

PROFESSIONAL TRAINING REPORT - II

entitled

Smart Optimization of Biogas Production for Enhanced Gas Yield

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Engineering degree in Computer Science and Engineering with
specialization in Internet of Things

by

S NANDHAKUMAR - [41732011]

R ABISHEK - [41732001]

M RAHUL RAGHAVENDRAN - [41732013]

A S VISHNU HARIHARAN - [41732018]



**DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING
SCHOOL OF COMPUTING**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

**Accredited with Grade “A++” by NAAC | 12B Status by UGC | Approved by AICTE
JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI – 600119**

MAY 2024



SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

CATEGORY-I UNIVERSITY BY UGC

Accredited "A++" Grade by NAAC | 12B Status by UGC | Approved by AICTE

www.sathyabama.ac.in

DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Professional Training Report is the bonafide work of **Mr. S. Nandhakumar (41732011)** who carried out the project entitled "**Smart Optimization of Biogas Production for Enhanced Gas Yield**" under my supervision from January 2024 to May 2024.

Internal Guide

Mrs. K. ABINAYA, M.E., (Ph.D).,

Head of the Department

Dr. S. VIGNESHWARI, M.E., Ph.D.,

Submitted for Viva voce Examination held on

6/5/24

Internal Examiner

External Examiner

DECLARATION

I, S. NANDHAKUMAR (41732011), hereby declare that the Professional Training Report-II entitled " Smart Optimization of Biogas Production for Enhanced Gas Yield" done by me under the guidance of Mrs. K. Abinaya, M.E., (Ph.D)., is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in Computer Science and Engineering with specialization in Internet of Things.

DATE: 06/05/24

S. Nandhakumar

PLACE: Chennai

SIGNATURE OF THE CANDIDATE

ACKNOWLEDGEMENT

I am pleased to acknowledge my sincere thanks to the **Board of Management of SATHYABAMA** for their kind encouragement in doing this project and for completing it successfully. I am grateful to them.

I convey my thanks to **Dr. T.Sasikala M.E., Ph.D., Dean, School of Computing, Dr. S.Vigneshwari M.E., Ph.D., Head of the Department of Computer Science and Engineering** for providing me necessary support and details at the right time during the progressive reviews.

I would like to express my sincere and deep sense of gratitude to my Internal Guide **Mrs. K. Abinaya M.E., (Ph.D).,** for her valuable guidance, suggestions and constant encouragement which paved the way for the successful completion of my Phase- 2 Professional Training.

I wish to express my thanks to all Teaching and Non-teaching staff members of the **Department of Computer Science and Engineering** who were helpful in many ways for the completion of the project.

COURSE CERTIFICATE

	CHENNAI INSTITUTE OF TECHNOLOGY (Autonomous)			
International Conference on Data Science, Agents and Artificial Intelligence ICDSAAI 2023				
Certificate				
◆ ◆ ◆				
This is to certify that <u>Nandhakumar S</u>				
from <u>Sathyabama Institute of Science and Technology</u>				
has participated in Conference / Tutorial / Presented the paper entitled _____				
<u>Smart Optimization of Biogas for Enhanced Gas Yield</u>				
in the International Conference on Data Science, Agents and Artificial Intelligence (ICDSAAI 2023) organised by Center for Artificial Intelligence and Research, Chennai Institute of Technology from 21 st to 23 rd Dec, 2023.				
 Convenor	In Association with  			 Principal
				

ABSTRACT

This study proposes a strategy to increase biogas generation by fusing the Internet of Things (IoT) strength with organic waste recycling. Organic waste can be used to create biogas, a renewable energy source, although the process can be time-consuming. In order to better regulate equipment, this study makes use of IoT technology, which entails connecting sensors to the Internet. Here, continuous tracking is an important parameter for monitoring temperature, acidity levels, waste volume, flow rate, waste kind, and gas production rate. Here the system's internal circumstances are modified and stimulated while it is operating by utilizing deep computer analyses and unique learning methods. Specifically, depending on the kind of waste being used, temperature and acidity levels are adjusted here. This strategy undoubtedly seeks to hasten the production of biogas while preserving an efficient and environmentally friendly procedure. Faster energy production, less resource consumption, and a shift toward creative, sustainable energy solutions are all intriguing potential consequences of this study.

TABLE OF CONTENTS

CHAPTER NO.	TITLE	PAGE NO.
	ABSTRACT	vi
	LIST OF FIGURES	viii
	INTRODUCTION	
1	1.1 Overview	1
	LITERATURE SURVEY	
2	2.1 survey	3
3	REQUIREMENTS ANALYSIS	5
	3.1 Objective	5
	3.2.1 Hardware Requirements	6
	3.2.2 Software Requirements	7
4	DESIGN DESCRIPTION OF PROPOSED PRODUCT	8
	Proposed Product	8
	4.1.1 Ideation Map/Architecture Diagram	9
4.1	4.1.2 Various stages	10
	4.1.3 Internal or Component design structure	11
	4.1.4 working principles	13
	Features	16
4.2.4.2	4.2.1 Novelty of the Project	
5	CONCLUSION	19
	References	20

LIST OF FIGURES

Figure No.	Figure Name	Page No.
I.	Working Flow of the System.	9
II.	Systematic approach of the Optimization.	11
III.	Circuit for measuring pH value.	12
IV.	Circuit for measuring Temperature.	12
V.	Circuit for measuring Gas Type.	13
VI.	Graph representing Preoptimized Value and Optimized Value.	15
VII.	Graph representing Best Possible Value and Predicted Value.	16

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Biogas generation from organic waste stands out as a strong response to the growing environmental problems and the need to switch to sustainable energy sources. Anaerobic digestion of organic matter yields biogas, a sustainable energy source with potential for both energy production and efficient waste management. The effectiveness of biogas production operations frequently falls short of its potential due to issues like poor process conditions, lengthy digestion times, and challenges in handling various waste compositions. This project uses the capabilities of the Internet of Things (IoT) in an effort to address these restrictions in a novel way that takes advantage of upcoming technology.

The way we interact with and manage our surroundings has been completely reimaged by the Internet of Things, which is defined by the internet-based connectivity of numerous objects. Incorporating IoT technologies to create an intelligent and adaptable biogas production environment, this concept suggests a paradigm leap in biogas production. The central idea centers on real-time data monitoring and dynamic parameter changes that adapt to the particular circumstances inside the biogas reactor. The system can optimize the biogas production process by continually measuring and analyzing key operational variables like temperature, pH, waste composition, load weight, and flow rate.

Conventional biogas production techniques frequently function in a static environment and are unable to adjust to changing microbial dynamics and waste properties. Due to this restriction, the rate of gas production is less than ideal, and the digestion time is prolonged. The proposed IoT-driven method includes real-time adaptation to close this gap. IoT sensors will gather data inside the biogas reactor, allowing for a thorough insight into the dynamics of the system.

To find hidden patterns, dependencies, and trends, the data will go through a thorough analysis using data analytics and machine learning techniques. These revelations will guide the skillful adjustment of critical process variables, particularly pH and temperature, with accuracy catered to the particular waste type being processed. By fostering a climate that encourages the growth of the microorganisms needed for effective biogas production, this dynamic optimization aims to increase gas yield.`

This project's significance has many different facets. The project directly contributes to reaching renewable energy targets and developing sustainable waste management practices by speeding biogas generation while guaranteeing ideal conditions. The primary goal of promoting eco-friendly practices is aligned with thr decreased resource usage and increased energy output. The combination of IoT-enabled intelligence has the ability to set a new course toward a greener and more efficient energy future as biogas grows in popularity as a workable renewable energy source.

CHAPTER 2

LITERATURE REVIEW

2.1 SURVEY

The production of biogas from organic waste has gained significant attention as a promising renewable energy solution and an effective means of waste management. However, the efficiency of biogas production processes has often fallen short of their potential, primarily due to issues such as poor process conditions, prolonged digestion times, and challenges associated with handling diverse waste compositions. This literature review explores the existing research and developments in the integration of Internet of Things (IoT) technology and machine learning (ML) algorithms to address these limitations and enhance biogas generation.

Biogas Generation and Anerobic Digestion

Biogas, a renewable energy source derived from the anaerobic digestion of organic matter, holds considerable promise for sustainable energy production and waste management. Anaerobic digestion involves the breakdown of organic materials by microorganisms in an oxygen-depleted environment, resulting in the production of biogas, primarily composed of methane (CH₄) and carbon dioxide (CO₂). Despite its potential, traditional biogas production processes have often struggled to achieve optimal efficiency due to the static nature of their operational conditions.

Integration of the IoT Technology in the System

The Internet of Things (IoT) is revolutionizing various industries by providing real-time data monitoring and connectivity to numerous objects and devices. In the context of biogas production, IoT technology allows for continuous tracking of critical parameters such as temperature, pH levels, waste composition, load weight, and flow rate within the biogas reactor. These sensors enable the collection of real-time data, providing valuable insights into the system's dynamics.

Machine Learning for Data Analytics

Machine learning algorithms play a pivotal role in harnessing the potential of IoT-enabled biogas production systems. These algorithms leverage historical and real-time data to identify patterns, correlations, and predictive insights. In the context of biogas production, ML algorithms can analyze data from IoT sensors to recommend optimal adjustments to key operational variables. For instance, ML models can suggest changes in temperature and pH levels tailored to the specific waste type being processed, promoting the growth of microorganisms essential for efficient biogas production.

Dynamic Parameter Adjustment and Optimization

One of the primary advantages of integrating IoT and ML in biogas production is the ability to dynamically adjust critical process parameters. Traditional biogas production methods often operate in static environments, unable to adapt to changing microbial dynamics and waste properties. By contrast, IoT-enabled systems continuously monitor and analyze data, allowing for precise adjustments to parameters such as temperature, feedstock ratios, and gas recirculation rates. These adjustments are made in response to real-time conditions, optimizing the biogas production process.

Energy Efficiency and Environmental Impact

The integration of IoT and ML technologies into biogas production offers several potential benefits. First and foremost, it can significantly accelerate the production of biogas, reducing the time required for digestion. This not only enhances energy production but also promotes efficient waste management practices. Additionally, the optimization of biogas production through IoT and ML contributes to resource conservation and reduced operational costs.

CHAPTER 3

REQUIREMENTS ANALYSIS

3.1 OBJECTIVE OF THE PROJECT

This paper proposes and demonstrates a strategy for increasing the efficiency of biogas generation from organic waste through the integration of Internet of Things (IoT) technology and machine learning. The primary goals and objectives of the paper include:

Enhancing Biogas Production Efficiency: The paper aims to improve the efficiency of biogas production processes, which are often hindered by slow gas generation and challenges in managing various types of organic waste. The proposed strategy seeks to address these issues.

Utilizing IoT Technology: The key objective is to leverage IoT technology, including sensors and real-time data monitoring, to continuously collect and analyze data from the biogas production system.

Dynamic Parameter Adjustment: The paper aims to dynamically adjust critical operational parameters in real-time, such as temperature, pH levels, and waste composition, based on the data collected and analyzed through machine learning techniques.

Optimizing Gas Yield: The primary goal is to maximize the production of biogas by creating an environment that fosters the growth of microorganisms essential for effective biogas production. This is achieved through precise parameter adjustments.

Promoting Sustainability: The research aligns with broader sustainability objectives by contributing to renewable energy targets and sustainable waste management practices. It aims to reduce resource consumption and increase energy output.

Demonstrating Technological Innovation: The paper showcases the potential of combining emerging technologies like IoT and machine learning to revolutionize the biogas production industry.

Setting a Path for Future Research: The research serves as a foundation for future studies and initiatives seeking to further optimize biogas production processes and promote cleaner energy solutions.

3.2 REQUIREMENTS

The requirements of this project include the integration of various Hardware and Software components cordially to work together and these requirements are mentioned below:

3.2.1 HARDWARE REQUIREMENTS

- i.) **IoT Sensors:** Depending on the parameters aimed to monitor and control, various types of sensors such as temperature sensors, pH sensors, gas sensors, humidity sensors, and load cells to measure the weight of waste are used.
- ii.) **Microcontrollers:** Arduino Microcontroller is used to interface with sensors, collect data, and control actuators.
- iii.) **Actuators:** To implement dynamic parameter adjustments, actuators such as valves, heaters, and fans are used to control variables like temperature and gas flow.
- iv.) **Computer or Server:** A Computer or Server is used to act as the central processing unit for data collection, analysis, and control. This could be a PC, a cloud-based server, or a dedicated microcontroller depending on the complexity of the system.
- v.) **Electronic Components:** Resistors, transistors, capacitors, and other electronic components are used for circuit design and sensor interfacing

3.2.2 SOFTWARE REQUIREMENTS

- i.) **Programming Environment:** Software development tools for programming the microcontrollers. For Arduino, the Arduino IDE is commonly used.
- ii.) **IoT Communication Protocols:** Software for handling communication between sensors, microcontrollers, and the central processing unit, using IoT communication protocols like MQTT or HTTP is used.
- iii.) **Data Analysis Software:** Tools for data analysis and machine learning are used, such as Python with libraries like NumPy, Pandas, Scikit-learn, and TensorFlow.
- iv.) **Database Management:** Software for storing and managing the data collected, such as MySQL, PostgreSQL, or NoSQL databases like MongoDB.
- v.) **Machine Learning Frameworks:** For implementing machine learning algorithms, software frameworks such as TensorFlow, PyTorch, or scikit-learn are used.
- vi.) **Document Preparation:** Software for preparing the research paper, such as LaTeX, Microsoft Word, or Google Docs is used.
- vii.) **Visualization Tools:** Software for creating graphs, charts, and visual representations of your data, such as Matplotlib or Tableau is used.

CHAPTER 4

DESIGN DESCRIPTION OF PROPOSED PROJECT

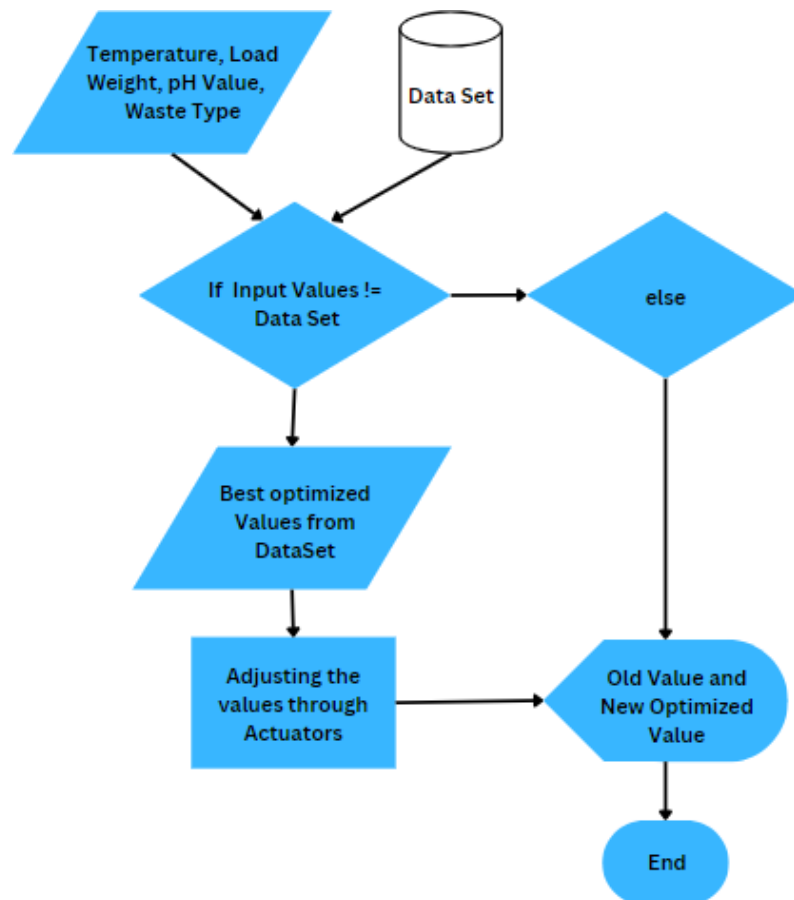
4.1 PROPOSED METHODOLOGY

Although the production of biogas from organic waste is a promising renewable energy option, efficiency issues including sluggish gas generation and unfavorable process conditions limit its potential. The potential of the Internet of Things (IoT) and biogas production systems must be combined in an innovative way to increase gas yield and streamline waste-to-energy conversion.

The development and deployment of an IoT-enabled system that optimizes biogas production by dynamically altering key operational factors is covered within the project's scope. The main goal is to employ real-time data gathering, analysis, and feedback systems to promote wiser decision-making within the biogas digester.

In order to achieve Real-Time Data Collection, analysis, and prediction of collected data, dynamic parameter adjustment, and user-friendly interface to provide insight on processes, production rate, and performance, the project will integrate sensors, microcontrollers, actuators, cloud computing, data analytics, and machine learning techniques. It will also allow users to manually intervene and adjust parameters.

4.1.1 Ideation Map/System Architecture



I. Working Flow of the System.

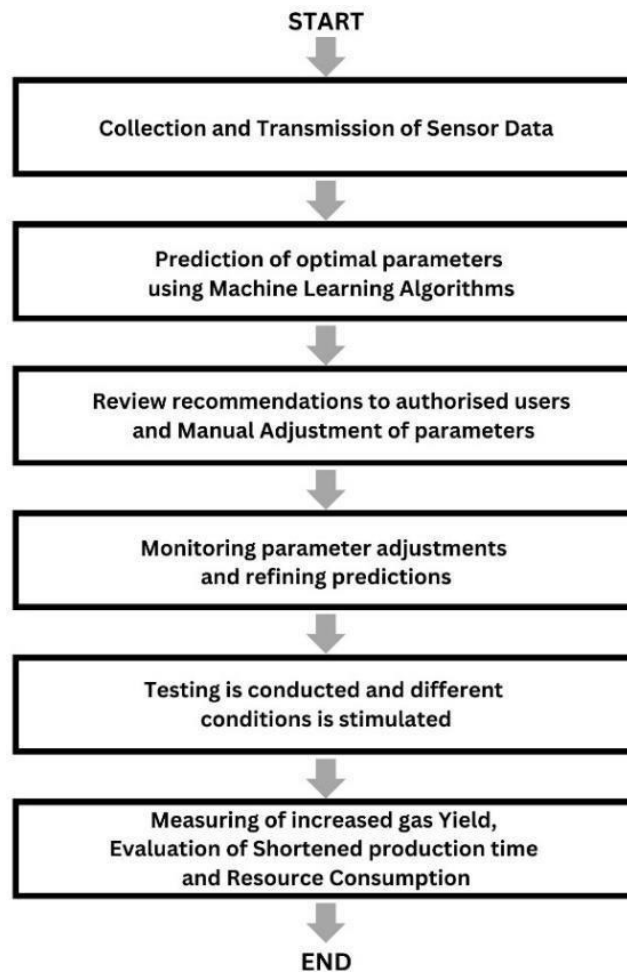
An extensive network of sensors is strategically positioned throughout the biogas production system as the project's foundation. These sensors continuously track vital indicators that are necessary for the production of biogas. Temperature, pH levels, gas composition, humidity, and other factors are among the parameters. The production environment is thoroughly understood thanks to the regular data collection. Using fundamental IoT networking techniques, the captured data is smoothly sent to a central computer. The center of the data processing is this computer. The incoming data is methodically organized and securely stored in a data repository once it reaches the central computer. This repository provides historical and real-time datasets and acts as a database center for data management.

4.1.2 Various Stages

The various stages that are implemented step by step in the system for Enhancing the Gas Yield are as mentioned below:

- i.) **Sensor Deployment:** An extensive network of sensors is strategically placed throughout the biogas production system. These sensors continuously monitor critical indicators, including temperature, pH levels, gas composition, humidity, and other parameters essential for biogas production.
- ii.) **Data Collection and Transmission:** Data collected by the sensors is transmitted in real-time to a central computer. IoT networking techniques are used to ensure the smooth transfer of data to the central processing unit.
- iii.) **Data Storage and Processing:** Upon reaching the central computer, the incoming data is methodically organized and securely stored in a data repository. This repository serves as a database center for data management, providing access to both historical and real-time datasets.
- iv.) **Machine Learning Analysis:** Sophisticated machine learning algorithms are employed to continuously analyze the incoming data. These algorithms use historical datasets and present-day sensor inputs to identify patterns, correlations, and predictive insights.
- v.) **Parameter Adjustment:** The machine learning algorithms provide suggestions for optimizing biogas production. Essential parameters in the biogas production system, such as temperature, feedstock ratios, and gas recirculation rates, are manually adjusted based on these suggestions.
- vi.) **Continuous Monitoring and Adaptation:** The system maintains vigilant monitoring of parameter changes and their impact on biogas production. In the event of unfavorable changes, authorized users are notified, enabling them to take manual control to mitigate potential risks.
- vii.) **Optimization and Efficiency:** The ultimate goal of this workflow is to produce biogas quickly and efficiently. The system achieves this by conducting ongoing data analysis, making in-the-moment parameter modifications, and adapting to changing industrial conditions.

viii.) **Smart, Self-Improving System:** The system is designed to continuously improve and adapt, resulting in a smart, self-improving biogas production method. This method maximizes biogas output while reducing resource consumption and operational costs.

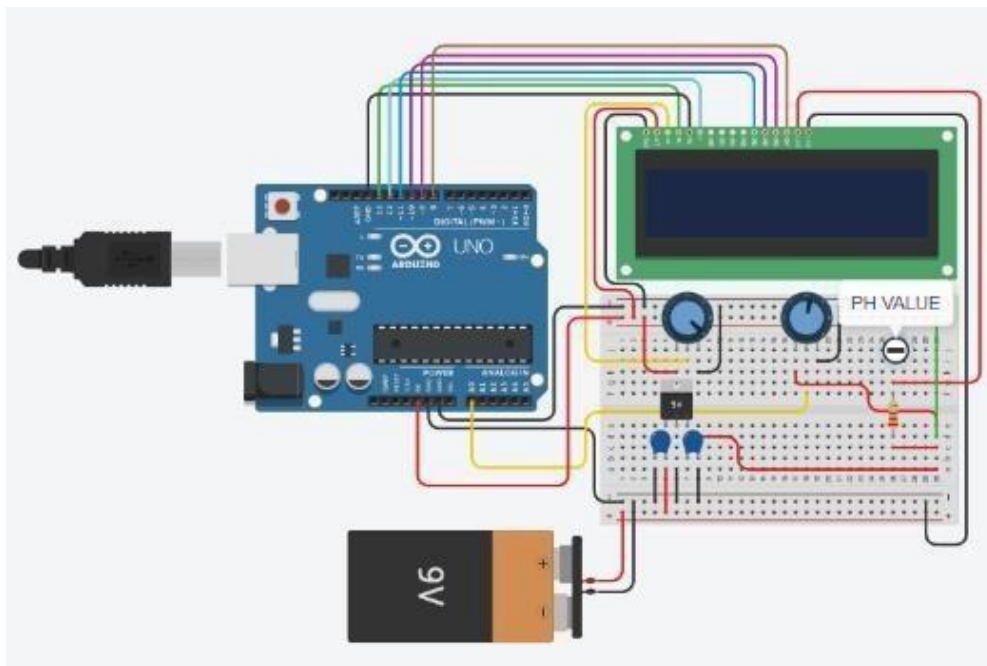


II. Systematic approach of the Optimization.

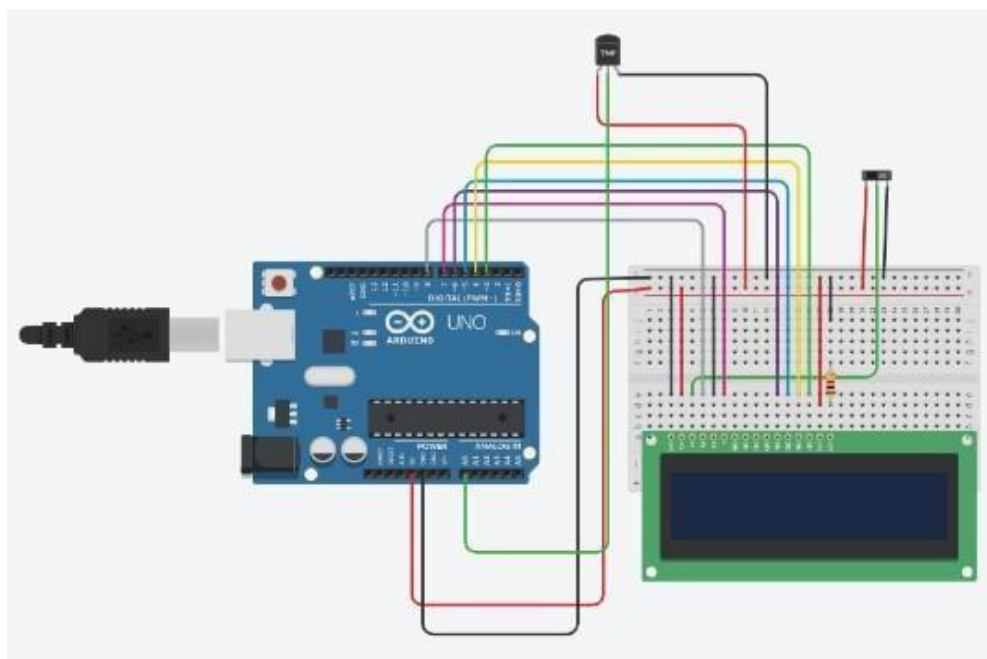
4.1.3 Internal or Component Design Structure.

Device Design.

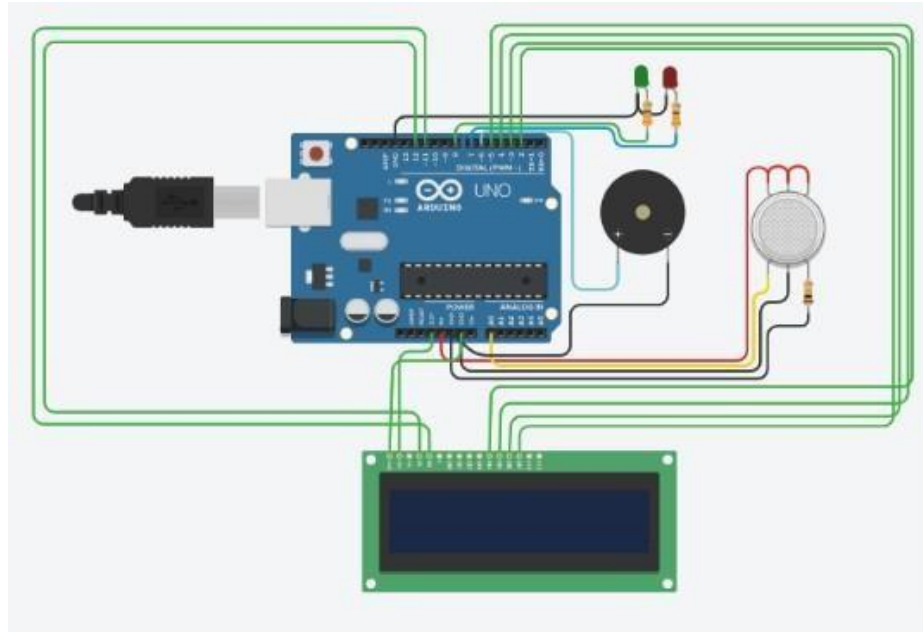
The device's design incorporates a number of circuits that were created independently and then merged to create a single working environment. The pH, temperature, and gas in the biogas tank are measured by these separate circuits.



III. Circuit for measuring pH value.



IV. Circuit for measuring Temperature.



V. Circuit for measuring Gas Type.

The Arduino Uno R3 Microcontroller, Power Source, Temperature Sensor, pH Sensor, Gas Sensor, Resistors, IC, Speaker, etc. are some of the electronic components used in the circuit.

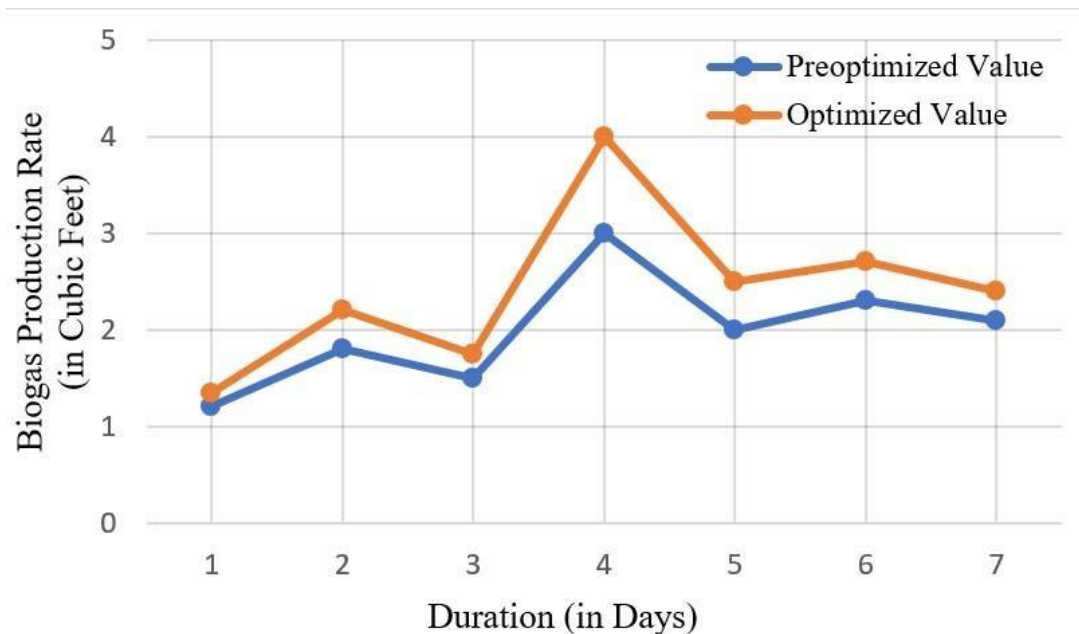
4.1.4 working principles

The working principles of this project involve the seamless integration of IoT technology, real-time data monitoring, machine learning, and dynamic parameter adjustments to optimize biogas production. Here are the key working principles:

- i.) **Continuous Data Monitoring:** Sensors strategically placed throughout the biogas production system continuously monitor critical parameters such as temperature, pH levels, gas composition, humidity, and other relevant factors.
- ii.) **Real-Time Data Transmission:** Data collected by the sensors is transmitted in real-time to a central computer using IoT networking techniques. This ensures that data is constantly flowing and up-to-date.

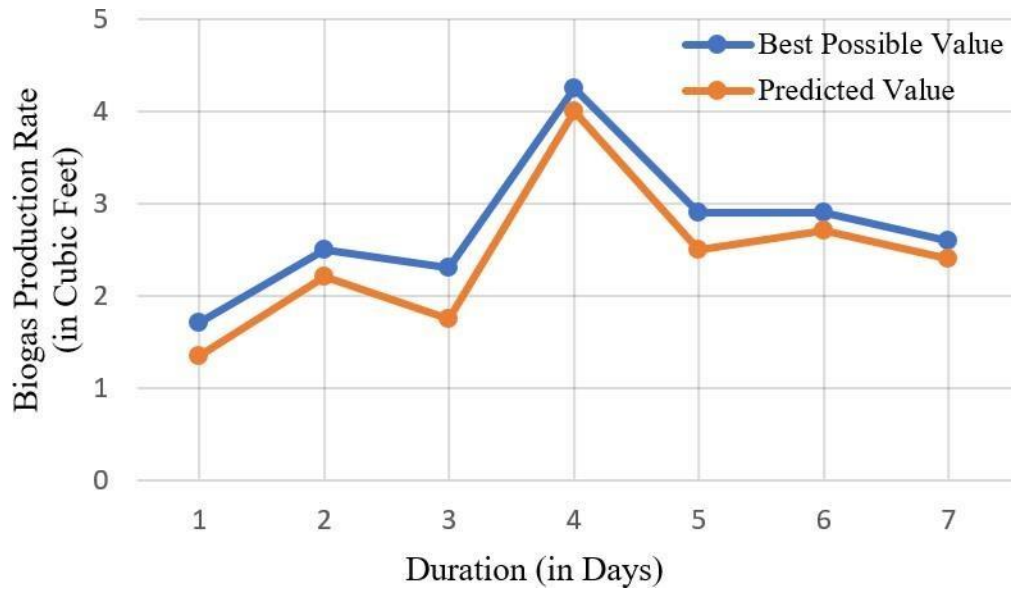
- iii.) **Data Processing and Storage:** The central computer processes and securely stores the incoming data in a data repository. This repository serves as a central hub for data management, providing access to historical and real-time datasets.
- iv.) **Machine Learning Analysis:** Sophisticated machine learning algorithms continuously analyze the data. They use historical datasets and real-time sensor inputs to identify patterns, correlations, and predictive insights.
- v.) **Parameter Adjustment Recommendations:** Based on the machine learning analysis, the system generates recommendations for optimizing the biogas production process. These recommendations are related to critical operational parameters such as temperature, feedstock ratios, and gas recirculation rates.
- vi.) **Manual Parameter Adjustments:** Authorized users manually adjust essential parameters in response to the machine learning algorithm's recommendations. This ensures that the system responds effectively to changing conditions within the industrial environment.
- vii.) **Continuous Monitoring and Adaptation:** The system maintains continuous monitoring of parameter changes and their impact on biogas production. It evaluates how these changes affect efficiency and output.
- viii.) **Notification and Risk Mitigation:** If unfavorable changes or unexpected challenges are detected, authorized users are promptly notified. Manual control can be used to mitigate potential risks to the biogas production process.
- ix.) **Optimized Biogas Production:** The ultimate goal is to produce biogas quickly and efficiently. The system achieves this by conducting ongoing data analysis, making real-time parameter adjustments, and adapting to changing industrial conditions. It aims to maximize biogas output while minimizing resource consumption and operational costs.

The working of the Model was tested and the production values are recorded and represented in the below graphs.



VI. Graph representing Preoptimized Value and Optimized Value.

Here, two Biogas Digestor were used at the same time for a period of over 7 days. These digestors were loaded with the same amount of compostable wastes of the same quantity. Here the orange line shows the enhanced production of Biogas as compared to regular biogas that were produced in another digester represented in Blue line.



VII. Graph representing Best Possible Value and Predicted Value.

The production of the Biogas has been improved by adjusting the values of pH and temperature. The values for adjusting these parameters were predicted by effectively comparing the biogas environment to the best environment as recorded in the used dataset in which the biogas were produced in the early days by regular methods.

The biogas that should have been obtained by the estimation is represented in the Blue line and the actual Biogas value that has been predicted and tweaked (adjusting the parameters dynamically) by the used Machine Learning Algorithm is shown in the Orange line. The accuracy of this production is 87.51 %

4.2 FEATURES

The project described in the provided text offers several advantages, including:

- i.) **Improved Biogas Production Efficiency:** The integration of IoT technology, real-time data monitoring, and machine learning allows for continuous optimization of biogas production. This leads to increased efficiency and higher biogas yields.

- ii.) **Resource Conservation:** By optimizing the biogas production process, the project reduces resource consumption. This includes optimizing factors such as temperature, feedstock ratios, and gas recirculation rates to minimize waste.
- iii.) **Environmental Sustainability:** The project contributes to environmental sustainability by promoting the use of organic waste for renewable energy generation. Biogas is a clean and eco-friendly energy source that reduces greenhouse gas emissions.
- iv.) **Reduced Operational Costs:** Efficiency improvements lead to reduced operational costs in biogas production. This can make biogas a more economically viable energy source.
- v.) **Real-Time Monitoring and Control:** The project provides real-time monitoring of critical parameters, allowing for quick responses to any deviations or issues in the production process. This ensures consistent and reliable biogas generation.
- vi.) **Adaptive Optimization:** The system adapts to changing conditions within the biogas production environment, ensuring that the production process remains efficient and effective over time.
- vii.) **User-Friendly Interface:** The user-friendly interface offers insights into the biogas production process, making it easier for operators to make informed decisions and adjustments.
- viii.) **Notification System:** The notification system alerts authorized users to any unfavorable changes or challenges, enabling timely manual interventions to mitigate risks.
- ix.) **Promotion of Clean Energy:** By improving biogas production, the project contributes to the generation of clean and renewable energy, reducing reliance on fossil fuels.

- x.) **Waste Management:** In addition to energy production, the project addresses waste management by utilizing organic waste for biogas generation, promoting efficient and eco-friendly waste disposal.
- xi.) **Scalability:** The project's technology and methodology can be scaled up for larger biogas production systems, making it applicable to a wide range of industrial settings.
- xii.) **Data-Driven Decision-Making:** The use of data analytics and machine learning ensures that decisions related to parameter adjustments are based on data-driven insights, enhancing the precision of the optimization process.

4.2.1 Novelty of the proposal

This project pioneers a transformative approach to biogas production through the integration of cutting-edge Internet of Things (IoT) technology, enabling real-time data collection of crucial parameters such as temperature, pH levels, gas composition, and humidity. Unlike traditional methods, it continuously gathers data, harnessing sophisticated machine learning algorithms to provide dynamic insights. This innovative system facilitates the optimization of key operational parameters, including temperature, feedstock ratios, and gas recirculation rates, based on real-time machine learning recommendations. A user-friendly interface empowers authorized users to make informed decisions, while a notification system ensures prompt responses to unfavorable changes in the production process. Ultimately, this smart, self-improving biogas production method aims to maximize output, minimize resource consumption, and reduce operational costs, revolutionizing the efficiency and sustainability of biogas production.

CHAPTER 5

CONCLUSION

This study represents a significant advance in the production of sustainable biogas. It has revealed a possible transformation in the efficiency of biogas generation through the seamless integration of IoT technology, machine learning, and dynamic control systems. This accomplishment supports the larger goal of promoting clean energy and environmental responsibility while also addressing the current production constraints.

This initiative serves as a light of the revolutionary impact technology may have on renewable energy and waste management methods as we travel towards a future distinguished by sustainability and ecological consciousness.

REFERENCES

- [1] B Deepanraj, V Sivasubramanian, S Jayaraj, "Biogas Generation through Anaerobic Digestion Process-An Overview", Research Journal of Chemistry and Environment, vol 18(25), 2014, pp. 80-93.
- [2] AKP Meyer, EA Ehimen, JB Holm-Nielsen, "Future European biogas: Animal manure, straw, and grass potentials for a sustainable European biogas production", Biomass and Bioenergy, vol. 111, 2018, pp. 154-164.
- [3] W. A. Ahmed, M. Aggour and F. Bennani, "Smart System for biodigester monitoring." in 3rd International Renewable and Sustainable Energy Conference (IRSEC), 2015.
- [4] S Yang, Y Liu, N Wu, Y Zhang, S Svoronos, "Low-cost, Arduino- based, portable device for measurement of methane composition in biogas", Renewable Energi, vol. 138, 2019, pp. 224-229.
- [5] F. Xia, L. Yang, L. Wang and A. Vinel, "Internet of Things." International Journal of Communication System, 2012.
- [6] D. J. Batstone, J. Keller and L. L. Blackall. "The influence of substrate kinetics on the microbial community structure in granular anaerobic biomass". Water Research, 2004.
- [7] Spiess, H., & Lay, J. "Biogas Production: Microbiology and Technology". Springer, 2015.
- [8] Boldrin, A., et al. "Review of Life Cycle Assessment for Biogas Production in Europe". Bioresource Technology, vol 102, 2011, pp. 403 – 412.
- [9] Raposo, F., et al. "Anaerobic Digestion of Organic Solid Wastes. An Overview of Research Achievements and Perspectives". Bioresource Technology, 2000.
- [10] Fdz-Polanco, M., et al. "Mesophilic Anaerobic Digestion of Sewage Sludge". Water Research, vol 33, 2016, pp. 1805 – 1813.
- [11] Ariunbaatar, J., et al. "Anaerobic Treatment of Municipal Solid Waste and Agroindustrial Residues: Influence of Mixing and Solid Concentration". Environmental Technology, 2012.
- [12] Yadvika, Santosh, Sreekrishnan, T. R., et al. "Review on Substrates and Inocula Used in Anaerobic Digestion and Co-digestion Processes". Environmental Technology, vol 30, 2009, pp.1027 – 1041.