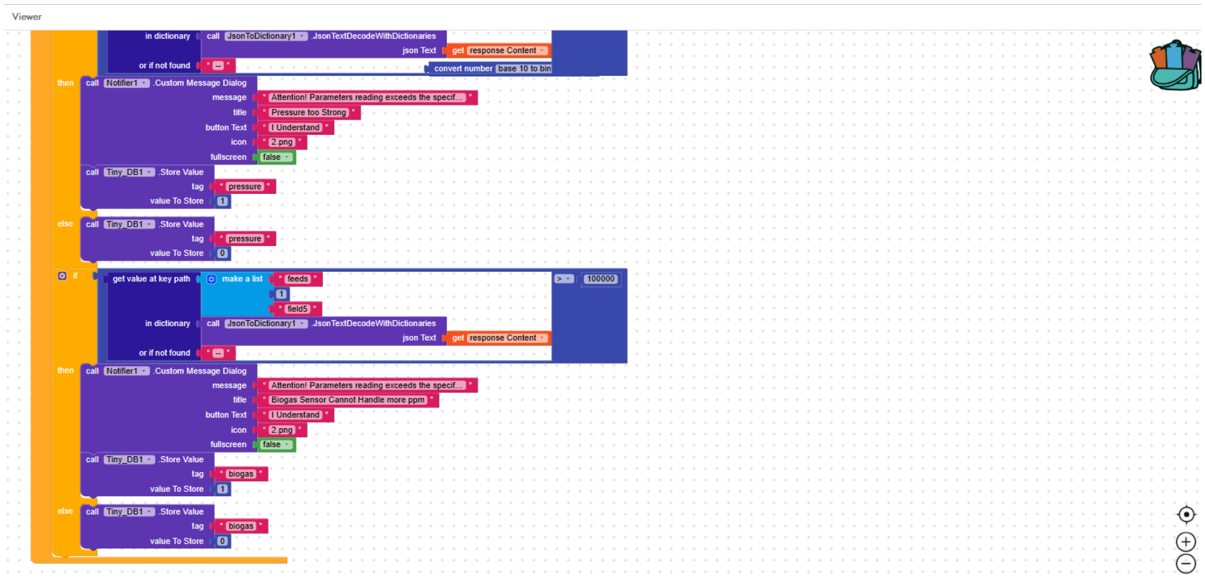
Home Screen (Parameters)



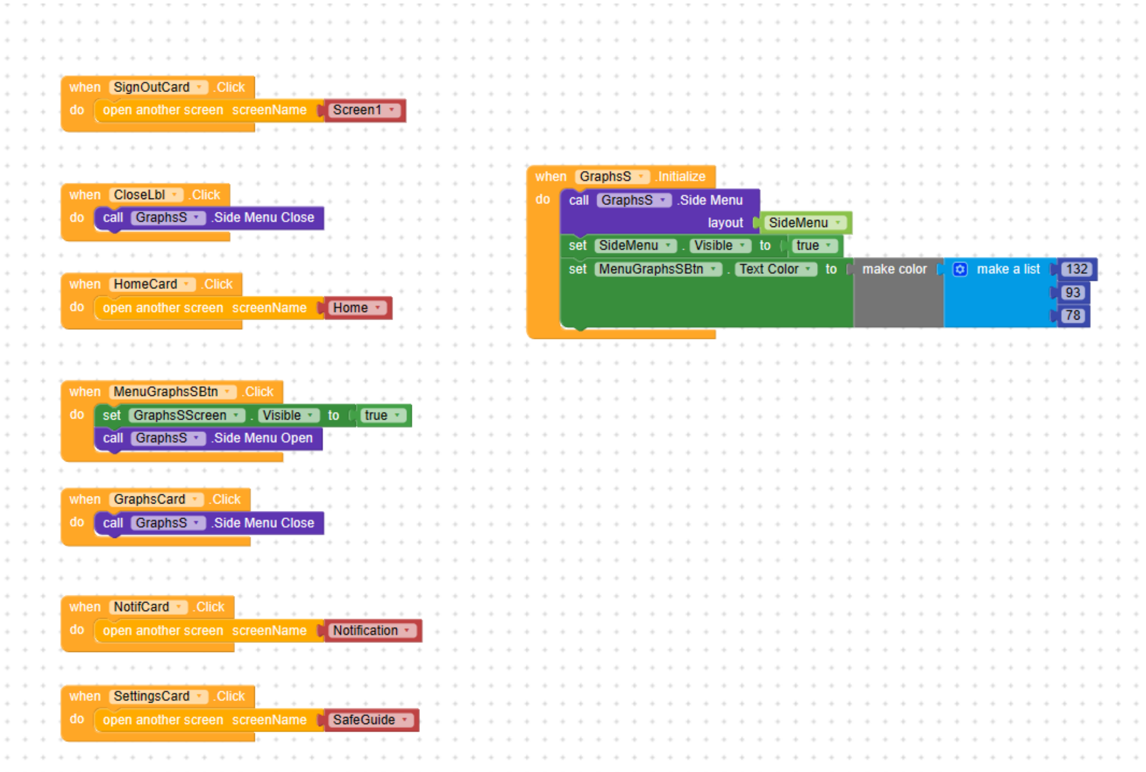

when HomeCard .Click
do call Home .Side Menu Close
when MenuHomeBtn .Click
do set HomeScreen . Visible to true
call Home .Side Menu Open
when GraphsCard .Click
do open another screen screenName GraphsS
when NotifCard .Click
do open another screen screenName Notification
when SettingsCard .Click
do open another screen screenName SafeGuide
set PHVal . Text to get value at key path make a list "feeds" 1 "field3"
in dictionary call JsonToDictionary1 .JsonTextDecodeWithDictionaries json Text get response Content
set PressureVal . Text to join get value at key path make a list "feeds" 1 "field4"
"Pa"
set BioPVal . Text to join get value at key path make a list "feeds" 1 "field5"
"ppm"
call Notifier1 .Custom Message Dialog
message "Attention! An abnormal status has been detected ..."
title "Sludge Temperature Abnormality"
button Text "I Understand"
icon "2.png"
fullscreen false
call Tiny_DB1 .Store Value
tag "sludge"
value To Store 1
Show Warnings


call Notifier1 .Custom Message Dialog
message "Attention! An abnormal status has been detected ..."
title "Gas Temperature Abnormality"
button Text "I Understand"
icon "2.png"
fullscreen false
call Tiny_DB1 .Store Value
tag "gas"
message "Attention! Parameters reading exceeds the specif..."
title "pH Level Abnormality"
tag "pH"
Show Warnings

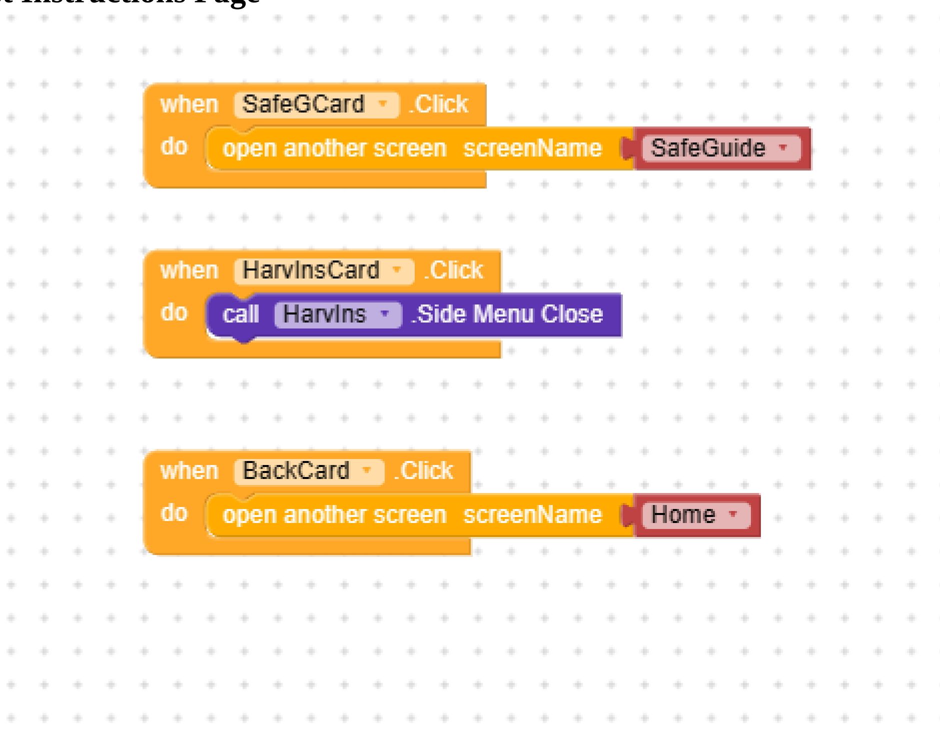




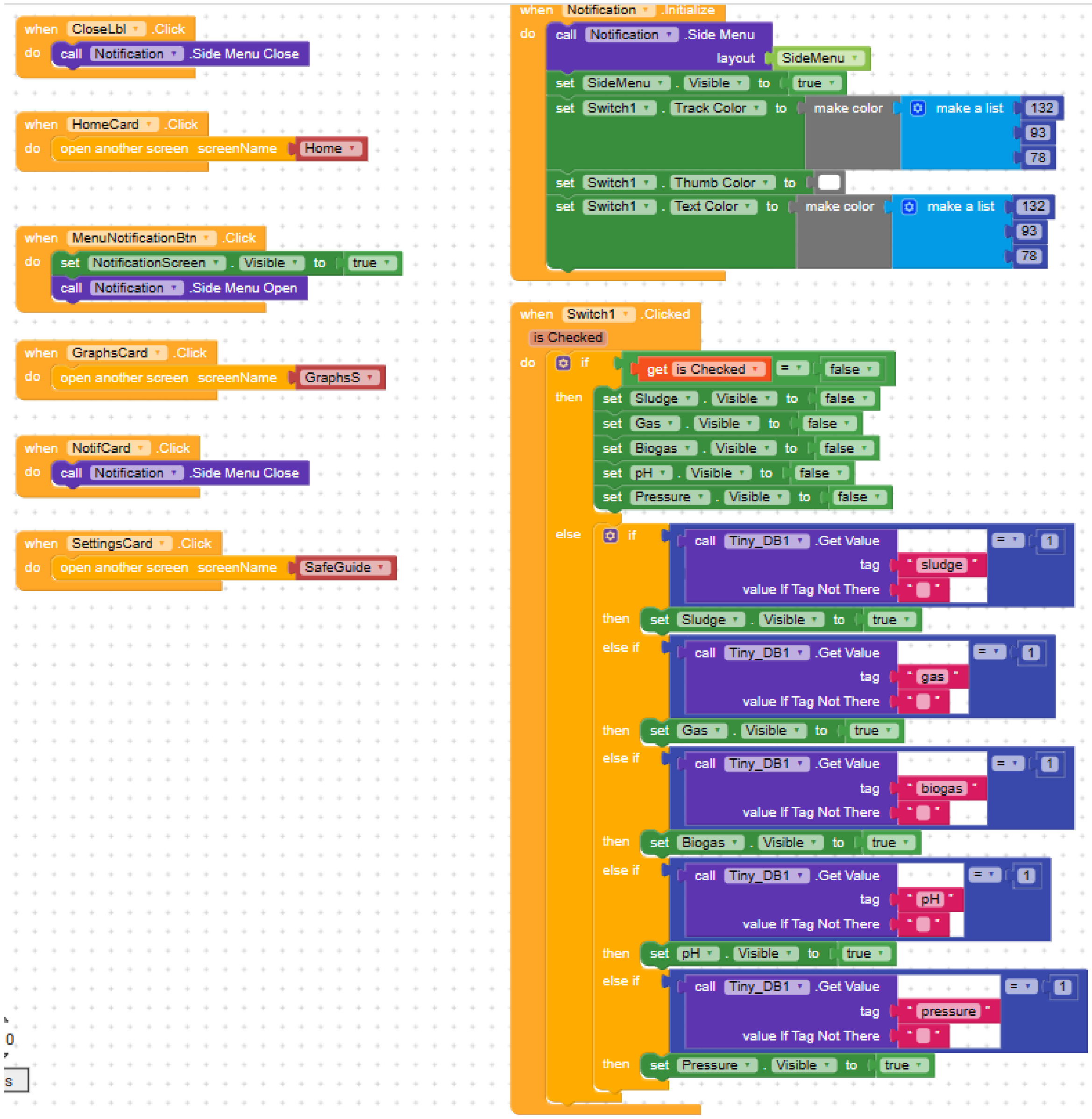
Graphs Page



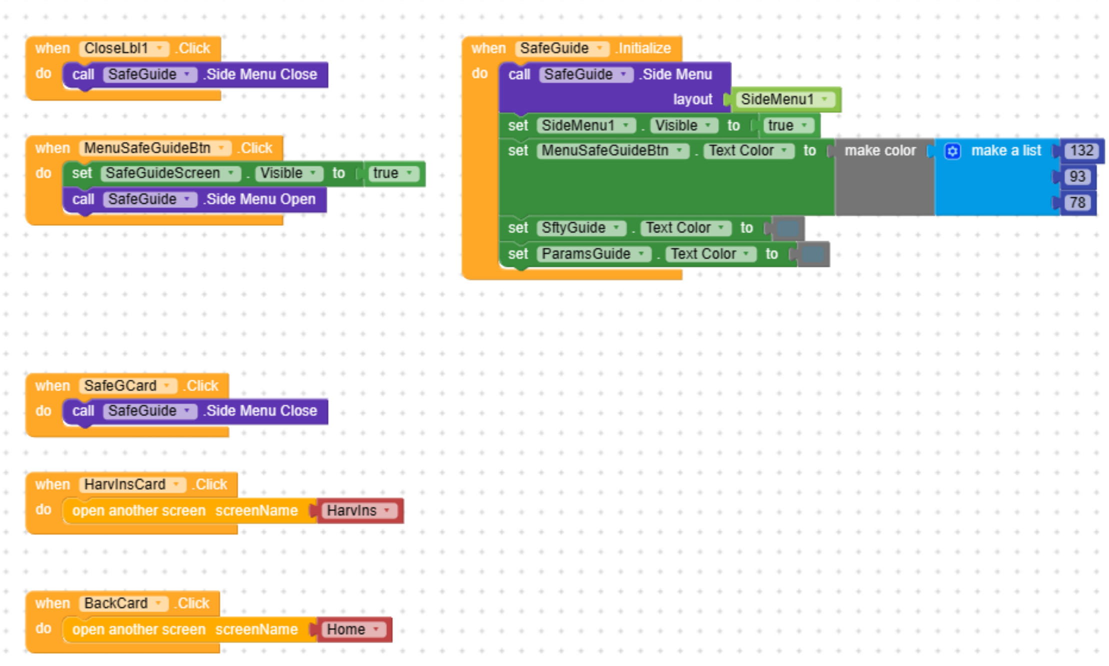
Harvest Instructions Page



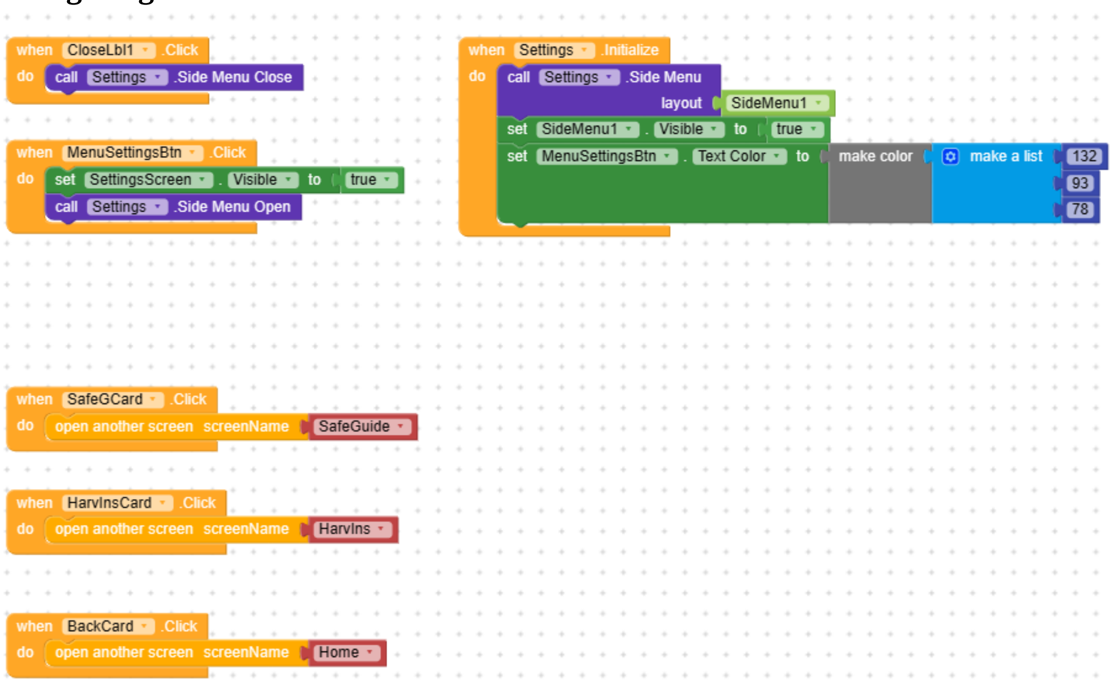
Notification Page



Safety Guidelines Page



Settings Page



ANNEX IV:
Bioptimize User Manual

User Manual

General Guidelines

In the event of any of the following situations occurring within the biodigester system, it is crucial for the user to immediately stop the process and take appropriate actions:

- If any parameter within the system falls outside the specified range of values, it indicates an abnormality. These parameters may include temperature, pressure, pH levels, gas composition, or any other critical parameter specified by the manufacturer. Stopping the process is necessary to prevent further complications or potential damage to the biodigester system.
- If there is a leakage in the biodigester tank, it poses a significant safety hazard. Leakage can result in the release of hazardous gases or the loss of substrate, compromising the efficiency and integrity of the system. In such cases, the user should immediately halt the process, isolate the gas produced in storage, and seek professional assistance to address the leakage and repair the tank.
- Should any of the sensors responsible for monitoring critical aspects of the biodigester system stop working or malfunction, it can lead to inaccurate data and potential risks. To ensure reliable and safe operation, the user must stop the process, investigate the sensor issue, and either repair or replace the faulty sensor as per the manufacturer's instructions.

When encountering any of these situations, the user's top priority should be safety. Stopping the process promptly helps mitigate further damage, prevent potential hazards, and allows for necessary maintenance or repairs to be conducted. It is advisable to consult the biodigester system's documentation or contact a qualified professional for guidance on troubleshooting and resolving the specific issue at hand.

Parameter Guidelines

List of optimal ranges of values for each parameter

Parameter	Optimal Value
Sludge Temperature	20°C to 40°C
pH Level	1 – 14
Gas Temperature	20°C - 45°C
Pressure	0 Pa – 500,000 Pa
Biogas	0 ppm to 100,000 ppm

Hardware Guidelines

For Temperature Sensors (DS18B20 Temperature Sensor):

Indication that the Temperature Sensor has stopped working:

- Not returning any value on the application screen. It might show “00” or “—”
- Value is not changing for a long time.

For pH Sensor (DFRobot Gravity Analog pH Sensor):

Indication that the pH Sensor has stopped working:

- Not returning any value on the application screen. It might show “00” or “—”

- Value is not changing for a long time.
- Value is beyond the limit specification limit. (See Parameter Guidelines)

For Gas Sensor (MQ-9 Gas Sensors)

Indication that the Gas Sensor has stopped working:

- Not returning any value on the application screen. It might show “00” or “—”
- Value is not changing for a long time.

Note: Going beyond the specification limit of the Gas Sensor does not necessarily mean that the Gas Sensor has stopped responding but adds risk of Gas Sensor to not work properly in the future.

For Pressure Sensor (Pressure Transducer Transmitter Sensor)

Indication that the Gas Sensor has stopped working:

- Not returning any value on the application screen. It might show “00” or “—”
- Value is not changing for a long time.

Note: Going beyond the specification limit of the Pressure Sensor does not necessarily mean that the Pressure Sensor has stopped responding but adds risk of Pressure Sensor to not work properly in the future.

Troubleshooting Steps for sensors

1. Verify the internet connection: If the sensor is not returning any value or the value remains unchanged for an extended period on the application screen, check if there is a loss of internet connection as it may be causing the issue.

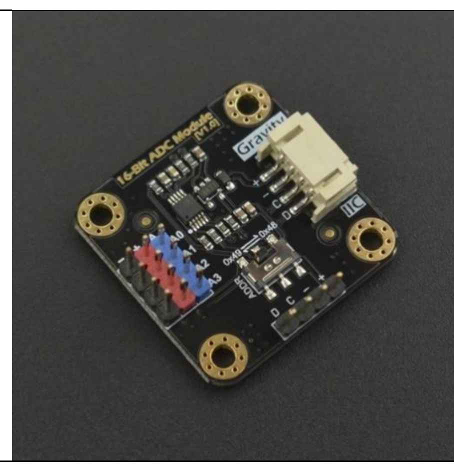
2. Restart the Raspberry Pi: Restart the Raspberry Pi device as it could resolve any potential bugs or glitches that might be affecting the sensor's functionality.
3. Inspect sensor wiring: Ensure the sensor's wiring is secure and properly connected. Keep the wires protected from animals that may cause damage.
4. Consider sensor replacement: If the problem persists even after checking the above steps, it is possible that the temperature sensor is defective and requires replacement.

By following these troubleshooting measures, you can address common issues related to the Sensors and restore proper functionality to the sensor within the biodigester system. If the issue continues to persist, it is strongly advised to seek professional assistance.

ANNEX V:
Bioptimize Duplication Manual

Duplication Manual

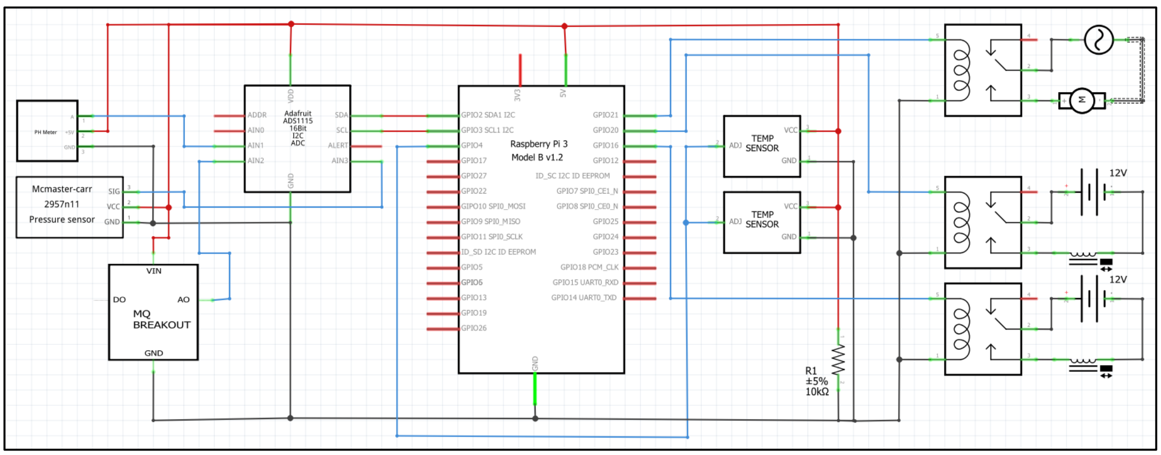
Materials for Duplication of System

Quantity	Component	Model	Actual Image
2	Temperature Sensor	DS18B20	
3	Relay Module	One Channel Relay Module	
1	Analog to Digital Converter	DFRobot I2C ADS1115 16-bit ADC	

1	pH Sensor	Gravity: Analog pH Sensor	
1	Pressure Sensor	Pressure Transducer Transmitter Sensor G1/4 Stainless Steel	
1	Gas Sensor	MQ-9 Gas Sensor	
1	Microcontroller	Raspberry Pi 4B	

2	Solenoid Valve	Normally Closed	

Schematic Diagram



STEP 1: Installation of DS18B20 Temperature Sensor on Raspberry Pi 4B

1. Enable One-Wire Interface.
2. Connect the Signal Pin of both Temperature sensor on GPIO4(GPCLK0) [Pin 7]
3. Make sure that the resistor is properly placed (VCC to GND)
4. Program the DS18B20 on the Raspberry Pi 4B using the code in the appendix.

STEP 2: Installation of Relay and its Components

1. Make sure to import RPi.GPIO in your code.
2. Set the GPIO mode first to BCM. This will enable the Raspberry Pi to properly locate the addresses of the Pins that you will specify.

3. For Solenoid Valve to UP the pH level use GPIO20; for DOWN use GPIO16; for Motor Control use GPIO21.
4. Make sure you connect the Solenoid Valves in the Normally Closed (NC) pin of the relay for Solenoid Valves.
5. For Solenoid Valves: 12V sources positive side must be connected in common and the GND side of the sources must be connected on the GND side of the solenoid valves.
6. For Motor: AC Sources Fire Wire must be connected in common and the Zero Wire side of the source must be connected on the Zero Wire of the Motor. *(This Might depend on what type of motor you buy and rotation you want)*
7. Program the Relay on the Raspberry Pi 4B using the code in the appendix.

STEP 3: Installation of Analog Devices

1. Program the ADS1115 on the Raspberry Pi 4B using the code in the appendix.
2. Connect ADS1115 SDA pin to GPIO2 of Raspberry Pi.
3. Connect ADS1115 SCL pin to GPIO3 of Raspberry Pi.
4. Connect the ADS115 SCL A1 pin to pH sensor Signal Pin
5. Connect the ADS115 SCL A2 pin to Gas sensor Analog Pin
6. Connect the ADS115 SCL A3 pin to Pressure sensor Signal Pin

STEP 4: Put the Sensors in the Tank

1. Put the pH sensor and one DS18B20 on the place where the sensors can read the parameters of the sludge inside the tank.
2. Put the pressure, gas, and one DS18b20 temperature sensor on the top.

3. Put the Raspberry Pi on the safe place most likely in a box away from debris and water.

Note: When putting the sensor in the tank make sure that the tank is properly sealed after. This can be tested using overflowing water in the tank.

STEP 5: Creating a Local and Cloud Database

1. For Local Database make sure your Raspberry Pi has SQLite since we will be using that as our database.
2. Open SQLite in the Raspberry Pi GUI or terminal and create a table. In our case the table order of parameters is date and time, sludge temperature, gas temperature, pH, gas, and then pressure.
3. For Cloud Database, make sure that your Raspberry Pi 4B is connected to the internet to avoid errors. Then, create an account in thingspeak.com create your own channel and put the fields in this order sludge temperature, gas temperature, pH, pressure, and gas.
4. Put your API key in the code below to enable communication between the Raspberry Pi and thingspeak.

STEP 6: Modelling of the Machine Learning

1. Install Pandas and NumPy and their dependencies. Do not delete anything, it might cause errors when running the code.
2. Using your computer or laptop create an interpreter for TensorFlow lite model. Since Raspberry Pi 4B uses TensorFlow Lite and NumPy might not work properly. With the help of interpreter, we will be able to bypass the errors between NumPy and TensorFlow Lite

3. Make sure to put the database in csv format to start the algorithm.

Python Script:

```
#Imports
import RPi.GPIO as GPIO
import time
import os
import sys
import glob
import sqlite3
import math
import pandas as pd
import numpy as np

from sklearn.preprocessing import MinMaxScaler
from sklearn.model_selection import train_test_split
from sklearn.metrics import mean_squared_error, r2_score
from tflite_runtime.interpreter import Interpreter

from urllib.request import urlopen
from twilio.rest import Client

#Sensors

def Sludge_Temperature():
    os.system('modprobe w1-gpio')
    os.system('modproble w1-therm')
    base_dir = '/sys/bus/w1/devices/'
    device_folder = glob.glob(base_dir +'28*')[0]
    device_file = device_folder + '/w1_slave'
    f = open(device_file,'r')
    lines = f.readlines()
    f.close
    while lines[0].strip()[-3:] != 'YES':
        time.sleep(0.2)
        f = open(device_file,'r')
        lines = f.readlines()
        f.close
    equals_pos = lines[1].find('t=')
    if equals_pos != 1:
        temp_string = lines[1][equals_pos+2:]
        Celcius = float(temp_string)/1000
        Celcius = round(Celcius,1)
```

```
        return Celcius

def Gas_Temperature():
    os.system('modprobe w1-gpio')
    os.system('modproble w1-therm')
    base_dir = '/sys/bus/w1/devices/'
    device_folder = glob.glob(base_dir +'28*')[1]
    device_file = device_folder + '/w1_slave'
    f = open(device_file,'r')
    lines = f.readlines()
    f.close
    while lines[0].strip()[-3:] != 'YES':
        time.sleep(0.2)
        f = open(device_file,'r')
        lines = f.readlines()
        f.close
    equals_pos = lines[1].find('t=')
    if equals_pos != 1:
        temp_string = lines[1][equals_pos+2:]
        Celcius = float(temp_string)/1000
        Celcius = round(Celcius,1)
        return Celcius

def AnalogConverter():
    sys.path.append('../')
    from DFRobot_ADS1115 import ADS1115
    ADS1115_REG_CONFIG_PGA_6_144V        = 0x00
    ads1115 = ADS1115()

    ads1115.set_addr_ADS1115(0x49)
    ads1115.set_gain(ADS1115_REG_CONFIG_PGA_6_144V)
    adc0 = ads1115.read_voltage(0)
    time.sleep(0.2)
    adc1 = ads1115.read_voltage(1)
    time.sleep(0.2)
    adc2 = ads1115.read_voltage(2)
    time.sleep(0.2)
    adc3 = ads1115.read_voltage(3)
    time.sleep(0.2)
    sys.path.remove('../')
    return adc0, adc1, adc2, adc3

def pH_level():
    adc = AnalogConverter()
    analog1 = adc[1]['r']
```

```
    _temperature      = 25.0
    _acidVoltage      = 3154.00
    _neutralVoltage   = 2540.0
    slope     = (7.0-4.0)/((_neutralVoltage-1500.0)/3.0 -
(_acidVoltage-1500.0)/3.0)
    intercept = 7.0 - slope*(_neutralVoltage-1500.0)/3.0
    _phValue  = slope*(int(analog1)-1500.0)/3.0+intercept
    _phValue = round(_phValue,2)
    return _phValue

def Gas():
    adc = AnalogConverter()
    analog2 = adc[2]['r']
    analog2 = int(analog2)/1000
    ratio = ((3.3/analog2)-1)*(996/850)
    ppm = 703*(ratio**-2.24)
    per = ppm
    return per

def Pressure():
    adc = AnalogConverter()
    analog3 = adc[3]['r']
    analog3 = float(analog3/1000)
    analog3 = (125000*analog3)-62500
    return analog3

#Application (IoT)

def ThingSpeak_DB():
    sludge_temp = Sludge_Temperature()
    pH = pH_level()
    gas = Gas()
    gas_temp = Gas_Temperature()
    pressure = Pressure()
    WRITE_API = "PUT THINGSPEAK API HERE"
    BASE_URL =
"https://api.thingspeak.com/update?api_key={}".format(WRITE_API)
    thingspeakHttp = BASE_URL +
"&field1={:.2f}&field2={:.2f}&field3={:.2f}&field4={:.2f}&field5=
{:.2f}".format(sludge_temp,gas_temp,pH,pressure,gas)
    print(thingspeakHttp)
    conn = urlopen(thingspeakHttp)
    print("Response: {}".format(conn.read()))
    conn.close()
```

```
def Notification():
    TWILIO_ACCOUNT_SID = "Put Twilio SID Account Here"
    TWILIO_AUTH_TOKEN = "PUT TWILIO AUTH TOKEN"
    TWILIO_PHONE_SENDER = "PUT TWILIO PHONE NUMBER"
    TWILIO_PHONE_RECIPIENT = "PUT YOUR CLIENT’S NUMBER HERE"
    if pH >= 50:
        time.sleep(5)
        Temp_S = TS.read_temp()
        if Temp_S >= 50:
            client = Client(TWILIO_ACCOUNT_SID,
TWILIO_AUTH_TOKEN)
            message = client.messages.create(
            to=TWILIO_PHONE_RECIPIENT,
            from_=TWILIO_PHONE_SENDER,
            body="The Sludge Temperature is too High. Please
store the gas for the safety and wait to cooldown"
            print(message.sid)
        else:
            print("Normal")
    elif BiogasA >= 90000:
        time.sleep(5)
        BiogasA = MS.Analog2a()
        if BiogasA >= 90000:
            client = Client(TWILIO_ACCOUNT_SID,
TWILIO_AUTH_TOKEN)
            message = client.messages.create(
            to=TWILIO_PHONE_RECIPIENT,
            from_=TWILIO_PHONE_SENDER,
            body="The Biogas Tank is almost Full. Please store
the gas for the safety and wait to cooldown"
            print(message.sid)
        else:
            print("Normal")

def local_database():
    conn = sqlite3.connect('PUT LOCAL NAME OF DB FILE HERE')
    sludge_temp = Sludge_Temperature()
    pH = pH_level()
    gas = Gas()
    gas_temp = Gas_Temperature()
    pressure = Pressure()
    c = conn.cursor()
    c.execute("INSERT INTO database VALUES
(datetime('now','localtime'),%d,%d,%d,%d,%d)"%(sludge_temp,gas_te
mp,pH,gas,pressure)
```

```
    conn.commit()
    conn.close()
    print("Succesfully recorded in the local database")

#Algorithms

def MachineLearning():
    # load the TFLite model
    interpreter = Interpreter('model.tflite')
    interpreter.allocate_tensors()
    input_details = interpreter.get_input_details()
    output_details = interpreter.get_output_details()

    # load the dataset
    df = pd.read_csv('database_0430.1.csv')

    # split the dataset into training and testing sets
    X = df.iloc[:, :-1].values # select all columns except the
last one
    y = df.iloc[:, -1].values # select the last column
    X_train, X_test, y_train, y_test = train_test_split(X, y,
test_size=0.2, random_state=0)

    # scale the data
    scaler = MinMaxScaler()
    X_train_scaled = scaler.fit_transform(X_train)
    X_test_scaled = scaler.transform(X_test)
    y_train_scaled = scaler.fit_transform(y_train.reshape(-1, 1))
    y_test_scaled = scaler.transform(y_test.reshape(-1, 1))

    # define a function to predict using the TFLite model
    def predict_tflite(input_data):
        interpreter.set_tensor(input_details[0]['index'],
input_data)
        interpreter.invoke()
        output_data =
interpreter.get_tensor(output_details[0]['index'])
        return output_data

    # make predictions on the testing set
    X_test_scaled = X_test_scaled.astype(np.float32)
    y_pred_scaled = np.array([predict_tflite(x.reshape(1, -
1)).flatten() for x in     X_test_scaled])
    y_pred = scaler.inverse_transform(y_pred_scaled).flatten()
```

```
    # evaluate the performance of the model
    mse = mean_squared_error(y_test, y_pred)
    rmse = np.sqrt(mse)
    r2 = r2_score(y_test, y_pred)

    sludge_temp = 50 # set the sludge temperature
    pH_range = np.arange(3, 8, 0.1) # set the pH range to test
    gas_output = []
    for pH in pH_range:
        X1_new = np.array([[pH]])
        X1_new_2d = X1_new.reshape(1, -1)
        X2_new = np.array([sludge_temp])
        X2_new_2d = X2_new.reshape(1, -1)
        X1_new_scaled = scaler.transform(X1_new_2d)
        X2_new_scaled = scaler.transform(X2_new_2d)
        X_new_scaled = np.concatenate((X1_new_scaled,
X2_new_scaled), axis=1).astype(np.float32)
        y_new_pred_scaled = predict_tflite(X_new_scaled)[0][0]
        y_new_pred =
scaler.inverse_transform(y_new_pred_scaled.reshape(-1,
1)).flatten()
        gas_output.append(y_new_pred[0])
    best_pH = pH_range[np.argmax(gas_output)]
    print('Best pH for maximum gas output:
{:.1f}'.format(best_pH))
    print('Mean squared error: {:.2f}'.format(mse))
    print('Root mean squared error: {:.2f}'.format(rmse))
    print('R-squared: {:.2f}'.format(r2))
    return best_pH

#Automation (aka Control System)

def add_pH():
    GPIO.setmode(GPIO.BCM)
    RELAY_1_GPIO = 23 #Pin 11
    GPIO.setup(RELAY_1_GPIO, GPIO.OUT) # GPIO Assign mode
    GPIO.output(RELAY_1_GPIO, GPIO.LOW) # out
    GPIO.output(RELAY_1_GPIO, GPIO.HIGH) # on
    time.sleep(10)
    GPIO.output(RELAY_1_GPIO, GPIO.LOW) # out
    GPIO.cleanup()

def subtract_pH():
    GPIO.setmode(GPIO.BCM)
    RELAY_2_GPIO = 24 #Pin 13
```

```
    GPIO.setup(RELAY_2_GPIO, GPIO.OUT) # GPIO Assign mode
    GPIO.output(RELAY_2_GPIO, GPIO.LOW) # out
    GPIO.output(RELAY_2_GPIO, GPIO.HIGH) # on
    time.sleep(150)
    GPIO.output(RELAY_2_GPIO, GPIO.LOW) # out
    GPIO.cleanup()

def Motor():
    GPIO.setmode(GPIO.BCM)
    RELAY_3_GPIO = 8 #Pin 13
    GPIO.setup(RELAY_3_GPIO, GPIO.OUT) # GPIO Assign mode
    GPIO.output(RELAY_3_GPIO, GPIO.LOW) # out
    GPIO.output(RELAY_3_GPIO, GPIO.HIGH) # on
    time.sleep(15)
    GPIO.output(RELAY_3_GPIO, GPIO.LOW) # out
    GPIO.cleanup()


#Process
def main():
    pH = pH_level()
    pH_optimized = MachineLearning()
    cycle = 0
    while cycle < 14:
        if cycle % 3 == 0:
            if pH > pH_optimized:
                subtract_pH()
                print("Optimizing pH level(-)")
                cycle = cycle +1
            elif pH < pH_optimized:
                add_pH()
                print("Optimizing pH level(+)")
                cycle = cycle + 1
        else:
            ThingSpeak_DB()
            Notification()
            local_database()
            cycle = cycle +1
            time.sleep(500)
    Motor()
    python = sys.executable
    os.execl(python, python, *sys.argv)

try:
    main()
```

```
except:
    python = sys.executable
    os.execl(python. python, *sys.argv)
```

ANNEX VI:
PROJECT DOCUMENTATION

Creation of the Bioptimize Mobile Application

Figure VI.1.1. Creating the user interface for the mobile application.

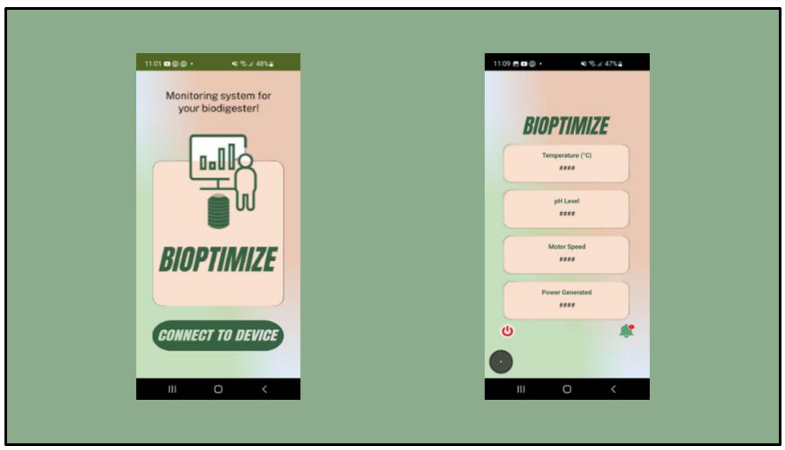


Figure VI.1.2.1. Draft front end of the mobile application.

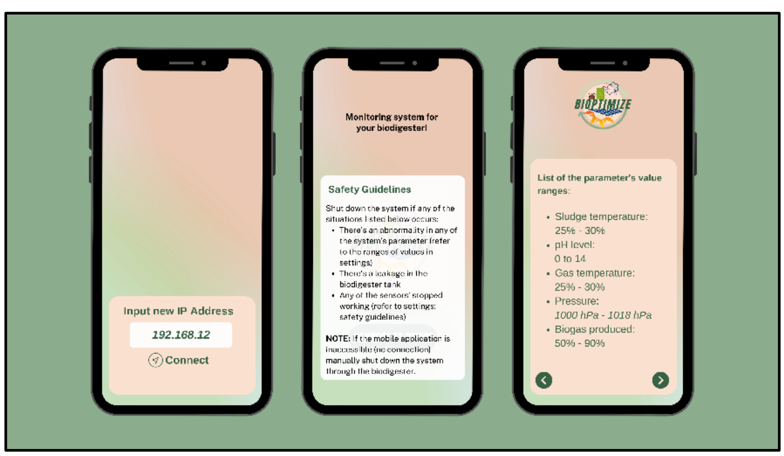


Figure VI.1.2.2. Draft front end of the mobile application

Creation of the Bioptimize Mobile Application

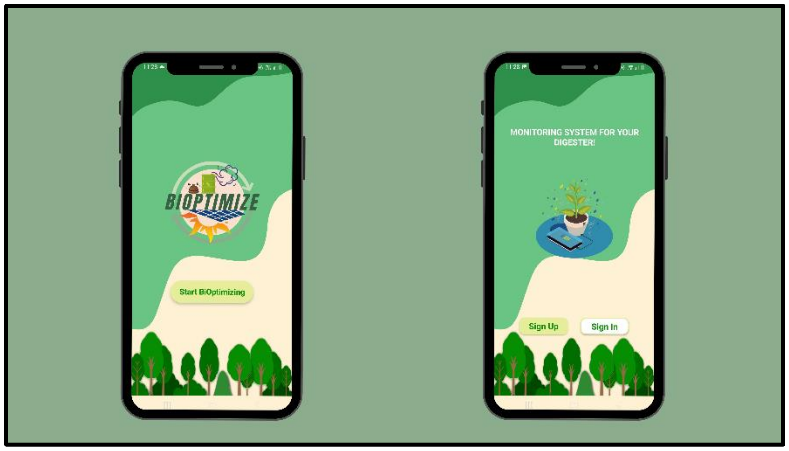


Figure VI.1.3.1. Final front-end design of the Mobile Application

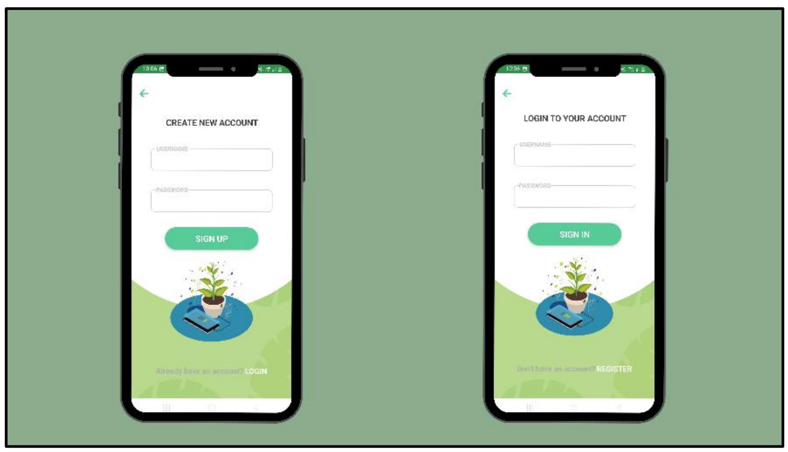


Figure VI.1.3.2. Final front-end design of the Mobile Application (Login / Create Account)

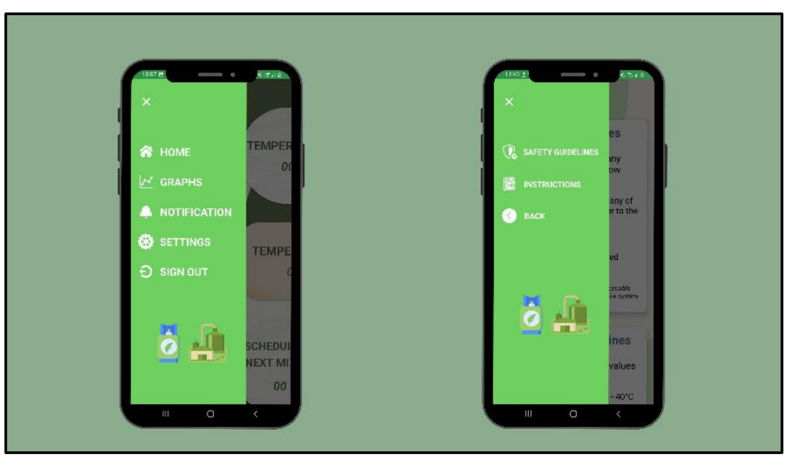


Figure VI.1.3.3. Final front-end design of the Mobile Application (Dropdown Navigation Bar)

Creation of the Bioptimize Mobile Application

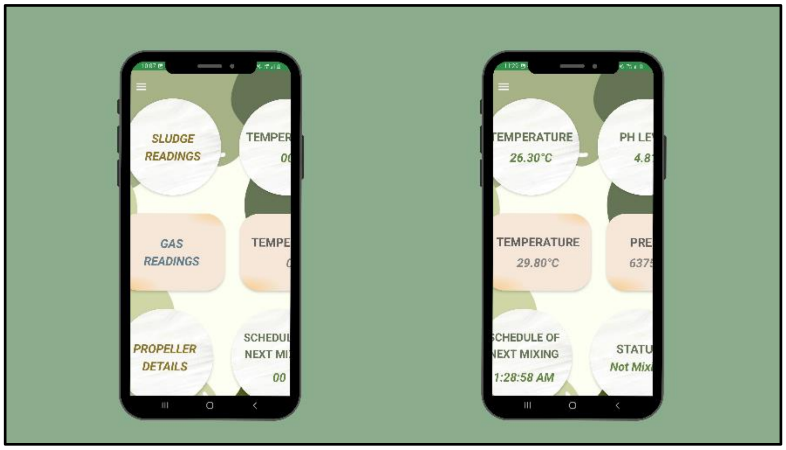


Figure VI.1.3.4. Final front-end design of the Mobile Application (Parameters)

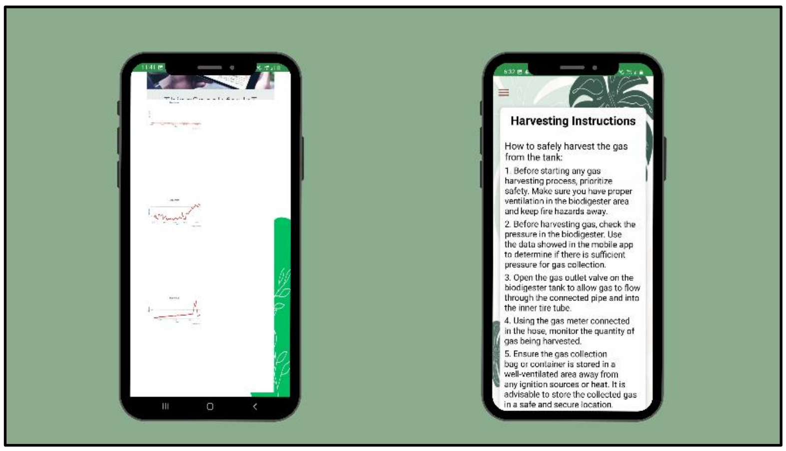


Figure VI.1.3.5. Final front-end design of the Mobile Application. (Graphic presentation of the parameters / Harvesting Instructions)

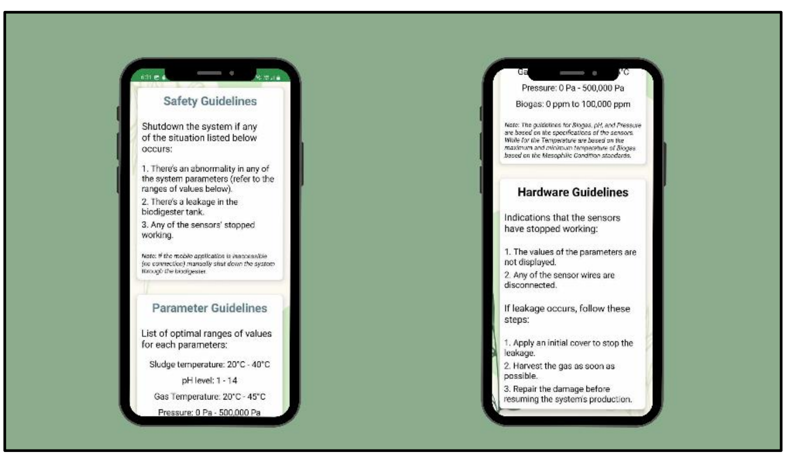


Figure VI.1.3.6. Final front-end design of the Mobile Application. (Users' Guidelines)

System Assembly

Figure VI.2.1. Integration of the Sensors.

Figure VI.2.2.1 Soldering of the sensors.

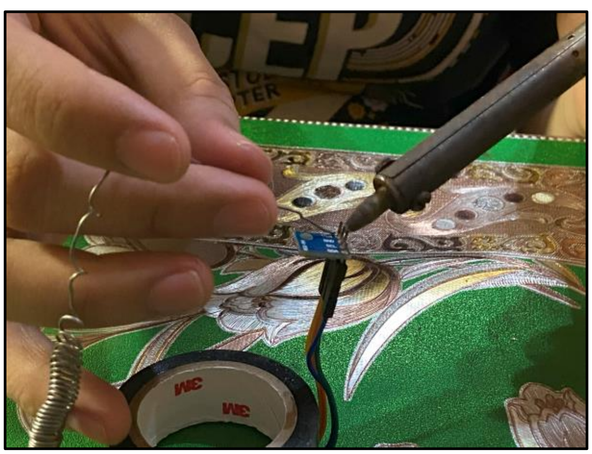


Figure VI.2.2.2 Soldering of the sensors.

System Assembly

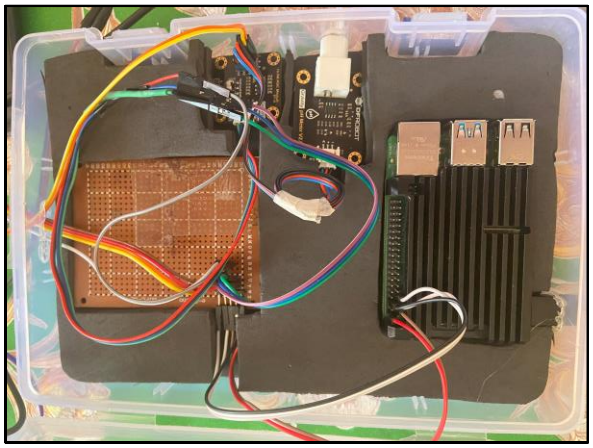


Figure VI.2.3. Construction of the initial container of the sensors

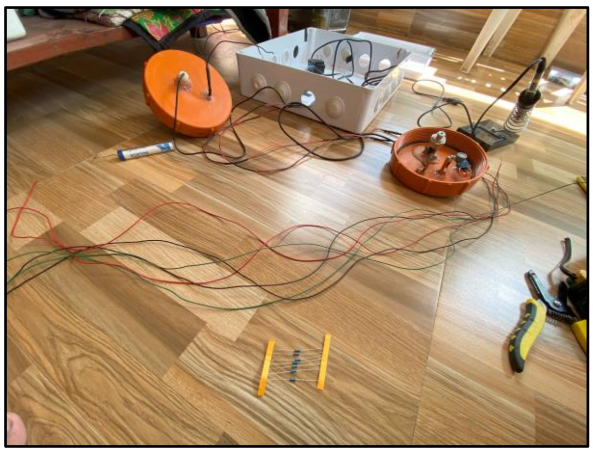


Figure VI.2.4 Construction of the final container of the sensors

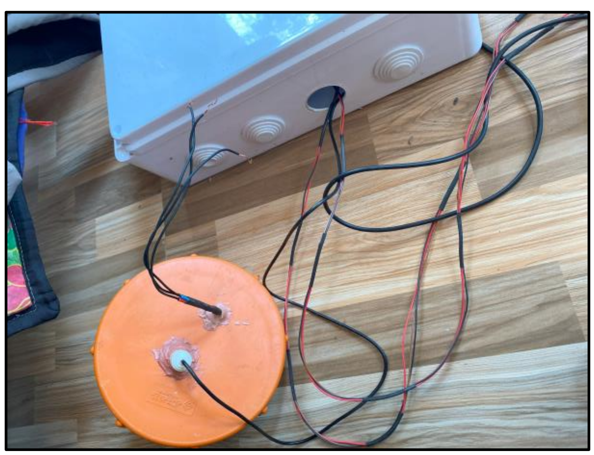


Figure VI.2.5 Final construction and container of the sensors

Biogas Storage Assembly

Figure VI.3.1. Installation of the y-valve to facilitate the connection of the hose.

Figure VI.3.2. Installing the gas meter connection within the pipeline.

Figure VI.3.3. Final output of the biogas storage.

Biogas Storage Assembly

Figure VI.3.4. Biogas storage connected in the tank's gas outlet

Construction of the Bioptimize Tank

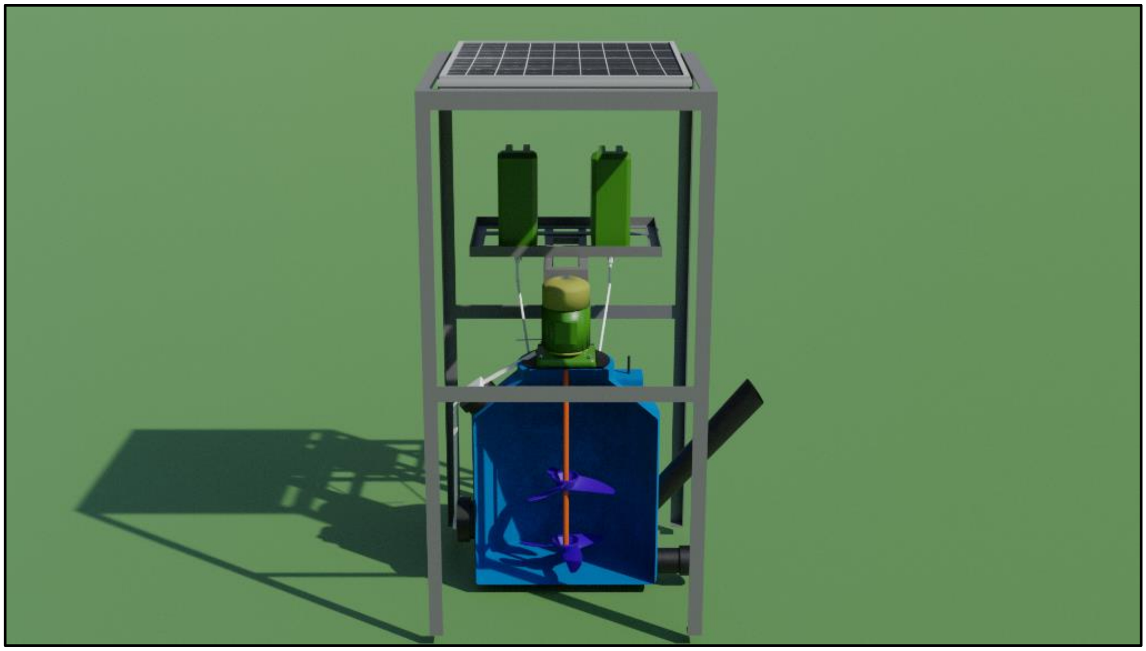


Figure VI.4.1. Conceptual design of the tank.

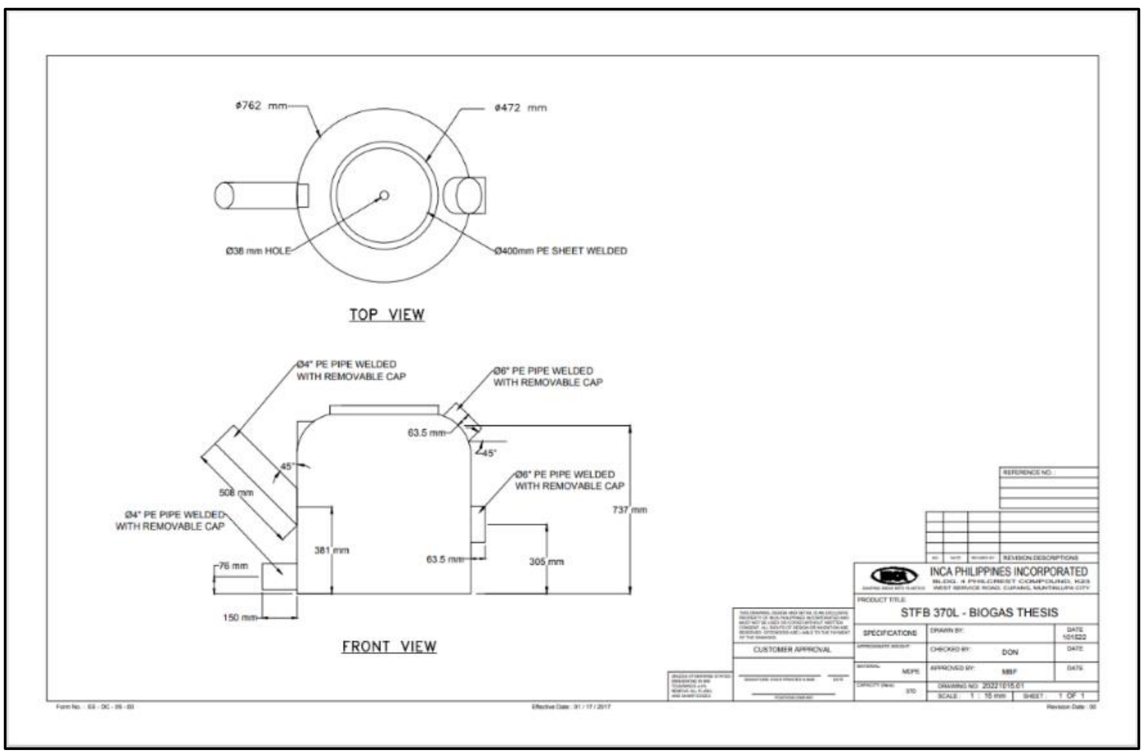


Figure VI.4.2. Final Blueprint Design of the Tank.

Construction of the Bioptimize Tank

Figure VI.4.3. Fabricated tank by INCA Philippines.

Figure VI.4.4. Construction of the solar panel frame.

Construction of the Bioptimize Tank

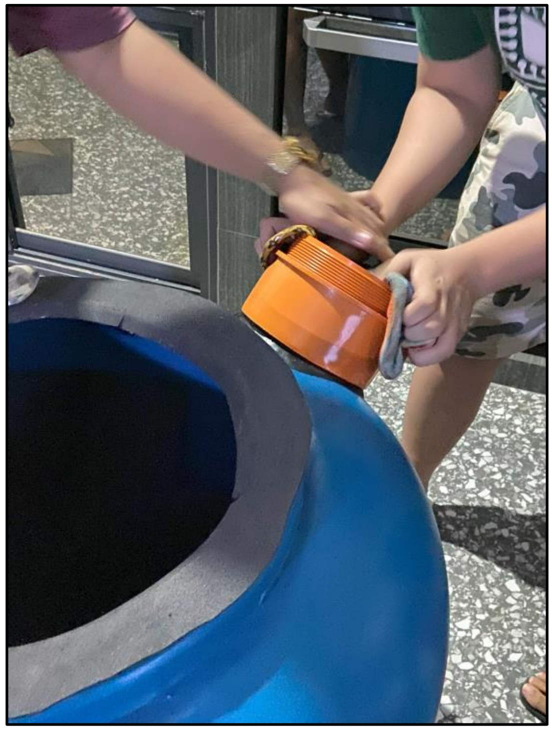


Figure VI.4.5. Fabricating the inlets and outlets of the tank.

Figure VI.4.6. Installing the motor, propeller, and chemical container within the tank.

Construction of the Bioptimize Tank

Figure VI.4.7. Installing the frame and solar panel.

Figure VI.4.8. Reconstruction of the motor and propeller's frame

Construction of the Bioptimize Tank

Figure VI.4.9.1. Reconstruction of the Chemical Containers.

Figure VI.4.9.2. Reconstruction of the Chemical Containers.

Construction of the Bioptimize Tank

Figure VI.4.10. Final design and construction of the Bioptimize Tank.

Pre-Deployment

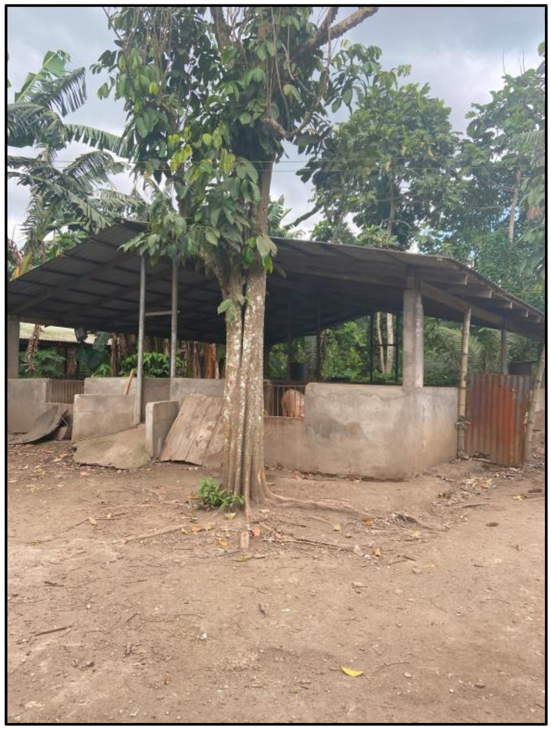


Figure VI.5.1.1 Conducting on-site visits in preparation for the deployment.

Figure VI.5.1.2 Conducting on-site visits in preparation for the deployment.

Pre-Deployment

Figure VI.5.1.3 Conducting on-site visits in preparation for the deployment.

Figure VI.5.2. Research Proponents with the Backyard Piggery Owner, Mrs. Riza Limbo Lubigan-Roxas

Deployment

Figure VI.6.1. Research Proponents in the final deployment site.

Figure VI.6.2. Applying water in the sludge for optimal mixture consistency.

Deployment

Figure VI.6.3. Loading of sludge for the initial data collection.

Figure VI.6.4. Unloading the tank for the next data collection.

Deployment

Figure VI.6.5. Tank fully working together with the propeller and pH optimization

Thesis Defense

Figure VI.7.1. Title Defense

Figure VI.7.2.1. Progress Defense

Thesis Defense

Figure VI.7.2.2. Progress Defense

Figure VI.7.2.3. Progress Defense

Figure VI.7.3. Pre-Final Defense

Thesis Defense

Figure VI.7.4.1 Final Defense

Figure VI.7.4.2. Final Defense

Appreciate

Figure VI.8.1. Bioptimize Appreciate Booth

Figure VI.8.2. Research Proponents with the TUP President, Dr. Reynaldo P. Ramos.

Appreciate

Figure VI.8.3.1. Bioptimize Research Proponents

Figure VI.8.3.2. Bioptimize Research Proponents

ANNEX VII:
PROPONENTS PROFILE

JOHN MICHAEL TARASONA

09999686059 johnmichael.tarasona@tup.edu.ph Muntinlupa City

PROFILE

I am a highly motivated and skilled individual with a strong background in leadership, project management, and effective communication. Experienced in overseeing affairs as President of the Organization of Electronics Engineering Students, demonstrating strong leadership and coordination abilities. Successfully managed organizational responsibilities while maintaining academic performance. Customer service experience as a part-time barista enhanced communication skills. Proven ability to maintain positive relationships with key stakeholders, acting as a bridge between students and administration.

EDUCATION

BS ELECTRONICS ENGINEERING
Technological University of the Philippines - Manila
August 2019 – August 2023

SENIOR HIGH SCHOOL
Polytechnic University of the Philippines - Sta. Mesa
June 2017 – April 2019

JUNIOR HIGH SCHOOL
Muntinlupa National High School
June 2014 – April 2017

SKILLS

- Leadership
- Project Management
- Strong Communication
- Decision-making
- MATLAB/Octave
- NI Multisim
- Cisco Packet Tracer
- Microsoft Applications

EXPERIENCE

PRODUCT MARKETING ENGINEER - INTERN
Lattice Semiconductor PH Corporation
August 2022 – September 2022

Key Responsibilities:
- Website Auditing
- Generating and Providing IP Tools and License for Clients and Staffs.
- Conduct workshop on how to use the Lattice Radiant Design Software.

PART-TIME BARISTA
Starbucks, Rustan Coffee Corporation
February 2022 – April 2022

ADMIN ASSISTANT
Lemniscate Enterprises
January 2019 – February 2019

SPES EMPLOYEE
Public Employment Service Office - Muntinlupa
March 2017 – May 2018

HONORS, AWARD AND CERTIFICATIONS

FORTINET NSE CERTIFICATION PROGRAM
- Certified Associate - Fortinet NSE Level 3 (May 2023)
- Certified Associate - Fortinet NSE Level 2 (May 2023)
- Certified Associate - Fortinet NSE Level 1 (April 2023)

MNET IT
- Master IP Addressing and Subnetting for CCNA (May 2022)

ORGANIZATION OF ELECTRONICS ENGINEERING STUDENTS
- Awardee - Outstanding Student Leader Award (A.Y 2021-2022)

DEPARTMENT OF SCIENCE AND TECHNOLOGY (DOST)
- Awardee - Junior Level Science Scholarship Grant (2021)

MUNTINLUPA SCHOLARSHIP DIVISION
- Awardee - Priority Scholarship Grant (2019)
- Receipient - MSD Scholarship Grant (2015-2019)

COLLEGE OF ENGINEERING, ECE DEPARTMENT
- Candidate for Dean's Lister (A.Y 2020-2021) (A.Y 2022-2023)

PUP SENIOR HIGH SCHOOL DEPARTMENT
- Awardee - With Honors (A.Y 2018-2019)

MUNTINLUPA NATIONAL HIGH SCHOOL - MAIN
- Awardee - Overall Top 3 With High Honors (A.Y 2016-2017)
- Awardee - With High Honors (3rd Quarter) (A.Y 2016-2017)
- Awardee - With High Honors (2nd Quarter) (A.Y 2016-2017)
- Awardee - With High Honors (1st Quarter) (A.Y 2016-2017)
- Awardee - Best in Drafting (A.Y 2016-2017)

ANGELLI KYLL ELVAMBUENA

09662572763 angellikyll.elvambuena@tup.edu.ph Sampaloc Manila

PROFILE

I actively engaged with my organization as a member of the Creative Committee for a year. During this time, I effectively collaborated with diverse individuals, fostering productive teamwork and achieving impressive outcomes, I consistently contributed my best efforts to group projects. Dedicated and responsible, I prioritize meeting my responsibilities and consistently deliver my best work. My elective in Telecommunication has provided me with extensive knowledge in the field, further enhancing my understanding of this domain.

EDUCATION

BS ELECTRONICS ENGINEERING
Technological University of the Philippines - Manila
August 2019 – August 2023

SENIOR HIGH SCHOOL
Wesleyan University - Philippines
June 2017 – April 2019

JUNIOR HIGH SCHOOL
Mallorca National High School
June 2013 – April 2017

SKILLS

- Effective management skills
- Strong analytical and problem-solving abilities
- Strong Communication
- NI Multisim
- Programming Techniques in MATLAB and Python
- Cisco Packet Tracer

EXPERIENCE

TECHNICAL AND DIGITAL TEAM - INTERN
DWWW 774
August 2022 – September 2022

Key Responsibilities:
- Audio Editing
- Commercial Playback
- Live Broadcasting
- Technical and Digital Support

TECHNICAL TEAM - INTERN
Wesleyan University General Hospital
May 2019 - June 2019

Key Responsibilities:
- CCTV Operation
- Equipment Maintenance
- Documentation

HONORS, AWARD AND CERTIFICATIONS

FORTINET NSE CERTIFICATION PROGRAM
- Certified Associate - Fortinet NSE Level 3 (May 2023)
- Certified Associate - Fortinet NSE Level 2 (May 2023)
- Certified Associate - Fortinet NSE Level 1 (April 2023)

MNET IT
- Master IP Addressing and Subnetting for CCNA (May 2022)

WESLEYAN UNIVERSITY PHILIPPINES SENIOR HIGH SCHOOL
- Awardee - With Honors (A.Y 2018-2019)

MALLORCA NATIONAL HIGH SCHOOL - JUNIOR HIGH SCHOOL
- Awardee - With Honors (2017)

SEAN CRISTOPHER D. GARCIA

09493950172 seancristopher.garcia@tup.edu.ph San Mateo, Rizal

PROFILE

Enthusiastic and dedicated individual pursuing a degree and future career in electronics engineering, with a solid foundation in programming and basic front-end web development. Possessing a deep passion for electronics engineering and has a continuous drive for learning and growth. I am a fast and adaptable learner, and with my experiences, I developed strong problem-solving skills and approach challenges with a determined and focused mindset. I actively seek out creative and effective solutions to overcome obstacles and achieve desired outcomes.

EDUCATION

BS ELECTRONICS ENGINEERING
Technological University of the Philippines - Manila
August 2019 – August 2023

SENIOR HIGH SCHOOL
Claro M. Recto Senior High School
June 2017 – April 2019

JUNIOR HIGH SCHOOL
Concepcion Catholic School
June 2014 – April 2017

SKILLS

- Computer Proficiency
- Python Programming
- Basic Front End Web Development
- Circuit and Design Simulation
- Editing skills (Photoshop, Blender)
- Communication
- Critical Thinking and Problem solving skills

EXPERIENCE

SITE INSTALLER/TECHNICIAN - INTERN
Stelsen Integrated Systems, INC.
August 2022 - September 2022

Key Responsibilities:
- Equipment Inspection (FDAS)
- Preventive Maintenance
- Site Troubleshooting

PRODUCTION TEAM - INTERN
Rebtrade International Corporation
April 2018 - June 2018

Key Responsibilities:
- Office Management
- Customer Service
- Production Staff

HONORS, AWARD AND CERTIFICATIONS

DEPARTMENT OF SCIENCE AND TECHNOLOGY (DOST)
- Leadership and Volunteerism for Community Resilience (June 2022)

MNET IT
- Master IP Addressing and Subnetting for CCNA (May 2022)

DEPARTMENT OF SCIENCE AND TECHNOLOGY (DOST)
- Awardee - Junior Level Science Scholarship Grant (2019)

COLLEGE OF ENGINEERING, ECE DEPARTMENT
- Candidate for Dean's Lister (A.Y 2022-2023)

CLARO M. RECTO SENIOR HIGH SCHOOL
- Awardee - With High Honors (A.Y 2018-2019)
- Mercury Drug Award for Academic Excellence in Mathematics and Science
- Best in Immersion

CONCEPCION CATHOLIC SCHOOL
- Awardee - With Honors (A.Y 2016-2017)

JEAN VENICE MAE B. ROSETE

09260558523 jeanvenicemae.rosete@tup.edu.ph Manila City

PROFILE

I am an ambitious individual who undertook a specialization in Telecommunication with the goal of acquiring advanced skills in this sector. With my specialized training, I am prepared to contribute my technical proficiency and drive innovation in the field of telecommunication. Alongside my academic pursuits, I had the opportunity to cultivate my creative abilities by creating visually captivating pubmats for an organization in my university. This experience showcased my expertise in both technical and artistic domains, highlighting my seamless integration of engineering knowledge with innovative design concepts. With a strong foundation in electronics engineering and a passion for creative expression, I bring a unique blend of skills and a fresh perspective to any team or project.

EDUCATION

BS ELECTRONICS ENGINEERING
Technological University of the Philippines - Manila
August 2019 – August 2023

SENIOR HIGH SCHOOL - STEM
Perpetual Help College of Manila
June 2017 – April 2019

JUNIOR HIGH SCHOOL
Cayetano Arellano High School
June 2014 – April 2017

SKILLS

- Adequate proficiency in Microsoft Office (Word, Excel, PowerPoint), Multism, MATLAB, GNU Octave, Cisco Packet Tracer, GNS3, Canva
- Data Gathering, Data Analysis, Experimental Research, Report Generation
- Adaptability, Leadership, Initiative, Critical Thinking, Time Management

EXPERIENCE

INSTALLATION ENGINEER - INTERN
Stelsen Integrated Systems Inc.
August 2022 - September 2022

Key Responsibilities:
- Responsible for installing and upgrading auxillary system, fire detection and alarm system (FDAS), and intercom system in housing or residential building.
- Analyzing blueprints and plans, and finding and repairing any malfunctions.
- Collaborated with the sales team and clients to gain comprehensive knowledge of product specifications and technical details.

CREATIVE DESIGN OFFICER
Organization of Electronics Engineering Students - TUP Manila
Graduating Class Division - TUP Manila
August 2021 - August 2023

Manila Traffic & Parking Bureau (MTPB) Marshal
Public Employment Service Office - Manila City
April 2022 - June 2022

QUALITY INSPECTOR - INTERN
CREOTEC Philippines Inc. - Manila Center
September 2018 - October 2018

Key Responsibilities:
- Responsible for ensuring the quality of the product produced, managed and worked with a team of 4
- Repaired damaged products before they can be included in the overall total production count which resulted in exceeding the minimum required output each day

HONORS, AWARD AND CERTIFICATIONS

FORTINET NSE CERTIFICATION PROGRAM
- Certified Associate - Fortinet NSE Level 3 (May 2023)
- Certified Associate - Fortinet NSE Level 2 (April 2023)
- Certified Associate - Fortinet NSE Level 1 (April 2023)

MNET IT
- Master IP Addressing and Subnetting for CCNA (May 2022)

Perpetual Help College of Manila - SHS Department
- Awardee - With Honors (A.Y 2017-2018)
- Awardee - Graduated with Honors (A.Y 2018-2019)

CAYETANO ARELLANO HIGH SCHOOL
- Awardee - Graduated With Honors (A.Y 2016-2017)

REMUEL SORIANO

+639292182842 remuel.soriano@tup.edu.ph Las Piñas City

PROFILE

I have a strong passion for programming and possess solid skills in Python, Java, and C++. With a deep understanding of software development principles, I excel at crafting efficient and elegant solutions to complex problems. Additionally, I have hands-on experience in web development, allowing me to create dynamic and user-friendly websites. I am an enthusiastic learner, always seeking new challenges to expand my knowledge and enhance my abilities. I am eager to contribute my skills and expertise to real-world projects and make a meaningful impact in the field of technology

EDUCATION

BS ELECTRONICS ENGINEERING
Technological University of the Philippines - Manila
August 2019 – August 2023

SENIOR HIGH SCHOOL
Parañaque Science High School
June 2017 – April 2019

JUNIOR HIGH SCHOOL
Parañaque Science High School
June 2013 – April 2015
Bernardo College
June 2015 - April 2017

EXPERIENCE

IT STAFF - INTERN
United Neon Media Group
September 2022 – November 2022

Key Responsibilities:
- Broadcasting (Shakey's Super League 2022)
- Network Troubleshooting
- Web Development

IT HELPER
IBEX Philippines
January 2019 – February 2019

SKILLS

Web Design
- Front End Development (HTML, CSS, JavaScript)
- Responsive Web Design
- Front-end frameworks (React)
- Back-end development (Django, Node.js)

Software Development
- Object-Oriented Programming
- Software Development Life Cycle
- Version Control (Git)
- Agile Method

Network Engineering
- Network Design
- Cisco Packet Tracer
- Network Protocols
- Network Security and Firewall

Programming Languages
- Python
- Java
- C++
- JavaScript
- HTML/CSS

HONORS, AWARD AND CERTIFICATIONS

FORTINET NSE CERTIFICATION PROGRAM
- Certified Associate - Fortinet NSE Level 3 (May 2023)
- Certified Associate - Fortinet NSE Level 2 (May 2023)
- Certified Associate - Fortinet NSE Level 1 (April 2023)

MNET IT
- Master IP Addressing and Subnetting for CCNA (May 2022)

"CODE UP " PROGRAMMING COMPETITION (2021)
- 3rd Placer - University Level
- 2nd Runner Up - NCR Level

COLLEGE OF ENGINEERING, ECE DEPARTMENT
- Candidate for Dean's Lister (A.Y 2021-2022)

GRADUATE OF PARAÑAQUE SCIENCE HIGH SCHOOL
- Awardee - With Honors (A.Y. 2018-2019)

ICEF RESEARCH CONTEST SENIOR HIGH SCHOOL DIVISION
- Awardee - 1st Runner Up (Division Level)

NATIONAL SCIENCE QUEST (2019)
- Awardee - 7th Placer (National Level)