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Automated Process Control System for Biogas Plant Optimization

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Abstract: This focuses on monitoring and controlling the formation of gas in a biogas system using Internet of Things (IoT) technology. The core objective is to track gas production levels and update the system's webpage in real time. To achieve this, a solenoid valve is integrated into the system for automatic control. The solenoid valve regulates the flow of the gas based on the data received from sensors monitoring the gas levels, ensuring efficient gas production and preventing over-accumulation. The real-time updates, displayed on a dedicated IoT webpage, allow users to remotely monitor and manage the biogas system, providing insights into its performance and facilitating immediate corrective actions when necessary. This system aims to optimize biogas production, enhance safety, and offer a user-friendly approach for monitoring biogas systems remotely
Keywords: IOT, real time monitoring, remotely

I. INTRODUCTION

A. Why This System?

Biogas plants play a significant role in renewable production of energy by converting organic waste materials into biogas. However, achieving the most optimal output in efficiency for biogas plants requires critical control and monitoring of numerous parameters involved.

An Automated Process Control System or APCS for optimizing biogas plants utilizes state-of-the-art technologies that include real-time monitoring, automation, and predictive analytics for improving the overall efficiency and reliability of biogas production. The APCS continuously measures and analyses critical parameters such as biogas composition, temperature, pH, and substrate concentration, ensuring that the anaerobic digestion process runs under optimal conditions. This will maximize biogas yield, minimize energy consumption, and lower operational costs. Real-time monitoring and control systems are vital for biogas plants to achieve maximum efficiency, improve safety, and minimize downtime. Traditional manual monitoring methods can be labor-intensive, time-consuming, and prone to human errors. On the other hand, real-time monitoring using AI-driven solutions enables continuous data collection, analysis, and control, leading to proactive decision-making and optimized plant performance. An APCS can be deployed to improve efficiency, stability, and productivity of biogas plants by facing these challenges. Advanced sensors along with real-time data acquisition through intelligent control algorithms ensure optimal conditions for the processes while minimizing

B. Objectives

Anaerobic digestion, the biological mechanism responsible for biogas generation, is a sensitive process to several factors such as temperature, pH, substrate properties, and microbial activity. Combining sensors, actuators, and sophisticated control algorithms, the system makes automated adjustments to achieve optimum digester conditions. Automation results in higher process stability, higher biogas production, lower operation costs, and optimized overall plant performance. With sensors, actuators, and sophisticated control algorithms, the system makes automatic adjustment to ensure optimal digester conditions. This automation results in enhanced process stability, higher biogas yield, lower operation costs, and better overall plant performance.

II. LITRETURE SURVEY

1) "An Overview of Process Monitoring for Anaerobic Digestion" by Ianny A. Cruz et al., published in Biosystems Engineering in July 2021, provides a comprehensive review of contemporary techniques for real-time monitoring of anaerobic digestion (AD) processes. AD is a traditional method for managing various organic waste sources while simultaneously generating renewable energy in the form of biomethane. The process relies on specific microbial communities and is susceptible to disturbances that can affect biogas production and methane yield. The authors emphasize the importance of selecting appropriate early-warning indicators and monitoring biosystems to obtain accurate information about the bioprocess.

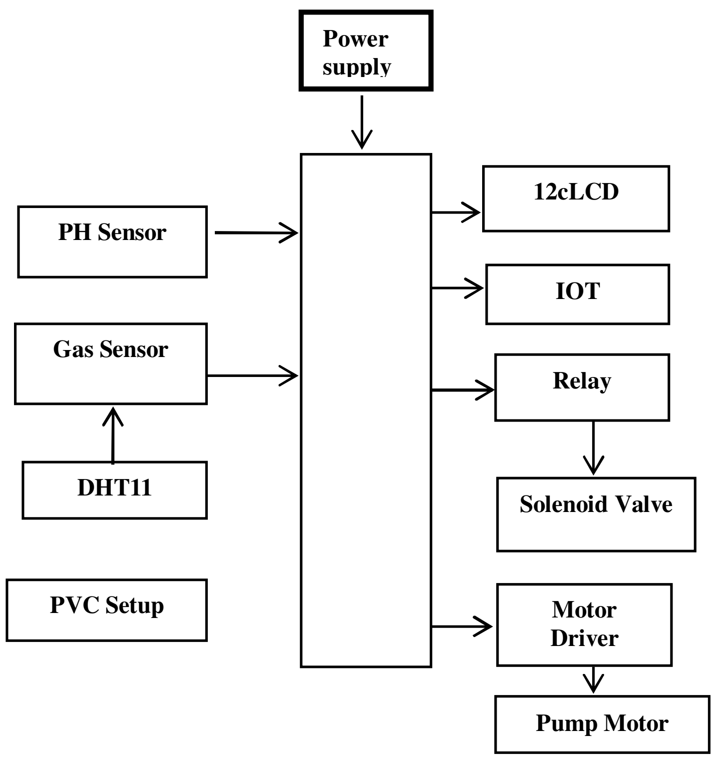
They also discuss the necessity of choosing suitable early-warning indicators and proper monitoring biosystems to achieve accurate information on the bioprocess. However, the implementation of online monitoring techniques has been limited due to their high cost, which restricts their industrial application. The paper concludes by highlighting the need for further studies to make real-time monitoring of AD more technically and economically sustainable.

2) *"Technical Challenges and Optimization of Biogas Plants"* by Z.U.R. Afridi et al., published in *Chembion Reviews* (2020), takes a close look at the struggles biogas plants face, especially in Pakistan. Even though the country has a strong agricultural sector and many biogas plants have been set up, most of them don't run as efficiently as they should. Issues like gas leaks, poor waste removal, scum buildup, and rusting of metal parts often cause problems. On top of that, many operators don't have the proper training, and skilled technicians are hard to find, making maintenance a major challenge. The authors suggest practical solutions, including better plant design with durable materials, proper training programs for operators, and stronger organizational support to keep things running smoothly. They emphasize that fixing these issues is key to making biogas a more reliable and sustainable energy source, not just in Pakistan but in other developing countries facing similar challenges.
3) *"Biogas Production and Process Control Improvements"* explores ways to enhance both the quantity and quality of biogas produced through anaerobic digestion. It focuses on key factors like optimizing operating conditions, improving monitoring and control systems, and using pretreatment methods to make organic waste more digestible. The study highlights the importance of maintaining stable conditions inside the digester—such as keeping the right temperature, pH levels, and organic loading rates—to ensure efficient microbial activity and consistent biogas production. It also emphasizes how advanced process control strategies can help detect and fix issues early, making biogas plants more reliable and efficient overall.
4) "IoT-Based Monitoring of Community Biogas Plant for Smart City Application" explores how IoT technology can improve the way biogas plants are monitored and managed in real time. Traditional biogas systems often struggle with stability and efficiency, which can impact overall production. To address this, the study introduces a smart monitoring system that uses sensors and a microcontroller (ESP8266) to track key factors like temperature, humidity, and gas flow. Since anaerobic digestion is highly sensitive to environmental changes, keeping a close watch on these parameters is crucial for ensuring stable and efficient biogas production.
5) *"Development of IoT-Based Monitoring of Biogas Plant"* explores how IoT technology can make biogas plant management more efficient and hassle-free. Traditional methods require constant manual monitoring, which can be time-consuming and impractical for large-scale operations. To solve this, the study introduces an automated system that uses sensors connected to a NodeMCU (ESP8266) microcontroller to track key factors like temperature, humidity, and pressure in real time. The collected data is then sent to a cloud-based platform, such as Thing Speak or a self-hosted Raspberry Pi server, allowing operators to monitor and control the plant remotely. By maintaining ideal conditions for anaerobic digestion, the system helps boost biogas production while cutting down on maintenance efforts. Secure data transmission is ensured through the MQTT protocol, and an alert system notifies users of any irregularities, improving safety and reliability. The research highlights how integrating IoT can make biogas plants more efficient, reduce operational costs, and enable real-time supervision of multiple facilities. Ultimately, the study concludes that IoT-powered solutions can enhance biogas production, improve process stability, and strengthen data security, with future improvements including advanced sensors to analyse gas composition more precisely.
6) **"***Making Biogas SMART Using Internet of Things (IoT)"* This research explores how IoT technology can make biogas plants more efficient and easier to manage. By using IoT-based monitoring systems, data collection and analysis become automated, helping to optimize biogas production. The study highlights how IoT can modernize traditional biogas systems, turning them into smart operations that improve sustainability and overall efficiency.
7) " IoT-Based Smart Solution for Biogas Plant Operation" This study explores how IoT technology can improve biogas production by making smarter decisions about feedstock selection and process control. By collecting and analysing real-time data, operators can determine the best type and amount of feedstock, leading to more efficient gas production and better resource management. Monitoring factors like moisture levels, feedstock quality, and chemical composition helps fine-tune the process, ensuring higher biogas yields and more stable operations driven by data-based insights.
8) "Monitoring of Biodigesters Through a Computerized System Integrated to IoT Platform" This study focuses on developing a real-time monitoring system for biodigesters using IoT technology to improve waste management and biogas production. By integrating electronic sensor modules into four prototype batch digesters, the system collects and transmits key data on methane (CH_4), carbon dioxide (CO_2), hydrogen sulphide (H_2S), temperature, humidity, and pressure. Built on low-cost microcontrollers and Industry 4.0 concepts, this system enhances the understanding of anaerobic digestion, optimizing biogas production and improving the efficiency of biomass and filtration processes.

The research highlights the importance of real-time monitoring in making biogas systems more effective and sustainable.

9) "Development of Data Acquisition Biogas Monitoring System Based on IoT" This study introduces an IoT-based monitoring system to improve biogas production by ensuring better control over key factors affecting the process. Traditional biogas plants often struggle with issues like improper organic material levels and temperature fluctuations, which can slow down or even halt anaerobic digestion. To tackle this, the researchers developed a system that uses sensors to track air temperature, humidity, organic material temperature, and biogas pressure. The data is processed using an Arduino and a Wemos D1 Mini module, then sent to the IoT platform Cayenne for real-time monitoring. The results show that temperature and pressure vary throughout the day, directly impacting biogas output. By offering accurate, real-time insights, this system helps optimize biogas production, making it more stable and efficient.
10) "Design and Implementation of IoT-Enabled Device for Real-Time Monitoring of Greenhouse Gas Emissions, and Pressure in Anaerobic Reactors" This paper presents a lightweight, sensitive, and low-cost monitoring device designed for real-time measurement of greenhouse gas emissions from livestock waste in anaerobic reactors. The device employs IoT technology to monitor gases such as methane and carbon dioxide, offering precise measurements even at low production levels. Its low power consumption and ease of deployment make it suitable for rural and farm environments. The study highlights the device's potential in assisting strategies aimed at reducing methane and carbon dioxide emissions under various on-farm environmental conditions, contributing to global greenhouse gas emission reduction goals.

III. METHODOLOGY



A. *System Architecture*

This system as a smart assistant managing an anaerobic digester, working around the clock to turn waste into energy. The power supply keeps everything running, while sensors—like the pH sensor, gas sensor, and DHT11—act as its senses, constantly checking acidity, gas levels, temperature, and humidity. At the core, a controller acts like the brain, making decisions based on what the sensors detect. If conditions need adjusting, it signals the feed stock system to add more organic material or the solenoid valve to control fluid flow. The anaerobic digester is where the magic happens, breaking down waste into gas. Meanwhile, the relay helps switch devices on and off, the motor driver keeps the pump motor moving, and the PVC setup provides the necessary infrastructure. Altogether, this system works seamlessly to ensure a smooth, efficient digestion process, turning waste into valuable energy with minimal human intervention.

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B. Hardware

1) Temperature Sensor

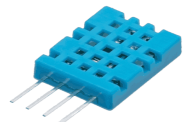

Fig 3.1 Temperature Sensor

The DHT11 is a basic, low-cost digital temperature and humidity sensor. DHT11 is a single wire digital humidity and temperature sensor, which provides humidity and temperature values serially with one-wire protocol. DHT11 sensor provides relative humidity value in percentage (20 to 90% RH) and temperature values in degree Celsius (0 to 50 °C).

2) PH Sensor

Fig 3.2 PH sensor

The pH of a solution indicates how acidic or basic (alkaline) it is. The pH term translates the values of the hydrogen ion concentration - which ordinarily ranges between about 1 and 10 x -14 gram-equivalents per litre - into numbers between 0 and 14. A pH measurement loop is made up of three components, the pH sensor, which includes a measuring electrode, a reference electrode, and a temperature sensor; a preamplifier; and an analyser or transmitter. A pH measurement loop is essentially a battery where the positive terminal is the measuring electrode and the negative terminal is the reference electrode.

3) Gas Sensor

Fig 3.3 Gas sensor

The gas diffuses into the sensor, through the back of the porous membrane to the working electrode where it is oxidized or reduced. This electrochemical reaction results in an electric current that passes through the external circuit. In addition to measuring, amplifying and performing other signal processing functions, the external circuit maintains the voltage across the sensor between the working and counter electrodes for a two electrode sensor or between the working and reference electrodes for a three electrode cell. At the counter electrode an equal and opposite reaction occurs, such that if the working electrode is an oxidation, then the counter electrode is a reduction .

4) Arduino

Fig 3.4 Arduino Board

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Arduino Uno is a microcontroller board based on the ATmega328P (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. You can tinker with your UNO without worrying too much about doing something wrong, worst-case scenario you can replace the chip for a few dollars and start over again.

TECHNICAL SPECIFICATIONS:

Table 3.1 Technical specification of Arduino board

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by boot loader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
LED_BUILTIN	13
Length	68.6 mm
Width	53.4 mm
Weight	25 g

5) Cloud Platfarm (Adafruit)

Adafruit IO is a cloud service that allows IoT devices to send and receive data in real time. We can use the Adafruit IO Dashboard on a web browser or integrate it with mobile apps (like MQTT apps) to view sensor data, control devices, and automate tasks. Logging temperature, humidity, GPS tracking, controlling smart devices, etc.

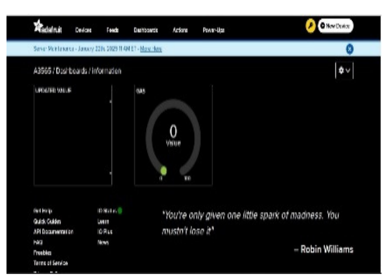

Fig 3.5 Adafruit io

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6) Relay

A relay is like a smart switch that helps control electrical circuits. It works by using a small amount of power to turn a bigger circuit on or off. Think of it as a remote control for electricity—it lets a low-power signal control something much stronger. Relays are used in all kinds of systems, from home automation to industrial machines and even cars. Inside, they use an electromagnet to open or close connections, kind of like flipping a switch without needing a person to do it. They play a key role in keeping electrical systems safe and efficient.

Fig 3.6 Relay

7) Solenoid valve

A solenoid valve is a device that helps control the flow of liquids or gases using electricity. Inside, it has a small coil of wire called a solenoid, which creates a magnetic field when powered. This magnetic force moves a tiny plunger, either opening or closing the valve to let fluid pass or stop it. Essentially, it acts like a switch for liquids or gases, making it useful in everything from home appliances to industrial machines.

Fig 3.7 solenoid valve

8) Cover node MCU

The NodeMCU is a handy little development board that makes it easy to build smart devices and automation projects. It's powered by the ESP8266 or ESP32 Wi-Fi module, so it can connect to the internet effortlessly. With built-in Wi-Fi, multiple GPIO pins for hooking up sensors, and support for Lua and the Arduino IDE, it's great for both beginners and experienced makers. To keep it safe from dust, accidental spills, or short circuits, you can use a protective cover or enclosure—often made from plastic, acrylic, or even a custom 3D-printed case.

Fig 3.8 cover node MCU

9) Drive

Drive components are the heart of any system that needs to transfer power and motion. Whether in a car, a machine, or even a computer, these parts work together to make things run smoothly. In a car, for example, gears, belts, and shafts help turn engine power into movement, getting you from one place to another. In electronics, motors and controllers regulate speed and energy, making sure devices function properly.

Fig 3.9 Drive

10) ESP-8266

The ESP8266 is a tiny, affordable chip that lets your devices connect to Wi-Fi, making it super popular for DIY electronics and smart home projects. Think of it as a mini brain that can talk to the internet — it can send and receive data, control sensors, and even be programmed like a small computer using tools like the Arduino IDE.

Fig 3.10 ESP 8266

IV. RESULT AND DISCUSSION

A. Sensor Data Visualization

The proposed system integrates IoT technology with sensors such as gas, pH, and temperature/humidity sensors to provide real-time monitoring of biogas production. Data from these sensors is sent to a web page via an ESP8266 module, enabling remote access to the system. Users can monitor key parameters like gas concentration and environmental conditions from anywhere, allowing for timely interventions and better management of the biogas production process.

B. Data Analysis

1) Real Time Monitoring

The IoT-based system allows for real-time remote monitoring of biogas plants. By using IoT technology, operators can access sensor data (such as gas levels, temperature, humidity, and pH levels) through a web interface or mobile application. This enables plant managers to monitor the status of gas production, detect anomalies, and take corrective actions remotely, reducing the need for physical presence and enhancing the operational efficiency of biogas plants.

2) Data Collection

The IoT-based system allows for real-time remote monitoring of biogas plants. By using IoT technology, operators can access sensor data (such as gas levels, temperature, humidity, and pH levels) through a web interface or mobile application. This enables plant managers to monitor the status of gas production, detect anomalies, and take corrective actions remotely, reducing the need for physical presence and enhancing the operational efficiency of biogas plants.
Collecting data through the Adafruit IO website is a straightforward way to monitor sensor information using a cloud-connected device like the ESP8266. After creating an account on io.adafruit.com, you set up a feed to store data such as temperature or humidity, and optionally create a dashboard to visualize it in real-time with widgets like charts and gauges. By programming your device with the Adafruit IO library (for Arduino or Python), and configuring your Wi-Fi credentials along with your Adafruit IO username and AIO key, the device can read sensor values and send them to the corresponding feed at regular intervals. Once connected, you can view, analyze, and track the data remotely through the Adafruit IO dashboard, making it a user-friendly and efficient way to manage IoT projects.

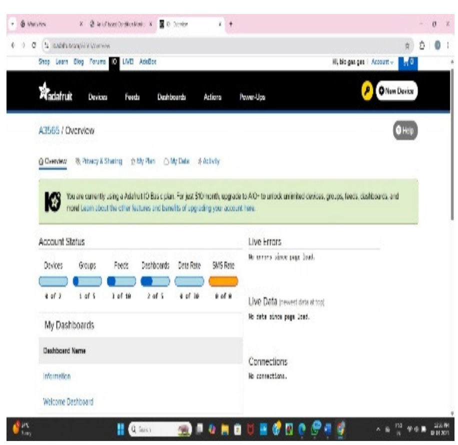

Fig 4.1 Dash Board of Website

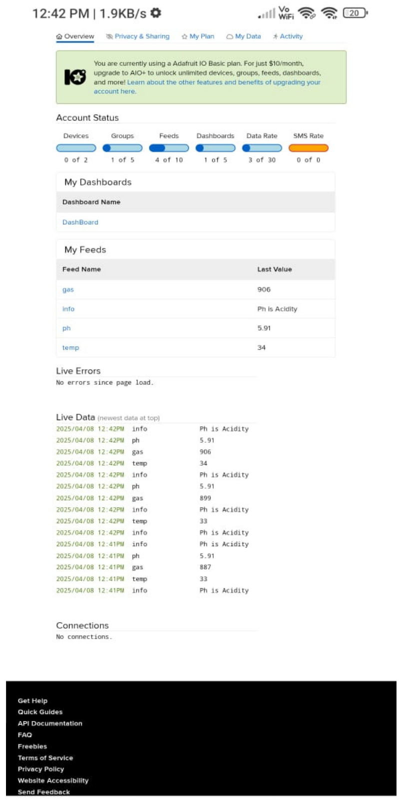

Fig 4.2 Real Time Data Collected by Minutes

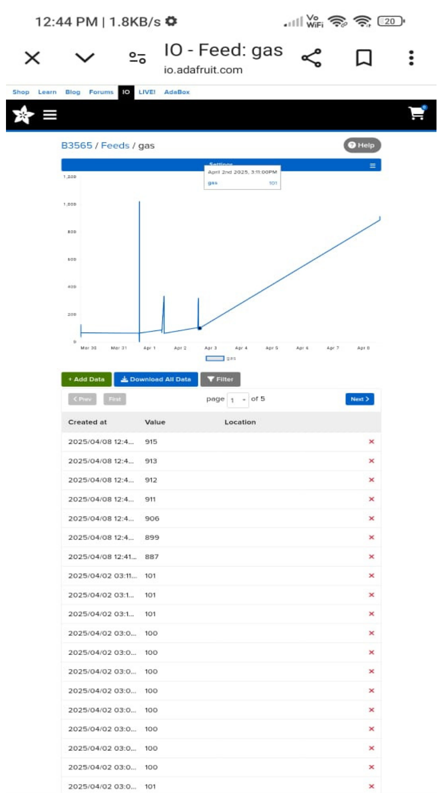

Fig 4.3 Feed Rate in graphical Rep

Fig 4.4 Dash Board For Parameters

The results you see on an Adafruit IO dashboard are the real-time visual updates of the data your connected device is sending—like temperature, gas flow rate, or pH levels. As your sensors collect information and send it to Adafruit IO, the dashboard brings that data to life using simple, interactive widgets like charts, gauges, and text blocks. These visuals make it easy to quickly check live readings, spot patterns or changes over time, and understand how your project is performing at a glance. Instead of digging through raw numbers, you get a clear, easy-to-read interface that helps you stay on top of everything your system is tracking.

V. CONCLUSION

In conclusion, the IoT-based biogas monitoring and control system offers a transformative approach to managing biogas production, enhancing efficiency, safety, and sustainability. By integrating real-time data monitoring, automatic gas flow regulation, and remote accessibility, the system provides a user-friendly and efficient way to optimize biogas production. The seamless interaction between sensors, control mechanisms, and IoT connectivity ensures that the biogas system operates under optimal conditions, preventing safety risks and maximizing gas output. This system represents a significant step toward improving the operational performance of biogas plants, fostering the use of renewable energy, and contributing to environmental sustainability. As the system continues to evolve, future enhancements can further refine its capabilities, making it an even more valuable tool for sustainable energy generation and management. Ultimately, the IoT-based biogas monitoring and control system serves as an effective solution for enhancing biogas production, supporting the growth of renewable energy systems, and promoting a cleaner, greener future.

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