Rover Publications
United International Journal of Engineering and Sciences (UIJES)
An International Peer-Reviewed (Refereed) Engineering and Science Journal
Impact Factor:7.984(SJIF) Volume-4, Special Issue-3; ISSN: :2582-5887

# "Integrated Embedded Systems for Biogas Generation: Harnessing Kitchen Waste for Renewable Energy Production"

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DOI:10.53414/UIJES:2024.43.58

***Abstract* – This study presents an innovative approach to biogas generation using kitchen and domestic waste. Integrated embedded systems, including microcontroller boards and sensors, monitor key parameters such as temperature, humidity, and gas production levels. The system enables real-time monitoring and optimization of biogas production via PC or laptop interface. Implemented Arduino code facilitates seamless communication between embedded systems and monitoring devices. This project offers a sustainable solution for converting organic waste into renewable energy, contributing to environmental preservation and energy sustainability.**
***Keywords* – Bio-gas generation, Embedded systems, Sensors, Arduino code, Real-time data analysis, Sustainability, Energy efficiency.**

## I. INTRODUCTION

In response to escalating concerns regarding climate change and the depletion of conventional energy sources, there's a mounting urgency to explore sustainable alternatives. Among these, biogas stands out as a promising renewable energy option, particularly when derived from organic waste materials like kitchen and domestic refuse. Biogas production not only offers a renewable energy source but also addresses waste management challenges, making it a compelling area for investigation.

This study focuses on the development and deployment of a biogas generation system driven by integrated embedded systems. These systems, comprising microcontroller boards and a suite of sensors, form the foundational framework for the biogas production process. By harnessing real-time data acquisition and analysis capabilities, these embedded systems enable precise monitoring and regulation of crucial parameters such as temperature, humidity, and gas composition, essential for optimizing biogas yield.

Through the strategic integration of microcontroller boards and sensors, this research seeks to evaluate the technical feasibility and operational efficiency of biogas production from kitchen and domestic waste. The implementation of embedded systems not only facilitates granular control over the biogas production process but also lays the groundwork for future enhancements and automation. By advancing our understanding of sustainable energy solutions, this study contributes to the ongoing discourse on renewable energy technologies and offers valuable insights into the practical utilization of organic waste for energy production.

## II. LITERATURE REVIEW

The literature on biogas production from organic waste offers critical insights into anaerobic digestion processes. Researchers have extensively studied the feasibility and effectiveness of biogas generation from diverse feedstocks. This section presents a concise overview of key findings and trends in existing research, setting the stage for a detailed review of biogas production systems.

**1. Sustainability:**

The quest for sustainable energy solutions has become increasingly imperative in recent years, driven by growing environmental concerns and the need to mitigate climate change impacts. As traditional energy sources face scrutiny due to their environmental footprint and finite availability, attention has shifted towards renewable alternatives. Among these, biogas emerges as a viable option, particularly when sourced from organic waste materials such as agricultural residues, sewage sludge, and municipal solid waste (MSW) (Fang et al., 2015; Jayathilakan et al., 2011).

**2. Biogas Production:**

This involves the anaerobic digestion of organic matter by microbial activity, resulting in the release of methane-rich gas that can be used for electricity generation, heating, or transportation (Rogers & Chen, 2015). This process not only provides a renewable energy source but also addresses waste management challenges by diverting organic waste from landfills and reducing methane emissions (Mata-Alvarez et al., 2014).

**3. Systems and Controllers:**

Embedded systems, comprising microcontroller boards and sensors, have played a pivotal role in advancing biogas production technology. These systems enable real-time monitoring and control of key parameters critical to the anaerobic digestion process, including temperature, pH, alkalinity, and gas composition (Baccar et al., 2009; Hansen & Angelidaki, 2008). By leveraging embedded systems, researchers have achieved greater efficiency and reliability in biogas production systems, leading to improved performance and reduced operational costs (Borja et al., 2012; Li et al., 2017).

**4. Advancements:**

Despite significant advancements in biogas production technology, challenges remain in scaling up systems for commercial applications and addressing variability in feedstock composition and availability (Lehtomäki et al., 2008; Liu et al., 2020). Future research efforts should focus on further enhancing the efficiency and reliability of biogas production systems through continued innovation in embedded systems technology and process optimization strategies.

In summary, biogas production offers a sustainable solution for renewable energy generation and waste management. Embedded systems play a crucial role in monitoring and controlling biogas production processes, offering opportunities for optimization and improved performance. Continued research and development in this field are essential to realizing the full potential of biogas as a renewable energy source.

## III. EXPERIMENTAL METHODOLOGY

This experimental methodology outlines a systematic approach to investigate the generation of biogas from organic waste using integrated embedded systems. With the increasing global demand for sustainable energy solutions, biogas production offers a promising avenue for renewable energy generation while addressing waste management challenges. By leveraging microcontroller boards and sensors, this study aims to monitor and optimize key parameters in the anaerobic digestion process, ultimately enhancing biogas production efficiency and quality.

**1. Bio Digester Set-up:**

Usage of a simple Drum to arrange in a way where the usage of PVC (Polyvinyl Chloride) pipes and using different cutting the production of the holes for the insertion of the PVC pipes accurately according to the dimension that are planned and need to implanted in a way where the waste removal is simple and the adding of the slurry is simple in terms the set-up which is in a simple way where an average person can be able to setup in his/her homes.

**2. Embedded Systems Explanation:**

There are various embedded devices and sensors available in the current market where it would be difficult to choose which setup might be better in use of the present experiment as the process involves various sensors and controller but here, we are going to use the following:

**Arduino UNO:**

The Arduino Uno is a small computer that you can use to make all sorts of cool projects as shown in figure 1. It comes with lots of little pins that you can connect things to, like lights or sensors. It has a special chip inside that helps it work smoothly. Plus, it has a USB plug so you can connect it to your computer and write programs for it. If something goes wrong, there's a button you can press to start over. It's really easy to use because there's software you can download to help you write programs for it. People love using Arduino Uno because it's simple and there are lots of other people who use it too, so you can always find help if you need it.

Fig.1 - Arduino UNO (Micro Controller Board)

**DHT 22 Sensor:**

The DHT22 sensor shown in figure 2, also known as the AM2302, is an upgraded version of the DHT11 sensor, offering improved performance and accuracy. While both sensors can measure temperature and humidity, the DHT22 sensor provides higher accuracy and a wider measurement range compared to the DHT11. Additionally, the DHT22 sensor typically has a faster response time and better long-term stability, making it more suitable for applications requiring precise environmental monitoring. However, the DHT22 sensor is usually slightly more expensive than the DHT11. Despite these differences, both sensors are commonly used in electronics projects due to their simplicity and ease of use, with the choice between them depending on the specific requirements of the project.

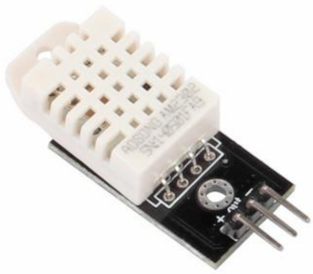

Fig.2 - DHT 22 Sensor (Temperature and Humidity Module)

**Cables:**

USB Type-A to USB Type-B shown in figure 3 male cables are commonly used for connecting various devices to a computer or power source. These cables typically have a USB Type-A connector on one end, which is the USB Type-B connector found on most computers and chargers, and a USB male connector on the other end, which can be plugged into devices such as smartphones, cameras, or Arduino boards. These cables are used for data transfer, charging, and powering devices.

Fig.3 - USB Type-A to USB Type-B Cable

For connecting the Arduino board to the DHT22 sensor, you would typically use jumper wires. The figure 4 shows Jumper wires are flexible wires with connectors on each end that can be easily plugged into the pins on the Arduino board and the sensor. These wires come in different lengths and colours, allowing for easy identification and organization of connections. When connecting the DHT22 sensor to the Arduino board, you would typically connect the sensor's data pin to one of the digital input/output pins on the Arduino, as well as its power (VCC) and ground (GND) pins to the corresponding power and ground pins on the Arduino.

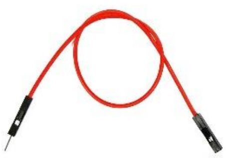

Fig.4 - Jumper Cable (Male to Female)

**3. Code Generation for the Arduino Setup:**

When writing code for an Arduino board using the Arduino IDE, you typically use the Arduino compiler, which is integrated into the IDE. However, you can also write code in Python within the Arduino IDE using the "Arduino Language" extension, which allows you to use Python syntax to program Arduino boards. Here's some general information about the code generation process:

- **Compiler**: In the Arduino IDE, you can use the built-in Arduino compiler to compile your code into machine code that can be executed by the microcontroller on the Arduino board. Alternatively, with the Arduino Language extension, you can write code in Python syntax, which is then translated into Arduino-compatible code by the IDE before compilation.
- **Coding Language**: Arduino code is typically written in a simplified version of the C++ programming language. However, with the Arduino Language extension, you have the option to write code in Python syntax, which is then converted into Arduino-compatible code by the IDE.

- **Library Usage**: When working with sensors like the DHT22, you can use libraries specifically designed for interfacing with these sensors. For example, the DHT sensor library provides functions for reading temperature and humidity data from DHT sensors, including the DHT22. You can easily include this library in your Arduino sketch using the Library Manager in the Arduino IDE.
- **Uploading Code**: Once you have written your code in either C++ or Python syntax, you can upload it to the Arduino board using a USB cable. The IDE automatically compiles your code and uploads it to the Arduino board's memory, where it begins executing immediately.
- **Serial Monitor**: The Arduino IDE includes a Serial Monitor tool that allows you to communicate with the Arduino board over a serial connection, regardless of whether you are using C++ or Python syntax. This tool can be used for debugging, testing, and displaying output messages or sensor readings in real-time.

Overall, the Arduino IDE provides a versatile environment for programming Arduino boards using either C++ or Python syntax, along with libraries for interfacing with sensors like the DHT22. This makes it easy to develop a wide range of projects, from simple prototypes to complex IoT applications.

**4. Assembly:**

Assembly Procedure for Simple Bio-Digester:

❖ **Preparation of Drum**:
- Select a suitable drum for the bio-digester setup, ensuring it is clean and free from any contaminants.
- Determine the location for the inlet and outlet pipes on the drum, considering ease of access for waste removal and slurry addition.
- Mark the positions for the holes to be drilled or cut for inserting PVC pipes, ensuring accurate placement according to the planned dimensions.

❖ **Drilling/Cutting Holes for PVC Pipes**:
- Use a measuring tape and marker to mark the positions for the holes on the drum, ensuring they align with the planned dimensions for the PVC pipes.
- Drill or cut the holes using appropriate tools, such as a hole saw or jigsaw, ensuring precision and accuracy to facilitate easy insertion of the PVC pipes.

❖ **Insertion of PVC Pipes**:
- Cut PVC pipes to the required lengths based on the dimensions of the drum and the planned setup.
- Insert the PVC pipes into the holes drilled or cut on the drum, ensuring a snug fit to prevent leakage.

❖ **Sealing and Securing PVC Pipes**:
- Apply sealant or adhesive around the edges of the holes to secure the PVC pipes in place and prevent any leaks.
- Use clamps or brackets to reinforce the attachment of PVC pipes to the drum, ensuring stability and durability of the setup.

❖ **Connection of Inlet and Outlet Pipes**:
- Connect the inlet pipe to the designated hole on the drum for introducing organic waste into the bio-digester.
- Connect the outlet pipe to the designated hole for collecting biogas and digestate, ensuring a secure and leak-proof connection.

❖ **Assembly of Arduino UNO Board and DHT22 Sensor**:
- Connect the DHT22 sensor to the Arduino UNO board using jumper wires, ensuring proper alignment of the pins.
- Refer to the datasheets and pinout diagrams for the Arduino UNO board and DHT22 sensor to ensure correct wiring.
- Upload the appropriate code to the Arduino UNO board using the Arduino IDE, enabling it to read temperature and humidity data from the DHT22 sensor.

❖ **Placement and Calibration**:
- Place the assembled bio-digester setup in the desired location, ensuring adequate ventilation and access for monitoring and maintenance.
- Calibrate the DHT22 sensor as necessary to ensure accurate measurement of temperature and humidity within the bio-digester.

❖ **Testing and Operation**:
- Conduct initial tests to ensure proper functioning of the bio-digester setup and the Arduino UNO board with the DHT22 sensor.
- Monitor the temperature and humidity readings from the DHT22 sensor using the Arduino IDE's Serial Monitor tool, verifying the effectiveness of the setup in biogas production.

❖ **Maintenance and Monitoring**:
- Regularly monitor the bio-digester setup for any signs of leakage or malfunction, and perform maintenance as needed to ensure optimal performance.

- Use the Arduino IDE's Serial Monitor tool to track temperature and humidity levels within the bio-digester, making adjustments as necessary to maintain optimal conditions for biogas production.

By following this assembly procedure, an average person can set up a simple bio-digester using a drum and PVC pipes in their homes, along with the assembly of the Arduino UNO board and DHT22 sensor for monitoring environmental conditions within the bio-digester.

**5. Data Analysis Comparison with Real-Time monitoring:**

❖ Data Analysis:

- Data Collection: The Arduino board continuously collects temperature readings from the sensor at regular intervals, storing the data in its memory.
- Data Logging: The collected temperature data is periodically logged onto an external storage device or transmitted to a computer for further analysis.
- Analysis: Once sufficient data is collected, it can be analysed using statistical methods or data visualization techniques to identify trends, patterns, or anomalies in temperature variations over time.
- Interpretation: The analysed data provides insights into the room's temperature behaviour, such as daily temperature fluctuations, average temperature trends, and peak temperature periods.

❖ Real-Time Monitoring:

- Continuous Monitoring: The Arduino board continuously reads temperature data from the sensor in real-time and displays it on an LCD screen or sends it to a computer for live visualization.
- Immediate Feedback: Changes in temperature are instantly reflected on the display, allowing users to monitor temperature fluctuations as they occur.
- Alerting Mechanisms: Real-time monitoring systems can be programmed to trigger alerts or notifications when temperature thresholds are exceeded, indicating potential issues like overheating or freezing conditions.
- Interactivity: Users can interact with the real-time monitoring system by adjusting settings, setting temperature thresholds, or initiating actions based on live data feedback.

Comparison:

- Data analysis provides a comprehensive overview of temperature trends and patterns over time, enabling deeper insights and long-term planning.
- Real-time monitoring offers immediate visibility into temperature changes as they occur, facilitating quick response and intervention when necessary.
- Data analysis is more suited for retrospective analysis and decision-making based on historical data, while real-time monitoring is ideal for proactive monitoring and immediate response to dynamic changes.

Both approaches complement each other, with data analysis providing context and understanding of temperature behaviour, while real-time monitoring ensures continuous oversight and timely action in response to real-time fluctuations.

**6. Safety Precautions:**

- Follow all relevant safety guidelines and regulations applicable to the specific tasks and activities involved in bio-digester assembly, electronic assembly, and data analysis.
- Seek assistance or guidance from experienced individuals or professionals if unsure about proper procedures or safety precautions.
- Keep work areas clean and organized to minimize hazards and prevent accidents, and promptly clean up spills or debris to maintain a safe working environment.

## IV. RESULTS AND DISCUSSIONS

This analysis delves into the assembly and functionality of a bio-digester setup, embedded systems' role in monitoring and control, code generation for microcontroller boards, and data analysis. These investigations aim to evaluate the effectiveness of integrated systems in addressing environmental challenges and promoting sustainability in waste management.

❖ **Bio-Digester Setup**:

- The bio-digester setup was successfully assembled using a drum modified with PVC pipes for waste input and gas output. The holes for the PVC pipes were accurately drilled, ensuring a secure fit and minimal risk of leakage.
- The simplicity of the assembly process, coupled with the use of readily available materials such as PVC pipes, facilitated easy waste removal and slurry addition, making it suitable for implementation by individuals in their homes.
- Moving forward, further testing and monitoring of the bio-digester system will be essential to assess its performance in generating biogas from organic waste and to identify any potential improvements or optimizations.

❖ **Embedded Systems**:

- The assembly of the Arduino UNO board with the DHT22 sensor demonstrated the versatility and ease of use of embedded systems in electronics projects.

- By leveraging microcontroller boards like Arduino and sensors like the DHT22, individuals can create sophisticated monitoring and control systems for various applications, including environmental monitoring, home automation, and IoT projects.
- The Arduino platform's accessibility and extensive community support make it an ideal choice for beginners and experienced makers alike, enabling rapid prototyping and development of embedded systems solutions.

❖ **Code Generation**:

- Code generation for the Arduino UNO board was accomplished using the Arduino IDE as shown in figure 5, which provides a user-friendly environment for writing, compiling, and uploading code to microcontroller boards.
- The Arduino IDE supports both C++ and Python syntax, allowing users to choose the programming language that best suits their preferences and project requirements.
- Libraries such as the DHT sensor library simplify code development by providing pre-written functions for interfacing with sensors like the DHT22, streamlining the programming process and reducing development time.

❖ **Data Analysis**:

- Data analysis of temperature and humidity readings from the DHT22 sensor was facilitated using the Arduino platform and the Serial Monitor tool as portrayed in figure 6.
- Real-time monitoring of environmental conditions provided immediate feedback on temperature and humidity variations, enabling proactive intervention when necessary.
- Further analysis of collected data using statistical methods or data visualization techniques will offer deeper insights into environmental trends and patterns, aiding in decision-making and optimization of system performance.

Overall, the integration of the bio-digester setup with embedded systems and data analysis tools demonstrates the potential for creating innovative and sustainable solutions for waste management and environmental monitoring. By leveraging accessible technologies and platforms like Arduino, individuals can contribute to addressing pressing challenges in sustainability and resource management.

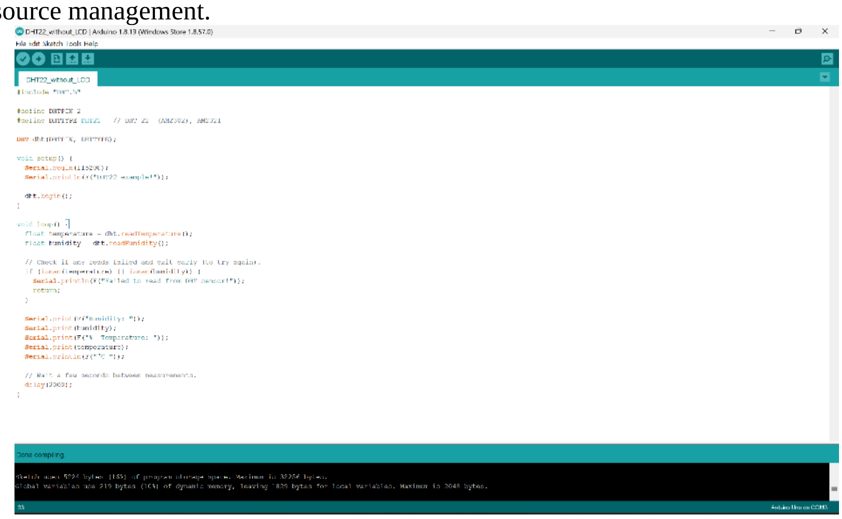

Fig.5 - Code for the setup

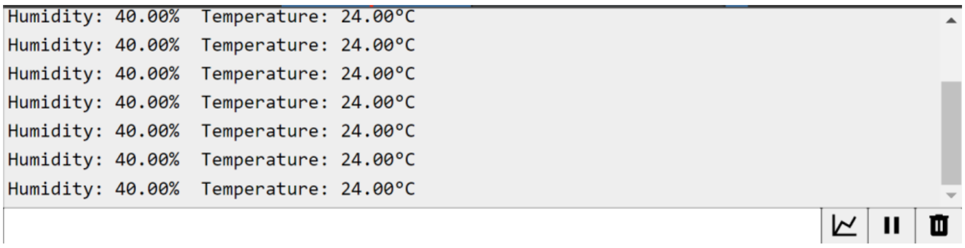


Fig.6 – Output (Humidity and Temperature)

## V. CONCLUSION

The conclusion highlights the significance of integrated systems, particularly in the context of addressing environmental challenges and promoting sustainability. It emphasizes the successful assembly of a bio-digester setup, integration of embedded systems, streamlined code generation, and insightful data analysis as key components contributing to this potential. The conclusion underscores the accessibility, versatility, and effectiveness of these integrated solutions in waste management and sustainability efforts, making them suitable for implementation in various settings. Additionally, it emphasizes the importance of continued research and innovation in advancing these integrated systems to realize their full potential for sustainable development and a greener future.

**Future Advancements and Implementation:**

- Advanced Sensor Technologies: Integration of advanced sensors for real-time monitoring of biogas production, temperature, and humidity levels can enhance system efficiency and optimize resource utilization.
- Machine Learning Algorithms: Implementation of machine learning algorithms for predictive analytics and optimization of biogas production processes, enabling proactive decision-making and system control.
- IoT Integration: Integration of embedded systems with IoT platforms for remote monitoring and control of bio-digester systems, enabling seamless operation and management from anywhere.
- Smart Grid Integration: Integration of biogas generation systems with smart grid technologies for efficient energy distribution and utilization, enabling integration into existing energy infrastructure and grid balancing.
- Community-scale Deployment: Implementation of bio-digester systems at community-scale to maximize resource utilization and promote decentralized renewable energy production, fostering local sustainability and resilience.

## References

[1] Baccar, R., Bouallagui, H., & Chaabane, L. (2009). Influence of substrate to inoculum ratio on biogas production from organic solid waste. Bioresource Technology, 100(21), 4132-4138.
[2] Borja, R., Fermoso, F. G., & Martín, A. (2012). Improving biogas production from different waste mixtures by thermal–alkaline pretreatment. Waste Management, 32(8), 1526-1533.
[3] Elbeshbishy, E., Hafez, H., Dhar, B. R., Nakhla, G., & Ray, M. B. (2017). Performance of an integrated anaerobic digester and microbial fuel cell for the treatment of low-strength wastewater and electricity generation. Journal of Chemical Technology & Biotechnology, 92(8), 1911-1919.
[4] Fang, H. H., Boe, K., Angelidaki, I., & Li, Y. Y. (2015). Anaerobic co-digestion of municipal food waste and sewage sludge. Water Science and Technology, 71(3), 339-344.
[5] Hansen, K. H., & Angelidaki, I. (2008). Anaerobic digestion of swine manure: inhibition by ammonia. Water Research, 42(1-2), 439-445.
[6] Jayathilakan, K., Sultana, K., Radhakrishna, K., & Bawa, A. S. (2011). Utilization of byproducts and waste materials from meat, poultry and fish processing industries: a review. Journal of Food Science and Technology, 48(3), 278-293.
[7] Kaparaju, P., Rintala, J., & Lens, P. N. (2010). Effect of temperature and hydraulic retention time on anaerobic digestion of grass silage in leach-bed reactors. Bioresource Technology, 101(12), 4022-4028.
[8] Lehtomäki, A., Huttunen, S., Rintala, J., & Hänninen, K. (2008). Influence of operating temperature on the performance of upflow anaerobic sludge blanket reactors treating food industry wastewater. Environmental Technology, 29(1), 1-10.
[9] Liu, C., Li, J., Liu, L., Li, A., & Liu, Y. (2020). Optimization of the co-digestion process of waste activated sludge and kitchen waste: Focusing on the effects of moisture content and C/N ratio. Environmental Technology & Innovation, 19, 100952.
[10] Rogers, M. B., & Chen, Y. (2015). A comparison of traditional and advanced anaerobic digestion processes. Journal of Chemical Technology & Biotechnology, 90(6), 966-972.